Hydrogen in the making – how an energy company organises under uncertainty

Anne Louise Koefoed

A dissertation submitted to BI Norwegian School of Management for the degree of PhD

Series of Dissertations 2/2011

BI Norwegian School of Management

Department of Innovation and Economic Organisation

Anne Louise Koefoed
Hydrogen in the making – how an energy company organises under uncertainty

Series of Dissertations 2/2011

ISBN: 978-82-8247-024-7
ISSN: 1502-2099

BI Norwegian School of Management
N-0442 Oslo
Phone: +47 4641 0000
www.bi.no

Printing: Nordberg Trykk

The dissertation may be ordered from our website www.bi.no
(Research – Research Publications)

Acknowledgements

I thank the Norwegian School of Management BI for granting me a doctoral scholarship. I am thankful to my supervisor Per Ingvar Olsen for challenging discussions and careful readings of my work along the way. I thank my Committee, Professor Tor Hernes and Professor Peter Karnøe, for guidance at the pre-doctoral defence. I am also grateful to Professor Atle Midttun, who involved me in research projects on renewable energy development. Our work together was the early seed and inspiration to what has become the centre of my empirical area of interest.

Over the years, I have received great inspiration and encouragement from peers in the doctoral programme and colleagues at the Department of Innovation and Economic Organisation. The Department was a great place to work. Special thanks to the Process group for inspiring gatherings that put me on track and nurtured the analytical interest in process studies.

Norsk Hydro made my study possible by opening up its organisation and allowing me to meet with company representatives in New Energy. Ivar Hexeberg, Bjørn Arne Sund, Christopher Kloed, Dag Roar Christensen, Egil Rasten, Elisabet Fjermestad Hagen, Helle Britt Mostad, Klaus Schöffel, Pål Otto Eide, Sjur Bratland, Torgeir Nakken, and Vera Ingunn Moe. Thank you for meeting with me for interviews on several occasions. I thank you all for your openness, time, and interest in my project. If I have failed to mention people, ideas and initiatives; misunderstood or misrepresented statements of these people; it is entirely my fault.

My family and friends have believed in me during, what seems to be, an everlasting period of time. I thank you for your support and cheering spirits. To Mie, Mathias, and Tore - love always - you have been very patient.

Before you start reading this thesis, I say what William James said in a lecture in December 1904 - “You may not follow me wholly in this lecture (thesis); and if you do, you may not wholly agree with me. But you will, I know, regard me at least as serious, and treat my effort with respectful consideration.”

Anne Louise

Table of Contents

1 Introduction to thesis

This thesis combines an analytical interest in innovation process studies with an empirical interest in clean energy development. There is an ever increasing awareness that the current production and use of energy is non-sustainable, and there is economic and political debate and focus geared towards the development of cleaner energy sources.

My work concentrates on innovation processes from initiation to realisation in a company setting focusing on hydrogen as an energy carrier. A Norwegian energy company, Norsk Hydro[1], is used as a case to explore the intraorganisational processes involved in business building. This is relevant to the research question - how hydrogen energy takes on reality and relevance for business activity? Further, a concrete hydrogen demonstration project involving research and development of a new technology combination, in collaboration with partners, has also been studied. This is relevant to the research question – how does the demonstration play a role in the organisation's innovation and development processes in hydrogen energy? The demonstration project is a site that embodies the challenge of combining and connecting resources, people and ideas in practice.

My work is positioned within studies of innovation processes. Studying the initiation of hydrogen activity brings to the fore the processes of mobilisation with relevance- and purpose building activity, and how organisational members try to advance and commit to a new area of business. Process theories of technology emergence have pointed to actors that mindfully deviate from established practice (Garud and Karnøe 2001, Van de Ven and Hargrave 2004) or innovative actors that react to crisis or shocks (Van de Ven et al. 1999), but there is a knowledge gap about activities and what happens in the very beginning of intraorganisational processes leading to new venture creation, development paths, and technology emergence. Further, the study of the demonstration project explores the multifaceted roles of the demonstration. The strategic niche management perspective (Kemp 1998a) within science and technology studies (STS) have emphasised demonstration projects as part of socio-technical transitions with a view to policy coordination; but less attention have been paid to the local experience of demonstration aspects. There is a knowledge gap in the understanding of learning and demonstration aspects in relation to the role(s) of the demonstration project in company development processes.

[1] I refer to the company as Norsk Hydro as my empirical work was ended before the StatoilHydro merger in October 2007. In some parts of the thesis, StatoilHydro is mentioned when it is relevant to the case study.

The initiation of hydrogen energy activity and the demonstration project provide the empirical underpinning to the study of innovation in the making. Trying to grasp development in its own setting will hopefully contribute to a better understanding of the initiation and creation of new ventures and technology paths. Actors that handle innovation processes navigate in a complex world and may offer us insight into the 'doing' of innovation over time; hence innovation processes inside a company present an opportunity to look at how organising is accomplished in open-ended and uncertain situations because development and projects are initiated without knowing if hydrogen as an energy carrier is going to work out.

1.1 The empirical domain and empirical area of interest

Technology development and innovation is by no means a new phenomenon to be interested in. Innovation has emerged over the last decade as possibly the most fashionable of various social science areas (Downs et al 1976). The attention given this topic has skyrocketed among policy makers, industry associations and businesses. In 1999, the Economist wrote: "Innovation has become the industrial religion of the late 20th century. Business sees it as the key to increasing profits and market share. Governments automatically reach for it when trying to fix the economy … it is the new theology that unites the left and the right of politics"[2].

The same attention continues to impel social science scholars to establish their part in the puzzle by figuring out how to portray and understand the central building blocks in innovation processes. What are constraining and enabling factors? How to understand processes and activities on the spectrum from idea generation to realisation, and development on the whole continuum from transitions as large societal ventures to development processes within organisations? If we knew where invention and innovation came from, we would go fishing in the same lake every time. Innovation is a fuzzy subject where a book of prescriptions would take away the mystery and newness aimed for. I approach innovation as a process and not as a final destination. What is innovative and becomes an innovation is the outcome of a dynamic interplay or 'mesh[3]-work' where interests, ideas, resources and people meet and are coupled. Approaching innovation as a process as opposed to an outcome means that the interest lies in the following types of issues: How are developments and projects initiated, carried out and how do they become and take on shape over time? How is the organisation in interaction with its surroundings and how does

[2]The Economist; London; Survey: Innovation in industry, February 20, 1999, Nicholas Valery, Volume 350, Issue 8107.
[3] http://www.merriam-webster.com/dictionary/mesh: entangle, to become entangled in

this influence the innovation project and process? What facilitates and what constrains the realization of innovation processes?

Moving on to combine the interest in innovation processes with the empirical domain and empirical area of interest; my study focuses on innovation and technological development processes in cleaner energy, as triggered by energy security and pollution issues that challenge existing technological systems in the energy industry. Security of supply concerns and environmental consequences of the existing predominantly fossil[4]-based energy system, have urged a political and to some extent also a public recognition[5] that a process of development of cleaner energy, change in technological systems and resource use are needed. "Climate change is among the gravest environmental, social and economic challenges facing mankind … Urgent action is needed to limit climate change to a manageable level and prevent serious physical and economic damage … worldwide emissions will need to be cut by up to half of their 1990 levels by 2050."[6]

With calculations of the costs associated with climate change[7], a business as usual path is not appealing. In the World Energy Outlook 2006 (IEA 2006), based on projections of currents trends, it was written that the energy future we are facing today is dirty, insecure and expensive. Business as usual could lead to price shocks and sudden interruptions in energy supply, as well as a huge growth in climate-wrecking carbon dioxide emissions. "Damaged economies, refugees, political instability, and the loss of life are typically the results of war. But they will also be the results of unchecked climate change."[8]

Energy system challenges has by Romm (2005) been visualised with the analogy of a coal-powered locomotive where we need a new engine, new fuel, and even new tracks. Hoffman (2002) extracts the main challenges and drivers toward cleaner energy:

«In the paste decades, efforts to harness renewable energies were driven partly by idealism but more by concerns about "energy security" – fears about the eventual drying up of the world's petroleum resources and about the increasing vulnerability of the long supply lines from the politically unstable Middle East. But as the twentieth century drew to its close, environmental concern had become a much stronger impetus driving the

---

[4] Fossil fuels: oil, natural gas, and coal.

[5] Eurobarometer - Energy: Issues, Options and Technologies, European Commission Directorate- General for Research, available March 6, 2003 http://europa.eu.int/comm/research/energy/pdf/eurobarometer_energy_en.pdf

[6]"Limiting Global Climate Change to 2 degrees Celsius": an EU Commission Communication in relation to the EU's Climate Change Package, 10 January 2007: Brussels http://www.europa-eu-un.org/articles/en/article_6666_en.htm

[7] The Stern Review (2006) : *Stern Review on the Economics of Climate Change,* Cambridge http://www.hm-treasury.gov.uk/stern_review_report.htm

[8] Stavros Dimas, Member of EU Commission, responsible for environment: "Climate change: Why a global response needs European Leadership", London 11 January 17, 2007.

world toward renewable, alternative forms of energy. Curbing and eventually doing away with pollution has become a universal concern. Dying forests in Europe and acid rain everywhere were among the initial wake-up calls to the need to curb sulphur, nitrogen oxides, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), particulate emissions, and other pollutants. At last it had begun to dawn on policy makers and large parts of the general population, less so and more slowly, in the US than other parts of the world – that the very process of combusting fossil fuels, that interaction of carbon in hydrocarbon fuels with the air's oxygen, and the consequent release into and accumulation in the atmosphere of carbon dioxide, carbon monoxide, and other climate-changing gases far above pre-industrial levels was raising the world's temperature – the famous Greenhouse Effect – and threatening to havoc with the world's climate. "Zero emission" from cars and buses, industry, ships, and home furnaces is becoming the new world standard – a standard to which industrialised countries and emerging economies are aspiring to with varying degrees of intensity and dedication. To the minds of many, taking the carbon out hydrocarbons and relying on the "hydro" part – hydrogen – as a zero emission chemical fuel is the obvious though technically difficult way to minimize and, it is hoped, eventually eliminate global warming»

Hoffmann (2002)

Focusing on hydrogen energy in the making, I chose to focus on hydrogen activities because in this area, the company more directly handles technology emergence and development processes. This was not to disregard the challenges in the other New Energy areas. For instance in the wind area, the company was a project developer putting together projects with purchased technology from leading wind technology manufacturers. Yet wind technology is much further down the development line and has proven to be a viable and reliable deliverer of electricity wherefore costs and expected returns can be calculated and projected. This is not the case with hydrogen yet.

The hydrogen area is still more at a visionary and exploratory stage wherefore development has been undertaken without a clear basis for calculation of potential and future profitability. Further, although cleaner energy research and development efforts and policies are under development; it is indeterminate if hydrogen energy will be part of the answer and part of future energy systems. Appendix I describes in more detail what it in fact entails when hydrogen is being considered as an energy carrier or "in the making". Appendix I has been developed because in the feedback from my committee at the midway defence of this thesis; one comment was related to my claim that innovation and technical development processes in hydrogen energy may be regarded as an uncertain development path – as processes of organising under uncertainty. The committee wanted me to say something about the degree of uncertainty, what it actually means? In Appendix I, the contours are drawn around what a transition to hydrogen energy actually involves in terms of development challenges, and it outlines a somewhat unknown time horizon. Hence, the appendix gives the reader a better understanding of hydrogen energy as a kind of world building activity.

The road to a society where hydrogen is used as an energy carrier is a long one. To give a brief indication of hydrogen energy as a world building activity some highlights are mentioned. Technical characteristics have not been captured or stabilised; there is an ongoing technological sorting-out process with technology validation and accordingly there is no settled technological order that allows the overall costs to be attached. Infrastructures do not develop overnight, are costly, there is uncertainty as to the extent of adaptations needed to infrastructure and overall little is known about the production and delivery model that will prevail. There is the challenge of producing competitively priced hydrogen including production, storage and distribution. There is uncertainty as to the timing and coordination of investments. There is ongoing market preparation to get into identified and potential applications, and in terms of use and future markets, such developments depend on the development of enabling technology, the fuel cell. It is uncertain if fuel cells will reach their potential and be moved from the lab to the marketplace, and meanwhile, other technologies may come along that reduces the need for the development of hydrogen energy. Demand for hydrogen energy is also eventually embedded in politicians and consumers, who need to be acquainted with a new energy carrier. Hydrogen needs to gain public acceptance and focus needs to be maintained among politicians for support.

Political plans and targets for cleaner energy establish a kind of demand and relevance for something. They create development openings, so to speak. For what they represent an opening is less certain. Many alternative technologies and clean energy solutions are discussed. Hydrogen has gained recognition as a potential future energy carrier but how and if it will be realised is far from certain. We cannot chart a single trajectory along which cleaner energy development is going to occur nor assert with certainty that hydrogen will become a contributing energy carrier in the future. We can approach it, and use hydrogen energy as an empirical example to get a better understanding of innovation activities and mechanisms that bring it about, thereby making such processes more intelligible.

1.2 The analytical area of interest

Looking at innovation processes, in the case of hydrogen energy, exemplifies the complexity of how something technical, economic, social and political actually comes into existence, and how business activity is organised under uncertain conditions. Organising innovation activities in the hydrogen energy area involves attempts at exploring and positioning the organisation for an unknown future and a moving terrain, which means action under uncertainty.

Innovation activity and development processes in the empirical domain are uncertain to embark on. There are conflicting descriptions about the sense in pursuing this or that clean energy development path typically backed by diverse advocates and interests, and there is diversity in energy policies, resources / resource endowments. Finally, technologies pursued add to complexity. From a company point of view, what development activities should be pursued among new energy alternatives, if any? How does a company make sense of and position itself in the environmental debate and how is the hydrogen energy trend, opportunity or threat interpreted and acted upon? The business case for embarking on a path of cleaner energy development is entangled in these debates. Development of new technological combinations takes place against the backdrop of existing technological fields. Creating the future sparks tension and controversy since different technological fields and industries wish to have a stake in future energy and what is opportunity for one industry population may mean sundown for others, as they become obsolete for economic, social or environmental reasons.

Development activity and innovation processes concern novelty in some sense and includes multiple and parallel activities of organising, conceiving, developing and implementing something non-familiar to the people involved. Hence innovation processes suggest some sort of transformation both in terms of actual projects, technologies, products being developed, but also in terms of the process itself through which a company / organisation enters new territories of activity; a process in which the company/ organisation itself is redefined and constituted anew. Innovation activity in the organisation however, is not the only thing moving; an innovation e.g. hydrogen technology is to enter a complex and dynamic world (changes in consumer trends, advances in technology, societal movements, natural disasters, diverse political ideologies, religions etc.), another moving target so to speak.

The complexity of innovation processes, as pointed to above, need to be reflected in the theoretical positioning of my work. My study has an interdisciplinary style where I combine insights. From organisation theory, March (1981), Weick (1995, 2005), Hernes (2008) have helped organisation studies to embrace the complexity in e.g. social and technological development by emphasising the importance of understanding organisation and technologies as resulting from processes of organising. I combine this with process theories of technology emergence including literature based on science and technology studies (STS).

“In the making” in my title denotes the interest in exploring how this something (hydrogen energy) comes to be or is in the process of becoming something e.g. materially-technically, politically and economically. Company projects and activities present an opportunity to look at how organising is accomplished in open-ended and uncertain situations because development and projects are initiated without knowing if it is going to work out. Actors and organisations that handle innovation activities navigate in a complex world and may offer us insight into the ‘doing’ of innovation over time. The interest that drives my project may be summarised in a simple sentence: understanding how this something (hydrogen energy) becomes relevant in a business setting and how it is created and constituted. This somewhat simple sentence and curiosity allow for a generative understanding of how things come into being through a heightened sensitivity to processes, action, actors in the situation, how things are redefined and how the shape of the present is made new.

1.3 Thesis outline

In this introductory chapter, I have presented the setting hydrogen in an energy company, the empirical area of interest as innovation processes and development in cleaner energy, and positioned the study within studies of innovation processes in terms of situating the analytical area of interest in process theories of technology emergence and organisation theory. In the introductory chapter I also briefly mentioned the uncertainty in the development of a hydrogen energy path, and the reader is referred to further empirical detail in Appendix I.

Chapter 2 presents research questions, the ontological underpinning and background thinking to this thesis, as well as methodological considerations and the research strategy.

Chapter 3 presents perspectives on innovation and the conceptual resources used to address aspect one and two and the research questions specifying my research.

Chapter 4 is an empirical chapter, which focuses on the initiation processes and pioneer activities behind the launch of the hydrogen energy venture. Business and path development in hydrogen energy had a long pre-history before pioneers or pathbreakers from diverse settings in the organisation managed to build a case for hydrogen energy. I triangulate the phenomenon by looking at the initiation of hydrogen energy from diverse settings in the organisation. Pioneers worked in research, with the technology provider, and in business development.

Chapter 5 Discusses relevance building and mechanisms in commitment-making, and discusses the study's contributions to the conceptual resources.

Chapter 6 is an empirical chapter on the initiation and realization of a demonstration project. The study portrays the Utsira demonstration project to explore the multifaceted roles of a demonstration project in company development processes.

Chapter 7 Discusses demonstration aspects, mechanisms of demonstration, and discusses the study's contributions to conceptual resources.

Chapter 8 provides some final reflections on this thesis.

2 Research questions, methods and process

2.1 Research questions and their process of becoming

A way to describe research questions is to say that they bring attention and focus on particular aspects associated with the innovation process. In doing so they also help structure the account of the study of practice, and they help to position what can be learned through the study.

The research questions presented here, and elaborated conceptually in chapter 3, were not presupposed or deduced from the theoretical resources. Frankly, the questions and particular aspects associated with the innovation processes were not singled out prior to the empirical field work and the conversations with practitioners. The questions have emerged along the way. In line with the spirit of ethnomethodologically-inspired research, to try to capture the 'insider's perspective', I tried to postpone imposing theory and concepts to reduce the contamination of my conversations and the reflective accounts of practitioners about projects and activities. Basically asking practitioners what they think they are up to before formulating my own assumptions.

My initial research question was trying to avoid over-determining the phenomenon. I started out with the following curiosity:

How do actors in a skilled energy company make interpretations and organise in relation to a certain energy trend in an open-ended and uncertain situation? Focusing on hydrogen activities - how do hydrogen and hydrogen projects become in an empirical setting?

Given the theoretical positioning in process theories of technology emergence, the original and tentative research question was:

When committing to innovation projects in an uncertain setting such as hydrogen, how do practitioners create an outlook, enact their intentions, and mobilise elements and support for their activities?

In retrospect, I see that it was broad, fuzzy, and more like an opening. But I think it served its purpose in the sense of pointing in the direction of what my study of hydrogen innovation processes would encompass. Most importantly, it was part of my wobbly steps and efforts to figure out *the purpose of my research project* in the area of novelty and technology emergence, and the processes from outlook and relevance building for a new venture, emerging project ideas, support, commitment, and to activities in the realisation of projects and a new venture.

At the mid way defence, I was supported in my embrace of *how* questions; but also reminded to remain faithful to the *how* aspect and avoid being deterministic in my writing. Just because there is the threat of climate change, air pollution, energy dependence challenges, there is no of course or automatic association and linkage to a hydrogen response. There is no guarantee that a transition to hydrogen as an energy carrier will happen. There is no natural business case. The question is *how* it will happen. *How* is this mobilisation happening; *how* does it become relevant for a business venture? From my research's point of view, I should look at *when* and *how* it became part of the relevance of the business activities, as seen from inside Hydro.

Naturally, the research question got its fair share of comments at the mid way defence pointing to intriguing dimensions in my empirical material that I could pursue. The central message was that I needed to pick and focus on certain *mechanisms* at work in bringing about something / a particular aspect associated with the innovation process that I wanted to follow and understand.

Accordingly, I decided to look at what *mechanisms* mean only to find that a PhD thesis could be written on the multiple meanings linked to the way *mechanism* is conceptualised. To minimize confusion in my work, I could a) do what seems to be commonly done, namely not specify it all, or b) define what it means to me. To pursue the spirit of b, I looked to the American Heritage Dictionary[9] defining a mechanism as: an instrument or process, physical or mental, by which something is done or comes into being. Leaning on this definition, I understand mechanism to mean:
The process through which something is done, comes into being, and has brought about the type of outcome that is sought explained.

To help impose some clarity on detailed practitioner accounts and to handle the rich empirical material on histories and hydrogen activity in Hydro; I hope to be able to contribute additional insight in two main areas or aspects associated with innovation processes. Interviews with practitioners put me on track toward what I thought was interesting. I landed on these two aspects from interacting with the field. Hence one may say that my research questions were empirically driven.

When being in the Hydro world interviewing people working with hydrogen, I noticed their accounts of the early days when there was no business, but only individuals trying to mobilise the hydrogen energy area. There were efforts to sort out information, build an understanding and a case for hydrogen energy that they were using in an internal sales job to convince their management that they should be allowed to initiate and undertake hydrogen energy projects. There was relevance building as the basis for the new business venture and as the basis for commitment. This concerned *how hydrogen had taken on relevance and a reality path in Hydro* and what

[9] American Heritage Dictionary, this is explanation number 3 out of 7

happened in the very beginning when embarking on a new venture or path. It concerned *the organisational processes leading to hydrogen energy business or venture creation*.

Grasping the relevance building and commitment making process is believed to enhance our understanding of the intraorganisational processes leading to new ventures, initiation processes of development projects, and path creation. To address these dimensions in the innovation processes, the following questions were developed.

2.1.1 Aspect one and questions to specify research

Aspect one, and output one from this thesis, is concerned with the becoming of "hydrogen energy" in Norsk Hydro. How hydrogen becomes a new energy activity in a large energy company. What happens at the very beginning of a possible path and how does the process unfold from ideas to purpose, to projects and to the launch of the hydrogen energy venture? More specifically:

- How does hydrogen energy as an idea and concept take on reality and relevance for business activities?
- Relevance building: what is relevance made of and how are elements mobilised to make it relevant?
- The emergence of commitment: what are the mechanisms in the commitment-making process from perceiving opportunity, creating attention to committing resources?

In addition to exploring pioneering activity in the initiation of the hydrogen energy path, I have also studied a hydrogen project. The Utsira demonstration project is the first full scale demonstration project of this type of technology combination driven by the initiative and vision of my study's focal organisation, Norsk Hydro. The Utsira demonstration project has been the site for private investment in an innovative project idea, for a concretization of a new technology configuration, and for activation of learning processes among the project's participants.

2.1.2 Aspect two and questions to specify research

Aspect two, and output two from this thesis, is concerned with the history and realization of the demonstration project. Based on interviews, it seemed that demonstration aspects related to a range of activities from research and technology development, organisational learning, and to market development. I suggest that the dynamics and what comes out of a demonstration project may be better understood.

The multifaceted roles of the demonstration in company development processes and the mechanisms of demonstration have been studied. This concerns what demonstrations do and why they are important. Hence the following questions:

- What are the mechanisms of demonstration and the particular demonstration aspects?
- How does the demonstration project play a role in the organisation's innovation and development processes and the emerging hydrogen energy path?

Mechanisms of demonstration draw attention to the importance of demonstration projects and the pre-commercial demonstration market to new technology development processes. Further, aspect one and aspect two in this thesis are related, as we may explore how the experience gained in the demonstration project becomes part of the effort to continue company activities in hydrogen energy.

I believe my study may further our understanding of these two aspects in emergent innovation processes. There appears to be gaps, and we need to know more about this at the conceptual level because these aspects are part of development activities and practice, yet inadequately discussed in the literature. We need to be sensitized to these aspects perceptible in practice, which in my opinion will further our understanding of novelty generation, technology emergence and path creation in organisations, and how actors orientate, make decisions on new ventures, and mobilise activities under uncertainty.

2.2 Ontological underpinning and background thinking

Hydrogen has been ascribed and attributed value as a possible future energy carrier. The potential realization involves processes of creating new realities in society in terms of technology, politics as well as uses and markets. As the researcher is neither a psychic nor a 'foreteller' or a fortune teller, I propose a performative approach to the study of innovation and hydrogen energy development processes. By tracing emergence, such an approach focuses on practical performance or achievements that need to be traced as they happen or have happened in time. As organisations do not encounter or have an agreed point of reference on which to base decisions and activities, organisations as well as we as researchers cannot predict optimal courses of action, rather practice happens in time with puzzle-solving and continual adjustments. Consequently one may ask, how are 'contributions' made? What contributions matter and what turns out to be/or is made relevant in the development of cleaner energy, in this case, the hydrogen energy venture and a demonstration project?

2.2.1 Dealing with a world full of agency

Science and technology studies have a long history of not taking for granted distinctions or limits between science and society; rather they ask how things, meanings, values are created, how they work, how they are 'reproduced' and stabilised.

One cannot up front define what or who may or may not be actors in dynamic processes such as development processes of science and technologies. Rather good studies follow the actors[10], whatever acts though this may cross over known categories. There are diverse actors connecting to try to advance their interests, technologies, visions, scientific research, bodies of expertise, interpretation of natural phenomena. Since the outcome of encounters and associations among actors is uncertain, the creation of tomorrow's energy system and the practical realisation of development paths are unpredictable as actions are changeable and drawn from a range of possibilities. Hence it becomes important to study how things or technologies come to life, are continually build or constructed and get to be a certain way (Asdal et al. 2001) and to trace how signification and meaning are produced.

2.2.1.1 A real-time understanding of practice

> "We all know of innovations which either made their creators a fortune or which led to their downfall. It is easy to retrospectively explain success as a stroke of genius or failure as a blatant mistake. Easy in retrospect, but what about innovation in the making? How does the innovator navigate the pitfalls which threaten him?"
>
> (Akrich et al. 2002)

Relevant to the interest in understanding innovation in the making and through my reading of STS literature, I encountered the work of Andrew Pickering. His work is rooted in science studies writing extensively about science as practice and culture (Pickering 1993, 1995). Pickering's thinking provides some implicit assumptions that provide a way to think about innovation processes and to frame experience, and I will therefore refer to his work in some detail.

Pickering (1995) talks about '*real-time understanding of practice' and contrasts this with retrospective approaches* that look backward from some terminus and explains practice in terms of the substance of that terminus. The point of departure is the idea that the world is filled not with facts and observations, but with *agency*. The world is continually doing things, things that bear upon us, not as observation statements upon

[10] Actor is understood as "one who and what takes part - a participant" (The American heritage dictionary, second college edition).

disembodied intellects, but as forces upon material being. Science and technology are among the ways human beings cope with this busy world. The weather: winds, storms, droughts, floods, heat, and cold – all engage with our bodies as well as our minds, and much of everyday life has the character of coping with material agency, agency that comes to us from outside the human realm and that cannot be reduced to anything within that realm. Science and technology should be seen as a continuation and extension of this business of coping with material agency. Scientists, as human agents, manoeuvre in a field of material agency, constructing machines that, as Pickering says, variously capture, seduce, harness, channel its flow, recruit or materialise that agency, taming and domesticating it, putting it at our service, often in the accomplishment of tasks that are simply beyond the capacities of human minds and bodies, individually and collectively. For example, a windmill grinds grain much faster than a miller could do by hand; the television set shows events distant in time and space that we could otherwise hope to view; a machine tool cuts metal at a speed and with a precision that no one could otherwise hope to achieve. These illustrations sketch out a basis for a *performative image of science*, in which science is regarded a field of powers, capacities, and performances, situated in machinic captures of material agency. Pickering uses the machine to conceive a balancing point between the human and nonhuman worlds, and between the worlds of science, technology and society (ibid, pp. 5-7).

Pickering refers to Actor Network Theory (ANT), the work of authors Callon, Latour and Law, and argues that these authors have pointed a way toward the performative idiom. They are similarly in the business of thinking about science, technology and society as a field of human and non-human (material) agency, where agents are associated with one another in networks and evolve together in those networks. However, Pickering's thoughts on time, agency and practice diverge from the ANT preference to think semiotically[11]. The appeal to semiotics is considered to be a detour and a kind of return to the world of texts and representation, and the semiotic explanation is not the only route to non-human agency (ibid, p. 13). Instead,

[11] The ANT preference is reflected in Law (2004a), who writes that "semiotics tell us that entities achieve their form as a consequence of the relations in which they are located. As it concerns performativity, Law again refers to the semiotic approach telling us that this also means that they (entities) are performed in, by, and through those relations". This is also communicated by Law in the book *Actor Network Theory and after*: "actor network theory is a ruthless application of semiotics ... I simply want to note that ANT may be understood as a semiotics of materiality" (Law et al., 1999, pp. 3-4). "Semiotics, the science of signs, is used in ANT to teach us to think symmetrically about human and nonhuman agents. In texts, agents (actors, actants) are continually coming into being, fading away, moving around and changing places with one another. Importantly, their status can easily make the transit between being real entities and social constructs and back again. Semiotically there is no difference between human and non-human agents; they can be continuously transformed into one another and substituted for one another" (Pickering 1995)

Pickering advocates thinking about material and human agency by thinking that both are temporally emergent in practice. The contours of material agency are never decisively known in advance; scientists (and practitioners in development processes alike) continually have to explore them in their work, problems always arise and have to be solved in the development of, say, new machines. And such solutions – if they are found at all - take the form of a kind of delicate material positioning or tuning (Pickering 1993, p. 564), where Pickering use "tuning" in the sense of tuning a radio set or car engine, with the caveat that the character of the "signal" is not known in advance.

Thus if we are interested in achieving a real-time understanding of scientific practice – innovation practice - then it is clear that the scientist is in no better a position than the sociologist when it comes to material agency. No one knows in advance the shape of future machines or what they will do, but we can track the process of establishing the shape without returning to a position where only human agency is involved in it (Pickering 1995, pp. 14-15). A key point to be made about the process of tuning is that it works both ways, on human as well as nonhuman agency. Machines establish a field of material performativity at any given time; however, this does not exist in a human vacuum. Their performativity is enveloped by the human realm, enveloped by human practices, practitioners – by the gestures, skills and whatever required setting machines in motion and to channel and exploit their power. In practice, material and human agency then collaborate in performances (ibid, pp. 16-17). However, just as the material performativity of new machines have to be found out in the real time of practice, so too do the human skills, gestures, and practices that envelop them. Hence human – and material agencies are interactively stabilised (ibid, p. 7).

Intentionality is discussed in the sense that practice is typically organised around specific plans and goals. We cannot make sense of such studies of practice without reference to the intentions of scientists (practitioners), to their goals and plans or orientation to goals located in the future. Scientists (practitioners) usually work with some future destination in view; whereas it does not help to think about the intentions of things (ibid, p. 17). Human intentionality then appears to have no counterpart in the material realm. BUT the intertwining between the intentional structure of human action and material agency is stressed; especially the temporal emergence of plans and goals and their transformability in encounters with material agency (ibid, p. 18).

In trying to understand the intentionality of practice, it is important to continue to pay attention to time. Humans live in time in a particular way, we construct goals that refer to presently nonexistent future states and then seek to bring them about. We aim to build a new kind of machine that we hope will display certain powers, and this is a respect in which the symmetry between human and material agency breaks down. But having said this, if one defines intentionality in terms of human plans and goals, the question concerning the origin and substance of such goals arises (ibid, p. 19). Goals are imaginatively transformed versions of its present. We create goals for the future based on: our experience; current situation and performance; present challenges; the existing field of machines, technologies etc. that serve as a surface of emergence for goals and practices. However goals located in the future are not a determinate destination. There is open-endedness in human agency and human intentionality, which is a necessary counterpart to the emergent quality of material agency, and this it what makes it possible to bring the two into relation with one another. In the struggles with material agency (that Pickering calls tuning) plans and goals too are at stake and liable to revision. Thus the intentional character of human agency has a further aspect of temporal emergence. The intentional character of human agency is being reconfigured itself in the real-time of practice, as a result of the intertwining with material agency, where both are reciprocally redefined (ibid, pp. 19-20).

2.2.1.2 A performative understanding

Pickering's basic image of science and practice is a performative one, in which the performances – the doings – of human and material agency come to the fore. Their contours emerge in the temporality of practice and are definitional of and sustain one another. The current situation (e.g. performance, present challenges, and technologies) constitutes the surface of emergence for the intentional structure of practice, and practice consists in the reciprocal tuning of human and material agency, tuning that can itself reconfigure human intentions. An outcome of such a process may be the construction and interactive stabilisation of new machines and the disciplined human performances and relations that accompany them (Pickering 1995, p. 21). The idea of tuning is a perceptive metaphor. Tuning in goal-oriented practice takes the form of a dance of agency. As active, intentional beings, tentatively construct something new like a machine. They then adopt a passive role, monitoring the performance of the machine to see whatever capture of material agency it might effect. Symmetrically, this period of human passivity is the period in which material agency manifests itself. Does the machine perform as intended? Has an intended capture of agency been effected? Typically there is a continual reversal of roles: human agency active in revision followed by a new round of material performance and so on. The dance of agency, seen asymmetrically from the human end,

> "The world makes us in one and the same process as we make the world"
> (Pickering 1995, p. 26)

thus takes the form of a dialectic[12] of resistance *(*resistance in the sense of a practical obstacle or block on the path to some goal) *and accommodation* (to circumvent the obstacle). Resistance denotes the failure to achieve an intended capture of agency in practice, and accommodation is an active human strategy of response to resistance. This can include revisions to goals and intentions as well as to the material form of the machine or technology in question, and to the human frame of gesture and social relations that surround it (ibid, p. 22).

The practical, goal-oriented and goal-revising dialectic of resistance and accommodation is a general feature of scientific practice, as well as development practice and innovation processes, and this is what Pickering calls *the mangle of practice* or the mangle. The mangle is found to be suggestive for the dialectic because it conjures up the image of the unpredictable transformations worked upon whatever gets fed into the old-fashioned device of the same name used to squeeze the water out of the washing. It draws attention to the emergently intertwined definition and reconfiguration of machinic captures and human intentions, practices and so on.

The idea of temporal emergence is central to grasp the mangle. In advance we have no idea what precise collection of parts that will constitute a machine or technology nor what its precise powers will be. Practice is emergent and open-ended. What happens next is always contingent on the unique trajectory behind it, so from the standpoint of the practitioner, one never knows in advance what will happen next. There is no thread in the present that we can hang onto which determines the outcome. We just have to find out, in practice, by passing through the mangle, how the next capture of material agency is to be made and what it will look like. Captures and their properties in this sense just happen in time, and this is offensive to ingrained patterns of thought. The latter looking for explanations – and the closer to the causal, mechanical explanations the better - while it seems in the analysis of real-time practice, in certain respects at least none can be given. The world of the mangle lacks the comforting causality of traditional physics or engineering, or of sociology for that matter, with its traditional repertoire of enduring causes (interests) and constraints. Pickering adds however, that in the analysis brute contingency is constitutively interwoven into a pattern that we can grasp and understand, and which explains what is going on. That explanation is what the analysis of goal formation, the dance of agency and the dialectic of resistance and accommodation is intended to accomplish. The pattern may repeat itself but the substance continually emerges unpredictably within it (ibid, p. 24).

---

[12] Dialectic - the way in which two aspects of a situation affect each other. Oxford Advanced Learners dictionary, Oxford University press, 6th edition, 2003.

To sum up some central points from Pickering's thinking. His work is useful when trying to conceptualize temporally emergent phenomena, and where an understanding of practise in its temporal unfolding is a central theme. Agency emerges in the real-time of practice, temporally emergent practice. No one knows in advance the shape of the future but it is clear that human agency is not only involved in it. Humans live in time, in a particular way, and construct goals that refer to future states and then seek to bring them about. But the intentional structure too emerges in practice. The trajectories of emergence of human and material agency are constitutively enmeshed in practise and emergently productive of one another. The construction of a technology or technology combination entails a kind of open-ended tuning and repeated reconfiguration of its material specification until some sort of desired or desirable performance emerges. No one can know in advance just what precise tunings will be made in practice - this is what is meant by temporal emergence (Pickering 1994, p. 415) There are tunings of different strata e.g. science, the material, the social, the conceptual and so on; and practical manoeuvres in fields of agency typically couple the tunings of these heterogeneous strata together so that the contours of e.g. a new technology may be interactively stabilised. Hence the central pursuit is to explore how something is constituted and performed – the doings – of human and material agency and to attend to the continuing practice of this tuning.

This is an important point to my work. I cannot read development and innovation processes as performed by causal circumstances that allows explicit formulation[13]. Rather to rewrite a sentence from Law (2004a, p. 87), there are different sources and a criss-crossing plethora of locations, organisations, materials, facilities, people, and policies that crosses and effects the development, projects and creation of the hydrogen energy path, and hence influence the activities of the organisation. Hence the focus shifts to understand practice / doings / actions - temporal emergence - where practice is emergent and open-ended.

2.3 Beyond method

> "The collecting of data is a discriminating activity, like the picking of flower and unlike the action of a lawnmower"
> (Arthur Koestler (1964 cited in Wadel 1991)

A performative understanding challenges the belief in the power of research and words to represent pre-existing things and their causal circumstances. The move towards a performative understanding shifts the focus from questions of

[13] Inspired by Law (2004a, p. 87)

correspondence between descriptions and reality (e.g. do they mirror nature or culture?) to matters of practices / doings / actions (Barad 2003, pg. 802).

Research methods need adaptation to a world of flux and general unpredictability – a world that is complex and generative (Law 2004a, pp. 7-8). Social science tend to work on the assumption that the world is properly to be understood as a set of fairly specific, determinate, definite and identifiable entities, and processes waiting to be discovered (ibid, pp. 5-6). John Law, on the other hand, discusses research where we no longer seek the definite, the repeatable, and the more or less stable. Investigating elusive realities - events, and processes that are not only complex in the sense that they are technically difficult to grasp but also complex because they may exceed our capacity to know them. The world is communicated as an unformed but generative flux of forces and relations that work to produce particular realities (ibid, p. 7). This requires that we unmake our methodological habits, including the desire for certainty, expectations that we arrive at stable conclusions about the way things are, and the expectation of generality wrapped up in what is often called 'universalism' (ibid, p. 9).

How might method deal with mess (Law 2003)? The term mess is used to describe the something that we try to study, which turns out to be a moving target and a shape-shifting target. Phenomena that, which are vague, diffuse, uncertain, elusive and / or undecided. Slippery phenomena that change shape and are fuzzy around the edges (ibid, pp. 4-6). If the world is complex and messy, then at least some of the time we have to give up on simplicities. The challenge is the process of getting to know this mess and methodologies for knowing mess (Law 2004a, p. 3).

«Methodology is mostly about guarantees. Sometimes I think of it as a form of hygiene. Do your methods properly. Eat your epistemological greens. Wash your hands after mixing with the real world. Then you will lead the good research life. Your data will be clean. Your findings warrantable. The product you produce will be pure. Guaranteed to have a long shelf-life….there are lots of books about intellectual hygiene. Methodological cleanliness…. No doubt there is much that is good in these texts. No doubt it is useful… but (inserted by this writer) …. in practice, research needs to be messy and heterogeneous, because that is the way it, research, actually is. And also, and more importantly, it needs to be messy because that is the way the largest part of the world is. Messy, unknowable in a regular and routinised way» (Law 2003, p.3)

As a researcher, one cannot distinguish a priori how the potential development of hydrogen energy will turn out. The outcome is not given in the nature of things or on grounds of principle; rather the outcome will be an effect of the interacting processes of organising that are worth studying. Hence, when there is no root principle that drives the processes of

development in a direction, then it must be something endogenous in the process itself that drives and generates the process - self-generating processes. Law (1994, p. 15) elaborates on this in the following way:
«Look at it this way: the social is a set of processes, of transformations. These are moving, acting, interacting. They are generating themselves. Perhaps we can impute patterns in these movements. But here's the trick, the crucial and most difficult move what we need to make. We need to say that the patterns, the channels down which they flow, are no different in kind from whatever it is that is channelled by them. So the image that we have to discard is that of a social oil refinery. Society is not a lot of social products moving round in structural pipes and containers that were put in place beforehand. Instead, the social world is this remarkable emergent phenomenon: in its processes it shapes its own flows»

From this follows that explanation for an apparent outcome e.g. the development of a technology does not lie in the characteristics of its substance. Rather instead it rests in the way that the hydrogen idea and technology are related to many other things over time and space. Explanation is relational, not substantial (Hernes 2008).

With the interest in a real-time understanding of practice (contrasted with retrospective approaches that look backward from some terminus), and the basic image of science and practice being a performative one, where the performances – the doings – of human and material agency come to the fore; the research approach to understanding is necessarily an empirical one. With temporally emergent phenomena, we can never know ahead of practice what its products will be (Pickering1994, p. 417). Temporal emergence further implies that looking for enduring explanatory variables anywhere is a mistake (ibid). The heart of performative studies is empirical research into specifics and knowledge about performativities in e.g. technology emergence; and research is objective, relative, and historical all at once. An implication of these views is that they deny the existence of the pure objects that pure disciplines purport to study (Pickering 1994, p. 415). By tracing emergence, the focus is on practical performance, concrete achievements, and the outcome of e.g. a hydrogen project, is a relational effect of the heterogeneous surrounding world with which the hydrogen venture and hydrogen project come into contact and are moulded.

2.3.1 Portions of reality – the interpretive frame

When entering the empirical field to study phenomena, the researcher at best sees a portion of "reality" at one time – namely that part on which the researcher chooses to focus. If we work in a network tradition, we look for networks, if we are interested in organisational culture; we find culture, if knowledge management we try to find what we call knowledge management, and so on and so forth. This means that we have to remember that "the map is not the territory", the territory – reality – is in a sense unknowable in it fullness. This also means that we see what we look for. As we seek to know the world not everything can be brought to presence. The bringing to presence is necessarily incomplete because if things are made present, then at the same time things are made absent.

This view builds on Thomas Kuhn (1962), who saw scientific practice as governed by so-called paradigms, and that the recognition of the world is steered by paradigms that upfront delimit what you can see, and what questions you ask. Kuhn argued against views of the history of science that portray it as a process of cumulative development towards the truth, achieved by rational investigation founded on evidence. Kuhn showed that the work of scientists is shaped by theoretical presuppositions about the world and that the validity of scientific claims is always relative to the paradigm within which they are judged; they are never simply a reflection of some independent domain of reality (Hammersley et al. 1995, pp. 12-13). Hence researchers' knowledge and accounts of the world are always mediated by the pre-understandings or ideas of the interpreter/the researcher about the same world. Ideas and concepts frame what is understood of the world. They facilitate a way to see and understand things, and accordingly, when describing things with the use of a conceptual framing, one at the same time explains. Having said this, knowledge production is partial and we 'see and understand' certain things when using this or that conceptual frame of reference. In other words, *people, not their eyes, see* (Hanson 1958 cited in Smith 1998, p. 138).

Using my own work as an example, what was written in section 2.2 - ontological underpinning and background thinking - is part of my frame of reference. My ontology is the carrier of implicit assumptions and nourishes the belief in a performative understanding as a way to conceive of development and innovation processes. This in turn has epistemological implications in terms of how I go about knowing and studying the phenomenon. In the intellectual realm, hydrogen projects consist of a core idea around hydrogen as an energy carrier, but the content of hydrogen projects and hydrogen activity, in the realm of practice, results from chains of events and heterogeneous actors and materials (economic, political, social, technological and natural) that are connected and associated over time. Practical performance and emergence/practices/doings/ actions out of which hydrogen projects become, are accordingly the achievements in practice that need to be traced and reflected upon by the researcher/me, as I as a researcher, never know in advance what will happen next in open-ended development processes.

Since a researcher's knowledge and accounts of the world are always mediated by the ideas of the researcher about the same world, scientific knowledge is a form of culture. This culture is a resource for making sense of a complex world. It is a shared interpretive resource (Law 2004b). Hence all research strategies are framed by assumptions that shape the course of inquiry in distinctive ways, inclining the researcher to see and engage with and interpret the world from one perspective rather than from another (Morgan 1983). Research strategies offer ways of realising knowledge of the multifaceted nature of social life. All social phenomena may have many potential ways of revealing themselves, and the way they are realised in practice depends on the mode of engagement adopted by the researcher (ibid, p. 390). A more relativistic view of the research process encourages us to see the different approaches as doing different things and to attempt to assess their contributions with this in mind (ibid, p. 397). Consequently, one strategy may be more effective for a specific purpose than for another.

As discussed in this section, theory or assumptions about the world and empirical research feed into one another because assumptions shape the researcher's vision. Hammersley et al. (1995) call this the fundamental reflexivity of research; namely the fact that we are part of the world that we study. Reflexivity implies that the orientation of researchers is shaped by the socio-historical locations, including the values and interest that these locations confer upon them. But if reflexivity is part of the problem, it is also part of the solution, researcher may be laden with ideas, and by becoming reflexively aware of ideas and presuppositions, one can reflect upon our actions as part of that world. Reflexivity in anthropology is about investigating how the interaction between the researcher and the 'others' under study, influence the empirical material that they are both part of. At the same time, reflexivity is a concept that shows how written research accounts, and the conditions that they describe, elaborate and modify each other in a circular process. Ethnographic descriptions about a certain world are constructed using expressions and concepts which meaning is derived from the same world (Hastrup 1992).

2.4 Research process

Hydrogen as an energy carrier is in a process of becoming something that is unpredictable in advance, and the organisation studied is part of the overall hydrogen energy creation process. How does the organisation become what it becomes in the area of hydrogen energy? Hydrogen activities, as said before, means organising under uncertainty and handling complexity is what practitioners in innovation processes do on a daily basis. The interpretive frame or resources I use, acknowledge complexity in development processes and in practice.

My analytical and empirical strategy is not new in the STS tradition. Ethnography has a long tradition of qualitatively describing human and social action, and phenomena based on fieldwork including participant observation, informal interviews and dialogue with insiders known as "informants" (Hess 1992, p. 4). As a scientific method, it does not mean being a fly on the wall and watching people's behavior, it means talking to and interacting with people and attempting to understand their worlds and action. As a scientific method and strategy for inquiry, ethnography is used to study a variety of settings where the starting point is an attempt to understand the world from the "native's point of view"[14]. The term "natives" is a less formal way of referring to the Other, the member(s) of society or a social group, who have a culture or perspective different from one's own, even if the Other is merely a different segment of one's own society. It may be better to speak of the starting point of the research, namely the tasks of interpreting the natives' points of view, and interpreting the voices of the various groups of constructors and re-constructors of science and technology.

With this discussion in mind, my study will consist of a single case study (Hydro) with an embedded case (the Utsira demonstration project). A case study allows for a processual and longitudinal analysis of the various actions and meanings, which take place within settings. By its proponents, case study research is said to excel at bringing us to an understanding of a complex issue or object. Yin summarises that the research situation where a case study has a distinct advantage is when: "how" or "why" questions are being asked about a contemporary set of events in which behaviour of the people or systems at the centre of the research problem cannot be manipulated. That is, the investigator has little or no control over the events (Yin 1989, p. 20). The role of case studies is also supported by two sources of information that are of limited use to other research strategies - direct observation and systematic interviewing, which are added to other sources of information e.g. documents, archival materials etc.. Dynamic processes and change are also characteristics, which can be explored by the case study method in ways that other research techniques either cannot or do poorly[15].

I use interviews to generate insight about the processes studied. I am using my information and conversations with practitioners not to prove but to exemplify. Individual recollection matched with other's recollection

[14] Hess (1992, pp. 2-3) points out, the idea of the "native's point of view" should not be taken too literally or narrowly as the study of foreign cultures, tribes etc. The natives in ethnographic studies are often cosmopolitan and include artificial intelligence researchers, environmentalists, legislators, consumers or inventors of technologies.

[15] I side with the ideas of Patton (1990, p. 39), who state that he prefers pragmatism to one-sided paradigm allegiance, and that a paradigm of choices rejects methodological orthodoxy in favour of methodological appropriateness. The issue then becomes whether one has made sensible methods decisions given the purpose of the inquiry, the questions being investigated, and the resources available.

present a history of pioneer activity and the project, and a sequence of actions, events, actors, company evaluations and interpretations. It has not been possible to be an observer nor an integrated participant in the hydrogen unit. Further, I was not given access to the electronic company archive. My contact person wrote me: *"This archive is where our most confidential documents are and it is probably understandable that no persons outside the company will be granted access to this. Sorry"*. The, at the time, recent strategy documents (2005/2006) were also classified as confidential and problematic to access. Instead the company preferred interviews/conversations as the most acceptable tool to get access to the company's thinking and activities.

I have supplemented my conversations with documentary evidence such as company power point presentations, project evaluations, speeches, annual reports, Internet pages, news articles, conference papers and brochures as additional sources of reference for constructing the sequence of events. These diverse sources of documentation added supplementary insight to the dynamism that carried the project and development processes forward in time. Some of the written documentation was brought to my attention and/or passed over to me by interviewed people in the hydrogen unit. Other documentation was uncovered using regular search tools.

The fact that the project and hydrogen activities were ongoing processes strengthened the relevance of the argument made by Law (1994, p. 8), namely that researchers should: "make an attempt to avoid starting off with strong assumptions about whatever it is they are trying to analyse. Everything deserves explanation and should be approached in the same way (symmetry); you don't want to start any investigation by privileging anything or anyone".

2.4.1 The hydrogen area and practitioners

The hydrogen energy area allows for an in depth look at how something technical, political, social, economical comes into existence. It allows us to look at innovation and technical development processes in their making as processes of organising under uncertainty. There is a challenge and methodological aspect in researching ongoing processes – emergent phenomena - since we do not have a definite outcome - an economy running on hydrogen or fixed hydrogen-based energy system, success or failure - that may be evaluated retrospectively and fitted into our analytical frameworks. The hydrogen economy is not here yet – it is still in an 'unfolding' phase of experimentation and demonstration – that is open-ended.

A consequence is that when entering the reality of organisations where a moving target and interwoven ongoing processes are found, the researcher becomes reliant on practitioners' experiences, accounts of the processes and in bringing forth aspects of the phenomena under investigation. In this situation - dealing with open-ended and ongoing processes - I considered it to be a sensible research strategy to 'follow' practitioners; how they try to mobilise elements and support for activities, and how they make choices, accommodations and adjustments along an uncertain development path. As Pickering refers to it as *resistance and accommodation*, that is how do practitioners deal with resistance in the sense of practical obstacles or blocks on the path to some objective, and how do they circumvent obstacles (Pickering 1995, p. 22). Grasping development in its own setting, and in its own terms, may provide a better understanding of the accomplishment and emergence of new technology paths with practitioners mentioning events, ideas, activities, material resources/objects, and actors important to the development path.

Practitioners' activities bring substance to heterogeneous engineering in practice. Connecting to the lived-experience of practitioners has also been important because when doing empirical fieldwork nothing ever happens right where and when the researcher is present in an interview. All important events happen at some other time, in some other place. "In the beginning, the researchers tend to panic and try to chase 'the action', but in time they learn that 'important events' become such in accounts. Nobody is aware that an important event is happening when it takes place. Events must be made important or unimportant." (Law 1994 cited in Czarniawska 2004)

The intent has not been to prioritise the human impetus in development processes; it is merely that connecting to the accounts and lived-experience of practitioners has made it possible to study the generative processes 'behind and in' the projects. This research strategy will also make it possible to access the non-linearity that is frequently used to characterise innovation processes.

2.4.2 Hydrogen activity and the project

I am not using the hydrogen business unit as my unit of analysis; rather *I am using pioneering hydrogen activity and a hydrogen development project in Hydro as my focal point*. Pioneering hydrogen energy activities and a hydrogen project are at the core of my research in terms of how they become in an empirical setting.

Firstly, the vision of hydrogen as an energy carrier will only materialise if it associates objects (material resources), people, and ideas. Concrete hydrogen activity and a hydrogen project will illustrate the dynamics in such processes with their own set of actors and coupling of activities through practice. Focusing on organisational structures may not suffice in the pioneering phase, as activity may precede any such formal establishment. Further, it is not a matter of showing the organisation's network with assumed given characteristics, rather it is more about 'mesh-work' and path creation efforts to position hydrogen energy as part of the organisation.

Secondly, having pioneering hydrogen energy activity and a hydrogen project as my focal point will also allow me to view the project from different angles i.e. with the experience of different people in different positions or units inside the company (the research centre, the management team, the hydrogen unit). But also from the 'outside' e.g. from the point of view of a partnering organisations, research institutions etc. This is important because hydrogen energy activity may illustrate how intra-organisational activity connects with the outside in the mobilisation and realisation of hydrogen development efforts. This is relevant as things become at the local level by making detours to the outside of the organisation, to society at large. The external environment exists but as a reservoir from which elements and relations is created, not as a neutral, constant, determining factor (Hernes and Weik 2007). But the challenge is to show how the 'external' is connected to the hydrogen activity in practice, and hence how it makes its way inside the organisation.

Thirdly, between the intention and mobilisation inside the organisation and the outcome in terms of experience from hydrogen activity and the demonstration project realisation, there is complexity over the course of the development process. There are connections between material resources, ideas, policies etc. and other actors, also possibly with other intentions, which mean that there is no direct link between the company's intentions and outcome. The connectivity and hence complexity in hydrogen energy activities and the demonstration project, mean that one can explore the dynamics and reciprocal shaping of the intentions and strategic orientation of the organisation with experience and how the project unfolds (outcome). That is in the 'doing' of hydrogen activity there is interaction across things being connected. Sub-outcomes come along the way leading up to new decisions and new activities; other directions and paths may be conceived through the linking of objects (material resources), people and ideas. How does this shape the intentions/understanding/reality picture inside the company and the continuation of hydrogen energy activity?

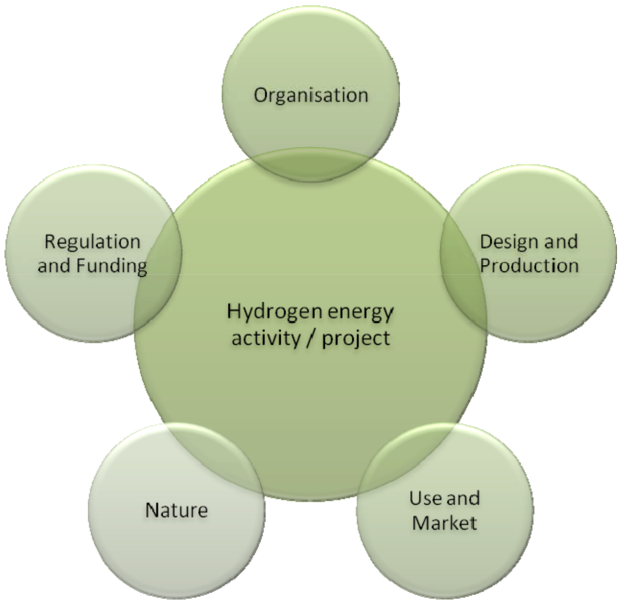
2.4.3 Focal points in studying practice

In my empirical field work, I also considered it helpful to have in mind the abstraction or scheme below, which builds on Karnøe and Garud (2003)[16]. The abstraction, points to agents that possibly have a bearing on the

---

[16] Karnøe and Garud's scheme (2003) point to distributed agents that have a bearing on the emergence of a technological path. I have modified it slightly, in lay out and content, replacing evaluation with organisation, as I think evaluation can be fused with regulation since technical evaluation / technical standards may be argued to be part of setting 'the rules of the game'. I have also added nature.

emergence of a technological path, but does not say anything about the process. However to borrow from Weick (2005), the abstraction "impose discrete labels on subject matter that is continuous", and thereby provides a guide post for how and where to 'look'. Hence, I have used it as a sensitizing framework (Patton 1990) in the empirical fieldwork and interview processes. A sensitizing framework helps orient fieldwork[17] by providing guidance in approaching empirical instances e.g. themes, events and activities, which are considered central to the field and phenomena, in this case, to innovation processes and technology emergence. Hence the abstraction highlights points of attention or 'activity arenas' that are not predetermined but potential travel points for hydrogen energy activities, which practitioners trying to advance hydrogen as an energy carrier may relate to and work on.



In the centre of the abstraction, there is the hydrogen energy activity / project studied, where we find actions, events, organising, talking, communicating or meshing in relation to five arenas. The five points of attention or activity arenas may be seen as containing opportunity as well as restraint. Restraint as they contain elements of established practice and possible competition from other energy solutions; yet opportunity because their content is not fixed. For the purpose of simplification, one may say that they are somewhat

[17] It is impossible to observe everything. The human observer is not a movie camera, and even a movie camera has to be pointed in the right direction to capture what is happening. For both the human observer and the camera there must be focus. Sensitizing concepts help orient fieldwork as they alert us to ways of organizing observations and include ideas that are fundamental to the field.

‘black boxes’, because the content of these arenas are not given a priori but becomes in interaction with hydrogen energy activity. They may be said to set the scope for hydrogen energy activity, to be the surface of emergence, but are also shaped by hydrogen energy activity.

This is easier to picture, if adding that the points of attention are arenas where activity or ‘mesh-work’ unfolds. Interests, ideas, resources, and people meet, are coupled and mutually shaped. The content and attributes of the five points of attention/ activity arenas emerge and change in the course of interaction with hydrogen energy activity and hydrogen advocates. It is always difficult to depict dynamics in an abstraction, and I have tried to depict an interlinked configuration with as few solid borders and arrows, as possible. This is done to convey the idea that as hydrogen energy activity evolves through meshing in relation to the five activity arenas; then hydrogen energy, e.g. a project, come to include attributes from the five arenas. Vice versa, the arenas are also transformed with hydrogen energy related features. Further, as activities unfold in relation to one of the arenas, points of attention, it may have bearing on the others. Hence I am trying to depict a continuous dynamics and presence of the attention points in relation to hydrogen energy activity.

1. *Regulation and funding*: relates to a range of allocations and initiatives such as laws, plans, R&D funding, product requirements, and other policy instruments that are used to legitimise, regulate and coordinate actions. These may constrain or provide incentives for hydrogen energy activities and shape the rate and direction of the hydrogen energy development path. However, the regulatory framework is not pre-given; it is often non-existing in relation to a new technology and has to be created. How does this point of attention have a bearing on the company’s hydrogen and hydrogen projects, and vice versa, how is hydrogen energy activity in the company connected to regulatory frameworks in Norway and internationally?
2. *Organisation*: concerns the act or process of organising or of being organised[18]. How are formative activities undertaken within the organisation in terms of sorting out possible activities, mobilising from ideas to decisions on the development of hydrogen energy initiatives? How does hydrogen become part of the strategic aim of Hydro? Organisation concerns internal Hydro processes, ways of organising hydrogen activity from initiation through implementation e.g. in-house research and development, partners, technical cooperation; and how hydrogen energy activity/project are positioned within the existing organisational structure.

[18]http://www.merriam-webster.com/dictionary/organization

3. *Use and development of markets*: have to be created for hydrogen. Arenas are needed where use and the hydrogen market may be rehearsed. How is hydrogen energy fitted into existing material and technical structures? New markets may be defined as hydrogen and hydrogen technology creates opportunities for new applications. Demo-markets / demonstration projects may be important for awareness, feasibility of hydrogen solutions. Identification of user benefits, user information and education on use and safety may also be important in this activity arena. If and in what way does the organisation relate to and get involved in the user and the market element?
4. *Design & production*: producers become involved in technologies based on their experiences. How are technologies, technical skills and competence generated (R&D, learning by doing and feedback from using, partnerships)? What are the resource endowments in terms of scientific and technological research as well as human resources, skills, educational training relevant to hydrogen energy? What type of role and position should the company have in a technology development process and path? Where should the organisation be in the process (the resource, idea and concept generation phase, technology developer; or technology purchase)? Looking into this point of attention, the contours or forms of material agency may also be explored as emerges in practice.
5. *Nature*: may denote the natural conditions under which hydrogen energy based technological systems shall operate (e.g. offshore conditions with storms and salt, hot and cold climates). Technologies must prove their functioning and viability, which links back to the production and design point. At another level, nature has an acting capability of its own. This concerns how hydrogen energy is related to contemporary societal problems e.g. pollution challenges ranging from acid rain to greenhouse gas emissions and climatic changes impacting human societies. These impacts influence efforts to make new technologies and shape attention and allocations. How is hydrogen energy linked to challenges?

As mentioned above, I have used it as a sensitizing framework in the empirical fieldwork and interview processes to make sure that conversations were related to these points of attention. This was done to find out if and how practitioners trying to advance hydrogen as an energy carrier related to and worked on these activity arenas that have been indicated to have a bearing on the emergence of a technological path.

3 Perspectives, positioning and disciplinary dialogue

3.1 Studying innovation processes and phenomena in the making

There is no single innovation theory. Rather innovation is discussed in a variety of different, but overlapping, research traditions representing a variety of economic and organizational perspectives. Literatures and researchers look at different aspects of the innovation problem / challenge. The interpretive frame of reference makes the researcher see a portion of reality, and "a way of seeing is also a way of not seeing" (Poggi 1965). Poole and Van de Ven (1989) has argued that because organizational theories attempt to capture a multifaceted reality with a finite, internally consistent statement, they are essentially incomplete. Theories with assumptions and explanations implicitly state what is relevant and what is not, and theories always constrain the theorist's field of vision. Theories are not statements of ultimate "truth" but alternative propositions about a multifaceted reality (ibid, pp. 562-563).

The Oxford Handbook of Innovation (Fagerberg et al. 2006a) indicates that the innovation literature is so large and diverse that even keeping up-to-date with one specific field of research is very challenging. Literatures diverge in their focus on e.g. micro dynamics and processes through which innovation occurs and actors take part. Focus on the firm and the location- and project specific linkages that evolve with other organisations. Or perspectives with focus on the roles of institutions, political factors, organisations and actors at the national and/or regional level, and are hence systemic or functionalist in their explanation of innovation. Fagerberg (2006b) in his guide to the literature, divide the discipline into: *innovation in the making* focuses on how innovation occurs; *the systemic nature of innovation* focuses on the external sources and the social system for innovation development; *how innovation differs*, focuses on innovation's variability over time and space in certain sectors, regions, and countries; and *innovation and performance* focuses on innovations and long term economic change.

Given the focus and questions in my study that draws attention to organisational phenomenon and origin[19]*;* the most relevant is Fagerberg's

[19] Literature on innovation provides categorisations such as product versus process, incremental versus radical, sustaining versus disruptive, continuous versus discontinuous but as Hargadon (2003, p. 32) points out such labelling do not distinguish an innovation's origins from its impacts.

discussion of the literature on *Innovation in the making*, which focuses on *how innovation occurs* (Fagerberg 2006b). This builds on the tradition of Joseph Schumpeter (1934), who emphasised three main aspects. *The first* is the fundamental uncertainty inherent in all innovation projects; *the second* is the need to move quickly before somebody else does (and reap the potential economic reward)[20]. *The third* aspect is the prevalence of "resistance to new ways" – or inertia- at all levels of society, which threatens to destroy all novel initiatives, forcing entrepreneurs to fight hard to succeed. Inertia is to some extent endogenous since it reflects the embedded character of existing knowledge and habit, which, though 'energy-saving', tended to bias decision-making against new ways of doing things (ibid, p.9).

Fagerberg argues that the literature on innovation projects in firms and the management of such projects has been slow to evolve. But, in general, research in the area coincides with Schumpeter's emphasis on uncertainty. In particular, for potentially rewarding innovations, one may simply not know what are the most relevant sources or the best options to pursue (still less how great the chance is of success). Balancing the opportunity for building first mover advantages with the risk of being locked into a particular path too early, may mean trouble because it may be too costly or too late to switch path (ibid, p. 10). Preserving openness, avoid being stuck to a particular path, and remaining open to competing ideas and solutions, pluralistic leadership that allows for a variety of competing perspectives are considered advantageous. To maintain a capacity for changing its orientation, the cultivation of so-called 'weak ties' is considered useful (Van de Ven 1999 cited in Fagerberg 2006b, pp. 10-12).

Based on Schumpeter's work and the definition of innovation as 'new combinations' of existing resources, Fagerberg applies an evolutionary logic and indicates that from this definition of innovation, it follows logically that the greater the variety of these factors within a given system, the greater the scope for them to be combined in different ways, producing new innovations which will be both more complex and more sophisticated (ibid, p. 10). There are some challenges associated with this view.

Firstly, the assumption that innovation is more likely to occur when there is variety in factors to be combined does not help settle what Fagerberg himself indicates to be the tendency of economics to treat the innovation process itself as a "black box". That is, how variation is generated or new technological configurations created, how a resource combination comes to be, and how it might change.

[20] In practice, Schumpeter argued, these two aspects meant that the standard behavioural rules, e.g. surveying all information, assessing it, and finding the 'optimal' choice, would not work. Other quicker ways had to be found. This in his view involved leadership and vision, two qualities associated with entrepreneurship (Schumpeter 1934 cited in Fagerberg et al. 2006).

Secondly, the other part of the argument that innovation leads to something more complex and sophisticated is tricky as there is research and literature that point out that innovation or new technologies may not necessarily outperform established technological combinations. Rather what seems to be relevant is to pursue the value proposition of the new combination of resources coupled with attention to the characteristics of possible users or customers and the emergence of market segments. New technology combinations may have other performance attributes that fringe customers value (Christensen 1997).

Pulling these challenges together, a process orientation brings in actions and agencies over time and enables us to look into how resources are combined into new configurations. Inspired by Håkansson et al. (2002) and Normann (2001, p. 108), it may be suggested that resources have 'positional' value rather than 'intrinsic' value; and resources as well as their worth / dimensions of merit change with development by recombining resources in new ways, in new contexts, and with new ideas that link them. This involves a dynamic understanding of resources[21], as the value of a resource element is variable depending on its combination with others and its use. Hence resources are not entities given once and for all, rather the value and the features of a resource gain meaning in constellations with other resources or combinations that have use.

In the introductory chapter to the Handbook of Innovation, Fagerberg (2006b, p. 20) concludes that "in spite of the large amount of research in this area during the past fifty years, we know much less about why and how innovation occurs than what it leads to. Although it is by now well established that innovation is an organisational phenomenon, most theorizing about innovation has traditionally looked at it from an individualistic perspective ……. but our understanding of how knowledge – and innovation – operates at the organisational level, remains fragmentary and further conceptual and applied research is needed".

In the Handbook of Organizational Change and Innovation edited by Poole and Van De Ven (2004), the editors indicate they were struck by the variety of theory and research on organisational change and innovation. The literature was vast and spread across a number of disciplines, and the editors represent a rich tapestry of theories. In the chapter by Van de Ven and Hargrave (2004), the authors review social, technical, and institutional change literature and subdivide this into four distinct perspectives on change

[21] Håkansson et al. (2002) indicate that embedded into the network approach, the heterogeneity of resources is mainly considered in terms of interactive effects. In an economic context all resources, whether natural or created, are used in combinations. It is from these combinations that their features are created and an important consequence is that a resource always has hidden qualities. The quality of a resource is never given once and for all but is created when embedded with other resources.

(institutional design, institutional adaptation, institutional diffusion and collective action). They focus on what they consider the leading theoretical contributions and exemplary empirical studies in each perspective. The four distinct perspectives address different questions and are also described in terms of their unique and respective motors of change referring to the generative mechanism / the mechanisms that bring it about (Poole 2004, p. 6).

My focus here is on the authors' literature review conducted on collective action, technological innovation and industry emergence, and process theories of technology emergence (Van de Ven and Hargrave 2004, pp. 277-292). Technology scholars have called attention to the interdependence of technical, social and institutional change in their studies of technological innovations, entrepreneurship, and industry emergence. For this reason scholars have focused on processes of collective action. *The collective action model focuses the analysis on efforts and processes at the interorganisational level rather than the individual actor.* Many actors play diverse roles in the interorganisational field that emerges around a technical innovation. Scholars working from this perspective are concerned with how new arrangements emerge from interactions among interdependent partisan agents (ibid, p. 264) as well as the interest seeking actions that actors find to influence these processes.

The collective action perspective comes across in the definition of the innovation journey (Van de Ven et al. 1999): New ideas that are developed and implemented to achieve desired outcomes by people, who engage in transactions (relationships) with others in changing institutional and organisational contexts (ibid, p. 6); and it comes across in the following quote: Seldom can an individual entrepreneur alone command the competence, resources, and legitimacy to develop and commercialise an innovation (ibid, p. 149). The literature on technological innovation and industry emergence focuses on the collective achievement aspect and abandon picturing innovation as an individual accomplishment. *To understand how any one relationship unfolds requires looking beyond that individual relationship to the larger web or network of relationships in which organisational parties become involved to undertake an innovative venture"* (ibid). *Hence technology entrepreneurship is a larger process that builds upon the efforts of many.* Skills and resources required to take an idea from its inception to commercial use have to be mobilized by drawing upon the generative impulses of actors from multiple domains (Garud and Karnøe 2003).

Examining the construction of innovations with the *collective action* perspective[22] focuses on the social, technical and political processes that

[22] In collective action models, the underlying assumption about the principle motor of change, that is the generative mechanism / the mechanisms that bring change about, is dialectical

facilitate and constrain technological development processes. Actors are partisan or biased in the sense that they participate from their own frames of reference and often have different, even conflicting interests (ibid, p. 289). Common interests and benefits are worked out through collective action processes in which actors promote their own interests, use strategies and tactics of partisan mutual adjustment (ibid, p. 283), and where shared ideas and action are worked out and emerge as an endogenous outcome of these processes of interaction.

New-to-the-world technologies transcend the boundaries of the individual firm and industry. There is a role for public and private-sector actors in creating the economic, political, and market infrastructure that a technological community needs to sustain its members. Garud and Van de Ven (1989, 1999) developed an augmented view of an industry where firms and organisations perform different functions in the construction of technology / projects, in the course of an innovation journey. In their view the components are: 1) institutional arrangements to legitimize, regulate, and standardise a new technology; 2) resource endowments for basic scientific knowledge and technological knowledge, financing and insurance arrangement, and training of competent professionals/ labour. Further, the components are: 3) development of markets, stimulation of demand, education of consumers since for new to the world technologies, informed competent, and responsible consumers do not pre-exist; and 4) proprietary (company) activities like research and development, production, and distribution functions by private entrepreneurial firms also transforming the available supply of public resources into products and services. Proprietary activities cover the traditional definition of an industry consisting of the set of firms commercialising innovations that may be close substitutes for each other. (Van de Ven et al. 1999, p. 161, Van de Ven and Hargrave 2004, p. 284).

From this perspective, a central implication is that innovation managers must be concerned with the macro-, the industrial infrastructure since it may facilitate or constrain the commercialisation of technology and product innovations. The necessary skills and capabilities needed to compete are not readily found under a single roof, and the technological process goes hand in hand with the evolution of the industry and its supporting institutions (Powell 1998 cited in Van de Ven and Hargrave 2004, p. 285). Further, when the components of the industry infrastructure does not exist, a firm sponsoring an innovation has to “run in packs” with other competing and / or cooperating firms in the public and private sector. Running in packs or

---

where confrontations emerge between conflicting entities espousing opposing thesis (ideas, views) and antithesis that collide to produce a synthesis, which in time becomes the thesis for the next cycle of a dialectical progression of changes (Van de Ven and Hargrave 2004, p. 292).

working collectively is a conduit to combine knowledge and skills into new resources and also a way to reduce uncertainty of not knowing the industry infrastructure components that may eventually emerge.

Van de Ven et al. (1999) indicate that from a macro point of view, to understand innovation processes is to know: "*How and when different components in the system emerge and are organised? What actors create and perform them? What consequences the various arrangements of this community infrastructure have on the time and costs of development and commercialisation of innovations?"* Further, from a micro point of view, the firm has to make decisions on: "*What function to perform? What other organisations should the firm link to or contract with to perform other functions? What organisations will the firm compete with on certain functions and cooperate with on others?"* As a consequence, the innovation process is undertaken at two levels. The system level is looking at the community infrastructure as a whole, interrelations (functions and components); and the behaviour at the individual entrepreneurial level within the industrial system (ibid).

The collective action perspective sees technology emergence as the result of action among *partisan actors,* in the sense that actors participate from their own frames of reference and interests that are worked out through collective action processes of mutual adjustments. Further, the collective action perspective sees technology emergence as the result of action among *distributed actors,* in the sense that many different public and private actors play a role, and that no single actor controls the development process. Finally, the collective action perspective sees technology emergence as the result of *embedded actors*, in the sense that because the technological development process is a collective one, their actions are constrained by and must be taken in concert with the actions of other actors in the process. Actors have differing interpretive frames and efforts are fused through a process of cumulative and creative synthesis (Garud and Karnøe 2003, Van de Ven and Hargrave 2004).

3.1.1 Organising development processes under uncertainty

From the performative understanding, phenomena exist in the doing of them. They have to be continuously performed to exist at all. This line of thinking goes well with the reality of innovation and development processes. Using the words of Pickering (1995), such processes are "temporally emergent". They take on shape and content as they happen in time from the doings of distributed and embedded actors acting on the basis of their interests and intentions. An outcome of this view is that reality in principle could have been or done otherwise, or as stated by Bijker and Law (1992, p. 8) "the technologies with which we are actually endowed could in another world have been different".

Development processes in clean energy is an uncertain path to embark on. There are conflicting descriptions about the sense in pursuing this or that clean energy development path typically backed by diverse advocates and interests, and there is diversity in energy policies, resources / resource endowments. Finally, technologies pursued add to complexity. From an organisation's point of view, what development activities should be pursued among new energy alternatives, if any?

How does an energy company position itself in the environmental debate, and how is the clean energy agenda, opportunity or threat interpreted and acted upon? The business case for embarking on a hydrogen energy path is similarly entangled in these debates. In such an empirical setting, creating the future sparks tension and controversy since different technological fields and industries wish to have a stake in future energy. What is opportunity for one industry population may mean sundown for others, as they become obsolete for economic, social or environmental reasons.

In Hydro's hydrogen activities, there may be no clear boundaries or upfront distinctions as to what will influence activities and impact the development processes. Development in the making may not be predictable. What may be argued, as common ground is the preoccupation with organisation - and the economy in general not as fixed points and stable entities or parts available for linear measurement - but organisation and technologies as resulting from processes of organising. March (1981) argues that seeing innovations as spreading unchanged is misleading because a fundamental feature of change is the way it is transformed as it moves. Organisational change develops meaning through the process by which it occurs, and therefore has a developing character. Similarly organisations are also transformed in the process of innovating as goals may be redefined and change along the way (Hernes 2008). Organisations create their own environments by the way they interpret and act in a confusing world, and transformations seem often to reflect occasions on which actions taken by an organisation (for whatever reasons) become the source of a new definition of objectives (March 1981, p. 570). Karl Weick writes about processes of organising and uses the concept of sensemaking to describe the search for meaning as a way to deal with uncertainty. In the words of Weick et al. (2005, p. 419): *"to deal with ambiguity, interdependent people search for meaning, settle for plausibility, and move on"*. When committing to innovation projects that hold uncertain outcomes, practitioners create an outlook based on which activity is mobilised. It is based on this understanding that activities and initiatives are explained; and processes of understanding are linked to concerns of reproduction inside the company - that is how conditions are created necessary for the initiation and continuation of innovation activities.

However, this reproduction may also be linked to how interests and resources are created and mobilised in society at large. Clean(er) energy development processes involve complex and plural processes to create new socio-technical worlds. They involve organising in several domains e.g. organisations, science, technology, uses, infrastructure, society. Law (1994) argues "it is all about complexity, mess, or as I would prefer to say, heterogeneity". The social world is materially heterogeneous, that is, it is composed of a range of materials, texts, people, and technologies. Similarly, our technologies mirror our societies, technology and its shaping has to do with the historical, the economic, the political, the psychological, as well as the sociological processes that give it shape (Bijker and Law 1992). Entrepreneurs, scientists, engineers may hence be characterised as bricoleurs linking bits and pieces together, heterogeneous bits and pieces (Callon and Law 1997, p. 168).

With the challenges and uncertainty surrounding the development of a new energy carrier (see appendix I Hydrogen in the making), there is no agreed transition or development orientation to point company activities in a certain direction. Rather the process of deciding and mobilising resources to the making of a particular energy carrier, technology combination, and cleaner energy path, involves processes of organising. Processes of organising involve a relationship between change and enactment and include sensemaking activities in a reality that is complex and fluid (Weick 1995, 2005). Sense-making processes attempt to reduce equivocality[23], and a basic idea of sensemaking is that reality is an ongoing accomplishment that takes form when people make sense of things by seeing the world – that is by reducing ambiguity through the selection and interpretation from an abundance of information, from a stream of experience.

This is similar to the attention that some scholars direct to the *framing* concept. Framing also concerns meaning construction and the mobilisation of ideas, and is central in the act of constructing an understanding based on which action may be based. To illustrate, social movement scholars, influenced by Erving Goffman's work on the topic (1974), are interested in the process and "the politics of signification" (Benford et al. 2000). By employing the word "framing", this denotes an active processual phenomenon. Social movement actors are viewed as signifying agents actively engaged in the production and maintenance of meaning and not as carriers of ideas and meanings that grow automatically out of structural arrangements[24]. Framing involves the strategic creation and

---

[23] Weick (1990): "An equivoque is something that admits of several possible or plausible interpretations and therefore can be esoteric, subject to misunderstandings, uncertain, complex and recondite…. Because new technologies are equivocal, they require ongoing structuring and sensemaking if they are to be managed".

[24] One of the aspects discussed to explain the emergence of social movements is *framing processes,* the collective processes of interpretation and attribution that mediate between

manipulation of shared understandings and interpretations of the world, its problems, and viable courses of actions. The framing process mediate between opportunity structures and action by providing the means by which people can interpret the opportunities before them and, thus, decide how best to pursue their objectives.

Similarities may be drawn between technology emergence and social movements ((Van de Ven and Hargrave 2004, p. 283) as entrepreneurs in technology development face the task of gaining cognitive and socio-political legitimacy and seek to mobilise resources for their specific cause. Entrepreneurs and intrapreneurs actively try to create and sustain a legitimate market space for new technologies. Like social movements, a central effort is to mobilise resources and to push and ride ideas into good currency – i.e. to win the battle over framing (ibid, p. 279). Mobilising ideas and constructing an understanding based on which action may be built, the organisation becomes a participant in the creation of socio-technical worlds. This is a continuing process since the material, natural and social world reacts back at each other and reconstitutes ideas and practices. As Pickering (1994, p. 414) emphasizes "the world is continually acting, the world is busy". As organisations do not encounter or have an agreed point of reference on which to base decisions and activities, organisations cannot predict optimal courses of action, rather practice happens in time with puzzle-solving and continual adjustments. Consequently one may ask, how are 'contributions' made, what contributions matter and what turns out to be or is made relevant?

3.1.2 Building on constructivist ideas

My study and the questions specifying my research draw attention to what Van de Ven and Hargrave (2004) refer to as collective action, technological innovation and industry emergence, and what Fagerberg (2006b) refer to as innovation in the making - phenomena in the making – that is the temporal processes that underlie the constitution of phenomena. The questions tie into perspectives on innovation and development that build on constructivist ideas. A constructivist perspective assumes reciprocal

---

political opportunity structures and collective action (Van de Ven and Hargrave 2004).To explain the emergence of social movements, scholars converge on three sets of factors: *mobilizing structures* which are the forms of organizations or collective vehicles (informal and formal) that are available to insurgents and through which people mobilize and engage in collective action; *political opportunity structures*, which are the institutional arrangements or the structure of political opportunities and constraints confronting the movement; and *framing processes,* the collective processes of interpretation and attribution that mediate between political opportunity structures and collective action (McAdam et al. 1996 cited by Van de Ven and Hargrave 2004).

interactions between economic technical and institutional forces that constitute technological object and actors involved (Garud and Karnøe 2001, p. 3). Garud and Van de Ven (2002)[25] summarise about constructivist writers such as Law (1992), Latour (1987), Callon (1986), and Weick (1979) that they adopt interactionist perspectives in which organizational purpose and meaning emerge from shared reflection. Development processes and change are most appropriately characterized as a "duality" (Garud and Van de Ven 2002) wherein organizations are shaped by a continual flow of events that they, in-turn help to shape (Garud and Karnøe 2000). My work builds on theorists and theoretical resources in the field of organisational theory (Weick, March); the umbrella of STS literature referring to (science, technology and society studies / science and technology studies) [26]; writers in the economic sociology literature, and strategic management concerned with understanding emergence and creation of new technological paths.

From a conceptual point of view, perspectives on innovation and development that build on constructivist ideas implies a shift from the standard economic timeless system of rational choice to evolving economic systems, which also means assuming the temporary dimension of economic action. This dimension implies a need to address the role of past activities, present action, action goals and choice. It means moving away from 'the technology of choice framework' in which agents make choices on the basis of given means, given goals (objectives) of action and perfect and complete knowledge about the states of the world (Cañibano, Encinar and Muñoz 2006). In my opinion, it is of central importance that concepts used are as heterogeneous as the actors' activities and as seamless as the web of associations of the social and the technical. Innovation processes are collective acts consisting of sequences and parallel activities over time, in many locations and with multiple actors participating, hence organizations

[25] Handbook of strategy and management / edited by Andrew Pettigrew, Howard Thomas and Richard Whittington, London Sage, 2002, pp. 206-231.

[26] Technological change is not an autonomous force, nor is it a haphazard process; it is structured and focused, geared toward solving particular problems that have grown in the process of development, and endogenous to the structure of economic incentives, firms' capabilities, (legal) standards, and economic interests. New technologies are not created outside society, but part and parcel of social-technical transformation processes (Kemp, Rip, Schot 2001, p. 271). This is a shared view in science and technology studies (STS). STS studies attempt to unravel the interaction between technological and societal development and to clarify how this complementarity and interaction should be conceptualised, that is to describe without differentiating a priori between content and context, and by referring to the close interrelation by the metaphor 'seamless web'. STS scholars oppose a dual repertoire using different concepts for analysing the content of technological development and the influence of the surrounding environment on this technological development. The emphasis is that the content of technological development is shaped simultaneously with the context.

are denied the ability to unambiguously navigate a stream of unfolding events (Garud and Van de Ven 2002, pg. 211).

Innovation processes are emergent as their paths may not be prescribed a priori by a blueprint. The development process and life of innovation projects emerge from local interactions in which plans and intentions are also continually shaped and subject to reformulation (Stacey 2006). This allows the researcher to look into action and organizing and to ask how managers actually proceed in the absence of reliable forecasts or foresight (Stacey 2007). The outcome of my study is intended to move perspectives toward a better understanding of action directed towards an uncertain, unknown future that agents imagine according to their cognition of reality, their beliefs and values; activity that emerge from the actions of individuals, the historical organizational trajectory, and interaction with the collective socio-technical environment.

Next, I will proceed with a discussion of particular writings that build on constructivist ideas and are rooted in the literature discussed above (collective action, technological innovation and industry emergence as summarized by Van de Ven and Hargrave 2004), and innovation in the making (as referred to by Fagerberg et al 2006); and more importantly, particular writings that have relevant discussions relating to my research questions.

3.2 Perspectives to understand initiation processes, relevance and commitment

…….Relevance too lies in the eyes of the beholder, and we need to know the 'what' those eyes are seeking before we can determine what's relevant…….[27]

Chia (1998) describes social organisation, and herein lies economic and development activity, as "complexity-reducing and reality-constituting activity. Organisation enables purposeful action and in a sense is about 'world-making' in which a new social reality may be brought into being through the cumulative aggregation of micro-organizational initiatives. Organisation is an ongoing reality-constituting and reality-maintaining activity which enables us to act purposefully in response to a deluge of competing and attention-seeking external stimuli. Simplification of the

27 Geoff Hart (2001) Content, structure, and relevance: the ploy's the thing http://www.geoff-hart.com

complex and the consequent economizing of effort in action is thus the ultimate aim of the impulse to organize".

That sounds quite abstract, but it can be related to a relevant question in the initiation of new energy development activities. Namely, what development activities and technological paths should be pursued among new energy alternatives, if any? A central challenge in planning and in setting a course of action among multiple new energy alternatives is to mobilize relevance and support for one path rather than another. If relating this to Chia's description of social organising as a complexity-reducing and reality-constituting activity, the energy company is flooded with competing and attention seeking external stimuli, information about competing technology candidates and opportunities in the new energy realm. Hence a central part of the job in a cleaner or new energy unit and in business development is minding the future while being immersed in present action. Exploring and sorting out information and deciding on courses of action. Choices need to be made as to what projects and initiatives it should support and undertake. This is simplification and making choices is the consequent economizing of effort in action as resources are allocated among alternative opportunities, purposes and uses. In the technological opportunities and technology paths chosen for pursuit, the organisation becomes part of production, future-constructing, or a reality-constituting activity, as Chia calls it (ibid).

When minding the future while being immersed in present action; exploring and sorting out information and deciding a course of action, choices are made as to what projects and initiatives they should support and undertake. Connecting with new energy activities provide insight and understanding of where the energy scene is moving, what ideas come into existence and gain strength, what are trends, what are technical obstacles, what are other organisations doing?. Developing an understanding of the new energy area not only concerns one's own understanding, but also the understanding of others. Weick et al. (2005, pp. 412,414) says that sensemaking is about action and the interplay of action and interpretation and summarise the argument that people organize to make sense of equivocal inputs and enact sense back into the world to make the world more orderly.

When reading about strategy and organisations we come away with the idea that firms are single, cohesive and coherent players. An appealing image that gives little attention to people and how people in organisations continuously work in organisations to fine-tune, define and redefine themselves simply because they operate in a changing, pulsating and dynamic world of which they are of little or no control (Hargadon 2003). Organisations are not monoliths but products of their creative participants. In my opinion, this is a central viewpoint when focus is on new courses of action and the creation and initiation of a technological path that deviate from the dominant lines of business in a large organisation.

Individuals matter and my study aspire to refrain from treating organisations as if they were things with a homogeneous unified purpose. I link individual action and the collective organisation, and refrain from splitting off the humans that constitute organisations. This is not to write a story about legends and overemphasize the character of outstanding individuals but merely to extend the thinking of Pickering (1995). We cannot make sense of innovation projects without reference to the intentions of practitioners, to their goals and plans or orientation to goals located in the future. Goals for the future are based on: experience, current situation and performance, and present challenges. Practitioners work with some future destination in view and then seek to bring it about. Being interested in the initiation process, is why I consider it relevant to ask how the organisation ended up doing what it is doing in the area of hydrogen - how practitioners have developed their understanding and argumentation and what it takes to instigate activities, and pursue support and commitment for technological path creation. Understanding the genesis of novelty, as Garud and Karnøe (2001) put it and managerial and entrepreneurial activities in this context.

However, neither organisations nor individuals in organisations are omniscient and there are multiple sources of inspiration and actors that may be said to trickle into and influence the interpretive dynamics and mobilisation processes in the organisation. Hence the importance of looking into the relevance building and commitment making process and how hydrogen as an energy carrier as an idea and venture take on reality and relevance for business activities. This is in turn believed to enhance our understanding of the intraorganisational processes leading to new business ventures and the initiation of innovation and development projects. To the best of my knowledge little has been done to describe and explore how this is done in practice.

3.2.1 Conceptual resources

To conceive of or establish a way to think about the initiation processes behind a new business / path/ venture; what happens at the very beginning of a possible path; and how hydrogen has taken on relevance and a reality path in Hydro; I went back to the literature on innovation processes to try to find conceptual resources that may grasp the interpretive and communicative element, and the interplay with concrete activities that are part of the initiation, relevance and commitment building process for innovation and development activity. The next three sections in this chapter is meant to prepare the reader in terms of the body of literature and conceptual resources that I mobilise to address this aspect and the questions specifying my research.

The literature share the view that organisational activity, innovation activity, objects (material resources) are embedded in conceptual systems, which act as a "glue" that keeps interfaces and actors together (Porac et al. 2001, pp. 221-23). Conceptual systems evolve through the coupling of doings and interpretation while being immersed in action, and may come to involve a shared conception of core attributes of e.g. a technological object, usage, standards of evaluation and behaviour between involved actors. Realities are enacted based on conceptual systems and enactment changes both actors and the environment as actors interact, ascribe meaning and negotiate the relevance of objects.

Firstly, since Karl Weick's work on organising and sense making is influential on the other strands of literature, I start out with an outline of some of his concepts and point out the importance of exploring sensemaking not only as a collective phenomenon among interactive organisational members inside the organisation, but that sensemaking and processes of enactment are a distributed phenomenon emerging while connecting with others.

Secondly, I elaborate on ideas fronted by the authors of the Innovation Journey (Van de Ven et al. 1999) about the initiation /gestation period and argue that the focus on shocks that stimulates action and thresholds for opportunity recognition may be supplemented.

Finally, I link my thesis to path creation thinking (Garud and Karnøe 2001) outlining entrepreneurship as the ability to span boundaries of relevance structures, translate objects and mobilize time as a resource. Entrepreneurs set path creation processes in motion in real time and attempt to shape institutional, social and technical facets of an emerging technological field. A process of mindful deviation lies at the heart of path creation and implies disembedding from the structures that embed entrepreneurs; however the perspective pays little attention to the initiation and path creation activities within organisations, and the actions to nurture and sustain relevance and commitment to new paths.

3.2.2 Equivoque, mindfulness, and sensemaking

The interplay between the interpretive and communicative element and concrete activities in relevance building and commitment making for the initiation of innovation and development paths may be inspired by the work of Karl Weick. Weick writes of process oriented organising[28] and has been a main advocate of the sensemaking perspective within organisation theory.

[28] Weick's focus is on process oriented 'organizing' (1979). Organising as a verb to avoid entrapment in entities and organisations as structures "What you will find is that there are

Viewing reality as complex and fluid, a goal in organizing is to make sense of equivocal information meaning that information or a given event can be interpreted to have several plausible meanings. “An equivoque is something that admits of several possible or plausible interpretations and therefore can be esoteric, subject to misunderstandings, uncertain, complex and recondite…. Because new technologies are equivocal, they require ongoing structuring and sensemaking if they are to be managed” (Weick 1990). “Sensemaking is what it says it is, namely, making something sensible” (Weick 1995, p. 16).

Sense-making processes attempt to reduce equivocality or to reduce multiple meanings in the information used by people in organisations, and when committing to and embarking on innovation projects that hold uncertain outcomes, people act in the world on the basis of how they make sense of it. There is a bombardment of information about projects, priorities, new investment opportunities, and the problem confronting people in innovation activity is one of equivocality as people may interpret information differently. The bombardment as to new technology alternatives means that people must impose their own interpretation and communicate this interpretation. Hydrogen energy organising processes are concerned with interpreting and making choices as to taking on activity, a role and position in hydrogen development paths.

In the information-rich contexts that characterize the world of executives today, the scarce resource is typically not information but the amount of *mindful* [29] attention that decision makers allocate to making information meaningful (Hansen and Haas 2001 cited in Fiol et al. 2003). In contrast, mindlessness is characterized by relying on past categories, acting

---

events, linked together, that transpire within concrete walls and these sequences, their pathways, and their timing, are the forms we erroneously make into substances when we talk about an organization. Just as the skin is a misleading boundary for marking off where a person ends and the environment starts, so are the walls of an organization” (Weick, 1979: 88)

[29] Langer (1989) introduced the *concept of mindfulness* as a state of alertness and lively awareness that is manifested in active information processing, characterized by the creation and refinement of categories and distinctions and the awareness of multiple perspectives e.g. multiple perspectives on energy system options, technology options, trends and drivers impacting the energy future. A mindful approach to any activity is said to have three characteristics: the continuous creation of new categories; openness to new information; and an implicit awareness of more than one perspective (Langer 1989, 1997 referenced in Fiol et al 2003). Mindfulness, mindful scanning and self-questioning interpretations are manifest among those who engage in thought patterns that allow them to make a larger number of currently relevant, more precise distinctions. By remaining alert to potential changes in their situation, mindful individuals are more adaptively responsive to shifts in their environment, and this fosters a rich action repertoire which to successfully greet the unknown (Fiol et al. 2003).

on automatic pilot, precluding attention to new information and fixating on a single perspective (Langer 1997 cited in Fiol et al. 2003, Weick et al. 1999).

Sensemaking is central in the context of understanding new courses of action, path creation, because it involves processes where meanings materialize that inform and constrain identity and action. In Weick et al.'s article (2005); they take stock of the concept of sensemaking. *Viewed descriptively sensemaking* is to portray organizing as the experience of being thrown into an ongoing unknowable unpredictable streaming of experience in search of answers to the question, "what's the story?" (ibid, p. 410). People who are organising can do so only on the basis of some sense of understanding, and sensemaking involves turning circumstances into a situation that is comprehended that serves as a springboard for action. Organizational sensemaking is first and foremost about the question, how does something come to be an event for organizational members? Second, sensemaking is about the question, what does an event mean? When people confront something unintelligible and ask, "what's the story here?" their question has the force of bringing an event into existence. When people then ask, "now what should we do?", this added question has the force of bringing meaning into existence, meaning which they hope is stable enough for them to act into the future, continue to act, and to have the sense that they remain in touch with the continuing flow of experience"(ibid, p. 410). So the operative image of organization is one in which organization emerges through sensemaking, not one in which organization precedes sensemaking or one in which sensemaking is produced by organization, thus sensemaking and organization constitute one another.

Viewed conceptually the nature of organized sensemaking is suggested through *a process of enactment, selection and retention* (Weick et al. 2005, p. 413), whereby an organization's members create a cognitive schema, or mental map, of the most important aspects of their collective experience. This map of experience channels future action that leads to further refinements of the map, leading to future action, and so on. Sensemaking does not begin de novo but like all organizing occurs amidst a stream of potential antecedents and consequences, it starts with immediate actions, local context, and concrete cues (ibid, p. 412).

The organizing process of *enactment* incorporates the complex flux of events that an organisation must attend to. Certain features are isolated, meaning is invented and acted upon, and this noticing and bracketing is guided by mental models acquired during work, training, and life experience. The flux of circumstances begins to be simplified into the orderliness of situations. Weick et al. (2005) emphasise "begin" because noticing and bracketing are relatively crude acts of categorization and the resulting information and events can mean several different things, but the result of these actions then become the focus, that is the number of possible meanings gets reduced in the organizing process of *selection***.** Here a combination of retrospective attention, mental models, and articulation perform a narrative reduction of the bracketed material and generate a locally plausible story. Though plausible, the story that is selected is also tentative and provisional. It gains further solidity in the organizing process of *retention*. When a plausible story / interpretation is retained, it tends to become more substantial because it is related to past experience, connected to significant identities, and used as a source of guidance for further action and interpretation. The close fit between processes of organizing and processes of sensemaking illustrates the main argument that people organize to make sense of equivocal inputs and enact this sense back into the world to make that world more orderly (ibid, p. 414). The idea that sensemaking is focused on equivocality gives primacy to the search for meaning as a way to deal with uncertainty (ibid, p. 414).

The question, how hydrogen energy, as an idea and concept, is incorporated into the organisation as something relevant for business activities, relates to the discussion of sensemaking. When committing to innovation projects and a new venture that hold uncertain outcomes, practitioners are involved in sensemaking, outlook and meaning creation based on which action is mobilised. It is based on this outlook and meaning creation that activities and initiatives are given good reason, which is used to convince, 'sell' and make sense of the innovative activities to the organisation at large. Patterns of organising are located in the actions and communications undertaken by practitioners. *Communication is a central component in sensemaking and organizing.* "We see communication as an ongoing process of making sense of the circumstances….The sensemaking, to the extent that it involves communication, takes place in interactive talk and draws on the resources of language …. as this occurs, a situation is talked into existence and the basis is laid for action to deal with it …a situation is talked into being through the interactive exchanges of organizational members to produce a view of circumstances including the people, their objects, their institutions and history, and their siting [i.e. location as a site] in a finite time and place" (ibid, p. 413).

The last part of the quote points to *sensemaking* through interactive exchanges of interdependent actors but is delimited to organizational members inside the organisation (Weick et al. 2005). However, the authors write that promising lines of development would seem to occur with work on distributed cognition that focus less on the assembling and diffusing of preexisting meaning and more on the collective induction of new meaning when information is distributed among numerous parties (ibid, pp. 417-418).

What my thesis elaborates is that in addition to sensemaking being a collective phenomenon among interactive organisational members inside the organisation; it may also be argued that sensemaking is a distributed phenomenon emerging while connecting with others. When connecting with others in concrete activities something becomes when one' understanding, ideas, people, objects (material resources) come together with the understanding ideas, people, objects (material resources) of others. This may be particularly relevant when trying to understand technical innovation and development activities in the making where scientific, technical, social, institutional dimensions not only come together but evolve together.

3.2.3 Path creation and mindful deviation

Path creation thinking and process theories of technology emergence may help to conceptualize how relevance and purpose are mobilised to achieve the outcome of commitment to a new venture and new energy area. Garud and Karnøe (2001, p. 12) offer an understanding of entrepreneurship in a way that: a) acknowledges the embeddedness of actions, b) explores temporal interconnections between processes, c) provides a role in explanation for context and action, d) is holistic rather than linear, and e) links process analysis to the location and explanation of outcomes.

The path creation framework is a reaction to the limitations of viewing novelty as a path dependent phenomenon and an extension of the past. The authors recognise and support the insight that novelty has historical antecedents and that novelty should be understood in process term. Yet the central puzzle that seems to drive their book is the balancing act between recognising human agency influencing in real time and path dependence thinking that suggests that temporally remote events play a role in the development of novelty. Thinking only in terms of path dependence in its extreme sense would mean that the future is a reproduction of the past. Problematic indeed for those interested in entrepreneurship and innovation processes because having noted that the past matters, it is useful to also address how the present matters (Hirsh et al. 2001)[30].

Karnøe and Garud (2001, p. xii) states the puzzle propelling their book as follows: "How should we conceptualize the nature and scope of human agency given that we are creatures caught in complex webs of our and others' making?[31] Central in the path creation framework is that entrepreneurs/ agents gain greater strategic choice by recognizing their embeddedness in structures and activities from which they may attempt to mindfully depart. There is a shift from describing past worlds to thinking of

---

[30] In path dependence, the emergence of novelty is serendipitous. Events that set paths in motion can only be known post-hoc. Consequently, the role of agency can be viewed as one of entrepreneurs watching the rear-view mirror and driving forward. Stated differently, although path dependence focuses on a sequence of specific microlevel events, it does not have an explicated theory of agency (Garud and Karnøe 2001, p. 7).

[31] Building on Giddens' (1979) notion of structuration, structures are both medium and outcome of human action, and an important facet of path creation is to recognize that agents are circumscribed in structures, hence the notion of embedded agency, while the same structures are negotiable and flexible (cited in Garud and Karnøe 2001, pg. xiii).

embedding dimensions as strategic components from which and with which to create new futures[32].

Path creation is described as a process of mindful deviation where actors (entre/intrapreneurs/ managers) mindfully deviate from established paths; have ideas and envision something different out of a reconsideration of past and current situations; and create new paths of practices and resource use. The term *mindfulness* means that entrepreneurs are conscious of their embeddedness and are able to depart from, and employ embedding structures in a meaningful way. Mindfulness implies the ability to disembed from existing structures defining relevance, and also an ability to mobilise a collective despite resistance and inertia that path creation efforts will likely encounter as potentially threatening to existing orders (Garud and Karnøe 2001:2,6).

Karnøe and Garud (2001, pp. 2-7, 23) introduce agency into the analysis, and focuses on potentiality for deviation. In their view, entrepreneurs meaningfully navigate a flow of events even as they constitute them. Rather than exist as passive observers within a stream of events, entrepreneurs are knowledgeable agents with a capacity to reflect and act in ways other than those prescribed by existing social rules and taken for granted technological artefacts. They believe entrepreneurs attempt to shape paths, in real time, by setting processes in motion that actively shape emerging social practices and artefacts, only some of which may result in the creation of a new technological field. The term ‘path’ is used to suggest that the accumulation of inputs at any point in the development of a technology is as much a position that actors have reached as it is one that they may depart from (Garud and Karnøe 2003, p. 281).

The world is in the making[33] and entrepreneurship is defined as involving judgement and choice about time, relevance structures and objects within which entrepreneurs are embedded and from which they must deviate mindfully to create new paths. As objects, relevance structures and time become strategic variables, there is a shift from conceptions of path dependence as ways of describing our past worlds to conceptions such as path creation as ways of shaping our current states to create new futures (Garud and Karnøe 2001, p. 9). The ability to endogenize objects, relevance structures and time, generates agency for entrepreneurs in their being able to

[32] Thinking about organisation in terms of processes implies a contingent aspect about the future as things; events; actions may have an enduring impact beyond their time and space, and may unpredictably re-emerge as influential to e.g. a development process. This form of contingency will belong to the process itself but indicates that historicity is central also when we try to grasp temporally emergent phenomena such as innovation processes.

[33] ‘In the making’ denotes the temporal processes that underlie the constitution of phenomena. Such a perspective assumes reciprocal interactions between economic, technical, and institutional forces that constitute technological artifacts and actors involved (Garud and Karnøe 2001, pg. 3)

disembed from existing technological fields as they shape emerging ones (ibid, p. 12).

Time is an important resource as "any system designed to be efficient at a point in time will not be efficient over a point in time" (Schumpeter 1942 cited in Garud and Karnøe 2001, p.6). Systems designed to be efficient in the present are associated with relevance structures that are likely to discourage experimentation because of associated inefficiencies. Experimentation requires time for new ideas to be refined and grow even as new institutional and market preference structures co-evolve. Therefore time is important in creative destruction processes. Entrepreneurs may intentionally deviate from existing artifacts and relevance structures, fully aware they may be creating inefficiencies in the present, but also aware that such steps are required to create new futures. A process of mindful deviation lies at the heart of path creation (ibid).

Hence path creation thinking presents a view of mindful actors or emergent mind actors inside a company and/or in cooperation with other actors that are able to deviate from established paths and create new technological paths. The perspective further implies that the definition of organisational reality, the configuration of merit, value, purpose, meaning of objects and activities appear to be endogenous dimensions in the "deviation" process in path creation activities, Garud and Karnøe (2001, p. 8) formulate it in a better way:

«Entrepreneurs creating new paths are not necessarily driven by a search for optimality. For those creating paths, errors are like red herrings as there are no pre-existing universal benchmarks that can flag the outcomes of an exploratory act as mistakes. Instead, entrepreneurs creating paths explore the creation of new dimensions of merit that, in time, may set in motion a sequence of events… In such a conceptualization, what is of value becomes endogenised within an overall process of entrepreneurship. That is, criteria that establish value about facts and artifacts do not lie in a market that is an overall arbiter of what is good and bad, but instead, become endogenised as a pattern of stabilised relationships within an emerging technological field. Thus the diverse actor-groups involved, including producers, users and regulators, create their own set of practices and relevance structures that co-evolve with technological artefacts»

In the quote above, a central point is that diverse actor-groups involved (producers, users and regulators) create their own set of practices and relevance structures that co-evolve with technological artefacts. Path creation is the binding of objects, relevance structures and time into an overall co-evolutionary process (Garud and Karnøe 2006).The perspective acknowledges that there are many constraints on human agency associated with entrepreneurship and the disembedding from established practice and webs of significance is central (Garud and Karnøe 2001, p. 25). However what is less clear is what relevance building is made of, and how it comes about in organisations, which on the other hand seems central to grapple as it addresses what happens at the very beginning of a possible path.

In path creation thinking and technology entrepreneurship, Garud and Karnøe (2001, 2003) appear to consider a collective and distributed sensemaking process as a basis for new technological paths. They talk about multiple actors with different levels of involvement and with different interpretive frames (Garud and Karnøe 2003, pp. 279-280):

«Technological change occurs through a synthesis of the inputs of a number of actors. From this perspective, it is not just the discovery of new opportunities by alert individuals or speculation on the future. In addition, technology entrepreneurship involves the creation of new opportunities by a collective ….. Creation occurs as different types of actors become involved with an emerging technological path. The multiplicity of actors involved with different frames suggests that this is a distributed process with interpretive asymmetries generating opportunities through a process of creative synthesis» (ibid, p. 281).

Multiple actors and hence distributed agency generate opportunities. The process of creative synthesis emphasises collective action in line with the tradition of the process theories of technology emergence (Van de Ven and Hargrave 2004, pp. 277-292). However what is less clear is how new paths are created inside organisations. Inside organisations, path creation activities are merely said to be fuelled by entrepreneurs that are knowledgeable agents with a capacity to reflect and act in ways other than those prescribed by existing social rules and taken for granted technological artefacts (Garud and Karnøe 2001, pp. 2-7, 23).

With attention to the process of technology entrepreneurship and path creation as the larger process that builds upon the efforts of many, this is arguably at the expense of attention to initiation and path creation activities within an organisation. This is tricky as collective path creation activities, to emerge and continue, rely on commitment from organisations. So path creation conceptualization should consider that the collective activity in innovation processes are connected with path creation activities within organisations. We cannot make sense of path creation without reference to the intentions of practitioners in organisations, their visions and plans or orientation to goals located in the future. Hence we need to pay attention to how pathbreakers in organisations mindfully organise and initiate new technology paths and new ventures.

3.2.4 From the Innovation Journey

When mapping the innovation journey, Van de Ven et al. (1999) summarised three common elements or periods that were empirically grounded and pertained to the initiation, development and implementation periods of the innovations. As relevant to aspect one and questions specifying my research concerning the initiation period (Van de Ven et al. 1999, pp. 23-34), they talk about a gestation period. This is frequently a lengthy part of the process that may last several years where people are engaged in a variety of activities that set the stage for innovation. Innovations are not initiated on the spur of the moment, by a single individual or by a single entrepreneur. "Shocks" or events come from multiple sources, such as deteriorating performance, changing conditions or awareness of technical possibilities, and happens in parallel and may trigger the recognition of the need for change, which then cause intra/entrepreneurs to start innovation efforts and identify the feasibility of a business idea or project as a vehicle to solve a problem and exploit a commercial opportunity. Initial ideas are developed into plans that may be submitted to resource controllers to obtain the resources needed to launch innovation development and in most cases, the plans serve more as "sales vehicles" than as realistic scenarios of innovation development.

Gestation events undertaken by intra/entrepreneurs send them on courses of action that often by chance intersect with the independent courses of action of others. The dynamics emphasized is that intersections provide occasions for interaction that lead actors to recognize and access new opportunities and potential resources. The Innovation Journey writers emphasise *shock* (ibid, pp. 28-29). Moving to concrete action to undertake innovations appears to be triggered by "shock" from sources internal or external to the organisation. Many innovative ideas may be generated but are not acted upon until some form of shock occurs where the shock serves to concentrate attention and focus the efforts of diverse stakeholders in the organisation. Some kind of shock stimulates people's action thresholds to pay attention and initiate novel action. Shocks allow people with innovative ideas to gain currency with potential stakeholders in the organisation that need to be convinced about the knowledge and the commercial or technical prospects of an innovative idea so as to support the idea. Shocks stimulate innovation activity; and in general, direct personal confrontations with sources of problems or opportunities are needed to trigger the threshold of concern and appreciation required to motivate people to act.

The prospect for innovative action, path creation and nurturing parallel venture or development paths depends on what qualifies as a shock, and paths are difficult to deviate from without a shock. However, an aspect relevant to be studied as part of path creation and initiation of a new business venture was triggered by the following sentence (ibid, p. 30): *"…. even though some people may perceive a given event as a shock that stimulates* *action; other may not share this perception".* The explanation given is that individuals have different adaptation and threshold levels for dissatisfaction and opportunity recognition, and the stimulus may not be of a sufficient magnitude to exceed the threshold and to cause the people to act to correct their situation. This also has to do with the challenge of handling equivocal information which the authors link to leadership. By looking at leadership roles they argue that leadership constellations needs to be pluralistic in order to consider diverse and opposing viewpoints so as to increase the chances for technological foresight and decrease the likelihood of oversight (Van de Ven et al. 1999, pp. 95-97).

I think there is more to say and explore in addition to the explanation above that sees it as a matter of stimulus magnitude, equivocality, and threshold levels for opportunity recognition. The reason is connected to what was said earlier, namely that organisations are not monoliths with a homogeneous unified purpose but products of their creative participants that, with or without shocks, initiate new courses of action through a dynamic process from perceiving opportunity, to building relevance, and to mobilizing commitment to one path and not another. Opportunities do not hang loose waiting to be recognised rather they must be created, committed to, and development and the recombining of resources is tied with ideas and efforts to shape an organisation's strategic agenda as much as shocks.

I have mobilised a set of resources to help address pioneering activity and the organisational processes leading to hydrogen energy venture creation.
In pioneering activity and initiation efforts, there is interplay between an interpretive and communicative element, and concrete activities that are part of the initiation, relevance building and commitment-making process for hydrogen energy and development activity. When committing to and embarking on innovation projects that hold uncertain outcomes, people act in the world on the basis of how they make sense of it. Sensemaking is about action and the interplay of action and interpretation. Path creation thinking outlines entrepreneurship as a process of mindful deviation and the ability to span boundaries of relevance structures, translate objects and mobilize time as a resource. Entrepreneurs set path creation processes in motion in real time and attempt to shape institutional, social and technical facets of an emerging technological field. Finally, Innovation Journey authors highlight the prospect for innovative action, path creation and nurturing parallel paths as depending on shocks and its perception and handling.

3.3 Perspectives to understand the role of a demonstration project in innovation processes

There is plenty of literature that focus on the characteristics of organisations and the innovative capacities and nature of technologies that incumbent/existing firms (with products and internal capabilities bound to existing technologies, current practice), and new entrants (unconstrained by prior technologies and organisational inertia) are likely to commercialise. *'White men can't jump[34]' and large companies have difficulty innovating, or bring out new technology combinations, is an assumption circulating in several texts* (Tushman and Anderson 1986, Foster 1986, Utterback 1994, Christensen 1997). The argument in brief is that many established firms fail to switch to new technologies and that most industry-shattering innovations do not spring from the established competitors in an industry but from new firms or from established firms entering a new arena. This is true even though innovations often are seen to be based on the synthesis of well-known technical information or components, occur step by step, and exist in embryonic form for many years before they become commercially significant. The argument focuses on the dangers inherent in large scale, which often leads to overemphasis on tending the current well-established business, a lack of entrepreneurial dynamism, and vulnerability to innovative competitors.

To take on technological advances and handle technological progress, a main challenge recognised in the literature then seems to be - how to nurture innovation projects that will enable a company to develop new technologies and exploit new lines of business while at the same time exploiting the current lines of business – implying a balancing act of activities. This balancing act of activities may be referred to in the terms "managing innovation", and it implies that organisations must be able to operate in multiple modes, managing for short-term efficiency and long-term innovation that is to organise for multiplicity (Tushman and Anderson 1997, p.12).

The demonstration and development project studied in this thesis has its origin in and is realised by a large established energy company with core business in conventional fossil fuel energy sources. The demonstration project was initiated by a private company pursuing a new to the world technology combination. This has presented an opportunity to explore how 'white men can jump' and to explore intrapreneuring in action. The project is not a product of a public research, development and deployment programme outlining prioritised activity. The project did get some investment support

[34] In the movie by the same name, Billy Hoyle (Woody Harrelson) and Sidney Deane (Wesley Snipes) are talented basketball hustlers, who team up to make a living by hustling street basketball players. Billy's white color is used against African-Americans who assume that "white men can't jump", that is assuming that Billy cannot play well because he is white.

from public authorities but the initiation of the project predates any political proposals in this energy area. For this reason, the project invited a closer look at the roles of the demonstration project in company development processes, a closer look at the mechanisms of demonstration on the part of the organisation as its key stakeholder; and a closer look at its role in relation to sustaining the innovation activity in a new energy area and business venture.

By looking at the realization of the demonstration project with the point of departure and focus on the organisation, I suggest our understanding may be enhanced. Exploring the multifaceted roles of the demonstration project in company development processes adds a focal point from where to enhance our understanding of private investments and the initiation of a new business venture. What were hurdles and considerations, and how were they overcome, impacting and inspiring the organisation? How were detours and the branched character of technological development handled? This will enhance our understanding of actor strategies and innovation efforts when working to advance a new technology combination.

3.3.1 Conceptual resources

As indicated in the discussion of perspectives to study innovation processes and phenomena in the making, Fagerberg (2006b, p. 10) argued that the literature on innovation projects in firms and the management of such projects has been slow to evolve. We know much less about why and how innovation occurs than what it leads to. Our understanding of how knowledge – and innovation – operates at the organisational level remains fragmentary, and applied research is needed (ibid, p. 20)

A demonstration project is a site where the emergence of technology, development activities, and how innovation occurs, at the organisational level, may be explored; and where the complexity of an innovation process, as the quote below points to, may be looked into. At the outset and initiation of a demonstration project, the potential and possible associated time path of benefits are uncertain. At the outset, neither the development process in the technology demonstration nor the future use of the new technology combination, are clear or anticipated. These aspects may be explored during the course of activities and are part of why the demonstration project is relevant.

A demonstration project also allows for exploration of activities beyond the organisation's sphere. It is not necessary to demarcate a level oriented study. The focal point is the demonstration project, which is the hub where activities in multiple areas and arenas are coupled. Obviously, the project takes place in a physical setting and is shaped by the organisation's historical path and setting, but individuals handling the project in the organisation are realizing development activity by combining people, ideas, and objects (material resources) to realize the project. Novelty and the attributes of the technical combination may be studied as they arise in the dynamics of the project undertaken by the organisation in a particular place and at a particular time.

> "In order to have a reasonably accurate idea of the complexity of the innovation process, imagine a rocket, pointed towards a planet whose long-term trajectory is unknown, taking off from a moving platform whose co-ordinates are only crudely calculated; additionally, imagine a division of tasks whereby some specialise in observing the planet, some in calculating the location of the platform, and others in defining the power of the engines; finally, imagine decision-makers who at all times need to consider the occasionally incompatible information produced by all of the specialists. Under such conditions, one can understand why the key words are "interaction", "de-compartmentalisation", "circulation of information", "cooperation", "adaptation" and "flexibility". This collective actor must be able to react to all fluctuations; it must be in a position to seize all opportunities.
> (Akrich et al. 2002)

To conceive of or establish a way to think about the multifaceted roles of the demonstration project in company development processes, I went back to the literature on innovation and development to find conceptual resources that may grasp what demonstrations do and why they are important. The next sections are meant to prepare the reader in terms of the perspectives and conceptual resources that may address the questions specifying my research on the role of the demonstration project. The conceptual resources share the view that development activity is embedded in collective action. Technology emergence is an outcome of collective achievement and builds on the efforts of many. This is so because skills and resources, to take an idea through development and to commercial use, reside with actors in different domains. Hence a common view is that technology entrepreneurship is about exploiting a networked landscape by seeing and making connections to harness resources; and also about handling interdependencies that arise when resources are drawn upon from actors in different domains.

Firstly, I elaborate ideas fronted on demonstrations projects, niche development or protected spaces where a technology combination may be demonstrated. But although demonstration and niche thinking indicate that novelty originate within existing regimes, starting at the microlevel of local practices; the dynamics of the initiation at the microlevel of local practices receive very limited focus. The perspective pays little attention to the roles of the demonstration project in company development processes, and hence there is a gap in the knowledge about demonstration projects, and how they are important to companies. I point out the importance of adding a focal organisation to exemplify the dynamics, mobilisation, choices and evaluations made along the way in the advancement of a new technology combination by a company.

Secondly, I explore the notion of innovations as recombinations since the innovative aspect of the demonstration is the new combination of individual technologies in terms of their integration into a new technical configuration. I explore writers that have discussed this notion of innovations as recombinations. However I point out that when considering innovation projects and innovative activity in the company, where new resource combinations are being created, and new ways of organizing activities are being pursued; there is a tendency to portray recombinant innovation as a matching process where the company soak up resources to recombine them within the four walls of the company. Hence there continues to be a gap in the sense that the recombination view should be supplemented by exploring the collaborative aspect of recombinant innovation. That is when putting new combinations together with other actors, partners.

3.3.2 Demonstrations and niche thinking

The hard times for new technologies are a common theme in the innovation literature. To develop a new idea into a prototype and product means overcoming resistance both outside and inside the innovating organisation. It requires a special kind of management: the management of attention, of riding ideas into currency, of managing part whole relationships (integrating functions, organisational units and resources), and the institutionalization of leadership. In the organization, new innovations often receive lukewarm support. Most innovations do not start out as a strategic activity but as a peripheral activity, as most of the research and development work in the organisation is geared towards improving existing products and reducing their production costs (Kemp et al. 1998, p. 176).

Trying to understand the processes involved in the formation and deployment of environmentally benign energy technology; science, technology and society (STS) inspired technology studies, have identified the importance of demonstrations or protected and local breeding spaces for new technologies in which they get a chance to develop. A central argument in favour of conducting experiments / demonstration projects builds on the assumption that experimentation increases the likelihood of developing new technology that may be integrated and developed in the energy system and society at large. This assumption is reflected in the following extracts:

“…. Niche markets or protected spaces for new technology may serve as ‘nursing or bridging markets’, to mass markets, where learning processes can take place, the price / performance of the technology be improved and new customer preferences may be formed….”(Jacobsson and Bergek 2004)

“Company learning and market development processes go hand in hand. The relevant characteristics, limitation and suitability of the technology become known through applications and prospective users learn about the potential product / technology….” (Hendry et al. 2007, p. 404)

”Niche markets can constitute protected spaces, which allow for testing, experimentation, demonstration, adaptation and further improvement. The main idea is that at a later stage when reliability has been demonstrated, product performance has been improved and manufacturing costs have been reduced, the new technologies can move to its main market. Thus niche markets function as incubators that allow new technologies to develop further in order to become competitive….” (Magnusson 2003, p. 350)

When referring to niche markets, this is not in the sense of those also existing in mature markets where a narrowly defined group of potential customers / buyers pay a high premium for e.g. clothing (Armani suit) and mobility (in a Ferrari car). Instead it is more appropriate to think of niche markets as early markets. In some instances there are early adopters in early markets that are willing to pay a higher price, a premium for a particular benefit gained from the specific characteristics of a new technology that add value e.g. back up power, remote power supply, energy documented as produced in a certain way and sold with a premium.

But for cleaner energy innovations, early markets do not automatically exist as benefits are at the collective level of societies (e.g. reduced air pollution, climate change and energy security objectives); the demand for energy are met by mainstream providers with existing energy technology making it difficult to compete on price; and customers are unable to articulate needs for a certain technological solution due to lack of knowledge about new technological possibilities. Therefore markets for cleaner energy solutions and innovations have to be created and technology co-created in the same process. By actually using a technology or innovation, users and producers create or learn about new needs, policy makers may create regulatory frameworks that fit the innovation so that industrial actors learn to improve the innovation and reduce costs. Scholars have called these early markets for technological niches. “*Technological niches are made operational through (a series of) protected test beds such as pilot-and demonstration plants where technologies are applied in a societal setting for the first time.*” (Raven 2007, p. 2391)

The principle aim of niches and demonstrations, whether publicly or privately initiated, is experimenting with a new technology, and learning is far more important than achieving high sales (Kemp et al. 2001, p. 293, IEA/ OECD 2003). In demonstration project there is technology – and organisational learning[35]. Demonstration projects are valuable in reducing uncertainty encompassing a range of issues: technology performance, product standards that may be imposed, uptake by potential markets, and possible sources of funding to develop and commercialize the technology.
Demonstrations allow developers to reduce some of the uncertainty by testing the process and learning about the drivers and barriers that the new technology combination faces. Demonstrations provide valuable stimuli at many stages of the innovation process from concept testing through design and to 'signal' an innovation to potential markets, customers and stakeholders (Harborne et al. 2007, pp. 168-170). Further, demonstration projects and niches as experimental settings may be distinguished in terms of purpose and the extent of development. Distinctions may be drawn between *demonstrations as early and experimental projects* designed to maximize learning about new products, processes and technology combinations; and the *demonstrations on markets and market growth* focusing on proving technological credibility, gain public acceptance, identify and reduce stakeholder opposition and identify issues that require policy action by governments (Harborne et al. 2007)

Aims of niches and demonstrations are summarised below (Kemp et al. 2001, p. 289) [36].

---

[35] A learning investment covers the cost greater than those of incumbent/current technologies. *Technology learning* refers to the progressive reduction in costs and prices and the improvement in performance shown by technologies as they are adopted and used. *Organisational learning* is about how to deal with other barriers that are not technological (cost and performance related) e.g. process of market entry, addressing stakeholders' concerns in adopting new technology, information dissemination, market restructuring, legitimacy issues, standards, handling customer feed back to tailor and refine technology.

[36]As compared with Kemp et al. 2001, Harborne et al (2007:169 also referencing Karlstrom and Andersson 1995) suggest similar categories of results from the support and realisation of demonstration projects: (i) learning, (ii) opening a market through increasing customer awareness and clarifying institutional barriers, and (iii) forming a network of actors to drive technology and policy change.

- To articulate the changes in technology and in the institutional framework that are necessary for the economic success (diffusion) of the new technology;
- To learn more about the technical and economical feasibility and environmental gains of different technology options, that is to learn more about the social desirability of the options;
- To stimulate the further development of these technologies, achieve cost efficiencies in mass production, to promote the development of complementary technologies and skills and to stimulate changes in social organization that are important to the wider diffusion of the new technology;
- To build a constituency behind a product of firms, researchers, public authorities whose semi-coordinated actions are necessary to bring about a substantial shift in interconnected technologies and practices.

Technological niches are bounded experimental settings to create a socio-technical incubator and allow a socially desirable innovation to progress prior to commercial demand. The importance of strategic niche management (SNM)[37] were emphasized by Kemp, Schot and Hoogma (1998, p. 186) indicating that the creation of a protected space for a promising technology gives it a chance to develop from an idea or showpiece in an exhibition into a technology that is actually used. Kemp et al. (1998, 2001) indicate that the management of niches can be done, by firms, governments and other social actors and need not necessarily occur in a systematic and coordinated way. Yet as part of the transition ambition, the basic premise of strategic niche management is that the direction of the co-evolution of technology and society can, and should, be modulated by strategic policy intervention in experiments (Brown et al. 2003, p. 293). Intervention consists of creating technological niches for promising new technologies where they can be tested and developed, and niches are part of the effort to manage a transition to environmentally sustainable energy. Demonstration projects, niches, niche management and transition management are suggested development tools for sustainable technologies.

Transition managers support what they hold to be desirable technological configurations by promoting protected institutional and market niches in which favoured configurations are supported and allowed to prosper. The goal is to enable them either to replace or transform dominant,

[37] Strategic niche management is the ‘collective endeavour’ of ‘state policy-makers, a regulatory agency, local authorities (e.g. a development agency), non-governmental organizations, a citizen group, a private company, an industry organization, a special interest group or an independent individual’ (Kemp, Schot and Hoogma 1998: 188).

unsustainable technologies. Thus experiments within the niche are intended to ‘seed’ processes of transformation within the existing technological regime (Berkhout et al. 2003). Strategic niche management (SNM) as discussed by Kemp et al. (1998, 2001, Geels et al. 2007) is a tool of transition, oriented towards policy makers and government support policies with the purpose of developing strategies to achieve transition to environmentally sustainable energy.

One challenge, however, is that since clean energy development is a large scale transformation, many technology studies seek to conceptualise all dimensions in one framework. In the work of Geels (2002), Kemp, Schot and Hoogma (1998), Kemp and Rip (1998), Kemp, Rip and Schot (2001), the researchers work with multi-level frameworks and analyse sociotechnical systems and sustainability transitions by looking at processes occurring at several levels (niches, regimes and the sociotechnical landscape[38]). The story of novelty creation is said to originate at the micro-level of local practices, and technologies are introduced against the backdrop of existing regimes and landscapes, following diffusion trajectories in which the technology and social context co-evolve under the influence of large-scale trends (Rip and Kemp 1998). So there are cross-level interactions.

A problem is that it leaves unclear the process of linking up action and developments at different levels. In a way Geels (2002, p. 1262) points to this shortcoming: *“…the addition to Rip and Kemp’s multi-level perspective still leaves unclear the process of breaking out of radical innovations from niche- to regime level”*. At the niche level, Geels indicates*”…actors in precarious networks work on radical innovations. Because a dominant design has not yet stabilised, the efforts go in all kinds of directions, leading to variety…. How does the arrow from niche to regime come about?”*

Although novelty is said to originate within existing regimes, starting at the microlevel of local practices with demonstrations (2001, p. 277), this does not say much about the dynamics of the development process at the microlevel of local practices. The perspective has paid less attention to explore demonstration projects from a company perspective. And as there is no focal organisation from which to study processes and development dynamics; this may contribute to a gap and inability to capture the linking processes occurring between conceptually created different levels. Companies participating in demonstration projects may not necessarily

[38] *Niches* are places where things are done and tested. A niche may be created by a company (sponsoring a new technology) or government. *Regimes* refer to dominant practices, rules and technologies that pertain in a domain, giving it stability and guiding decision-making (technology regimes, production regimes, user regimes and policy regimes). The *landscape* is the overall setting in which processes of change occurs. The landscape consists of the social values, policy beliefs, world views, political coalitions, income, costs, prices and sociotechnical lay of the land.

delimit themselves to working at what is referred to as the niche level, and by adding a focal organisation, this may be explored in practice.

My study will not provide a study of a grand societal transition and it is not clear whether the demonstration project will eventually be a part of a new energy carrier path. The main purpose here is to explore actor strategies in the initiation and undertaking of a demonstration project, which is built around the processes at the microlevel of local practices. We cannot make sense of demonstration activities without reference to the intentions and actions of organisations in demonstration projects. My study adds a focal organisation to illustrate the dynamics, mobilisation, choices and evaluations made along the way in the advancement of a demonstration project and its technology combination.

To a private company, a demonstration project is a research and development investment where the learning aspects and the associated time path of benefits are uncertain, maybe of no use or capture in the end. Studying the demonstration project also relates to the first research questions explored in this thesis, namely the dynamics in building relevance and getting commitment to new activities and technology paths. Hence it is relevant to explore how the experience gained in a demonstration project becomes part of the efforts to sustain action and new venture efforts in the organisation. So what a demonstration project does may be multifaceted. To the best of my knowledge, little has been done to describe and explore the multifaceted roles of a demonstration project in company development processes.

3.3.3 (Re)Combinations

To come back to what was discussed previous, many writers argue that innovation is about recombinations of existing resources. I wish to explore the notion of innovations as recombinations since the innovative aspect of the demonstration project studied is the new combination of individual technologies through their integration into a new technical configuration.
Hence the demonstration project is a site or the centre of activity where the challenges of combining and connecting resources, people and ideas may be investigated in practice.

Fagerberg (2006b, p. 10) refers to Schumpeter (1934), who defines innovation as “new combinations” of existing resources”. The combinatory activity was labelled “the entrepreneurial function” to be fulfilled by entrepreneurs. Historian of technology: Abbot Payton Usher in 1929 wrote: “Invention finds its distinctive feature in the constructive assimilation of pre-existing elements into new syntheses, new patterns, or new configurations of behavior” (cited in Hargadon 2003, p. 24).

Contemporary scholars continue to stick with this view. Fagerberg (2006b) points out that preserving openness to new ideas and solutions is essential for innovation projects and the principal reason has to do with a fundamental characteristic of innovation: that every new innovation consists of a new combination of existing ideas, capabilities, skills, resources etc. It is indicated that it follows logically from this that the greater the variety of these factors within a given system, the greater the scope for them to be combined in different ways, producing new innovation (ibid, pp. 9-12). Another point made is that in the search for new ideas and sources of inspiration and in the interdependencies in knowledge and resources, organisations must cultivate their capacity for absorption (ibid, p. 11). Combined there seems to be a tendency to portray recombinant innovation as a matching process, and a sponge-like image of the company is presented, where the company soaks up resources to recombine them in new combinations within the four walls of the company.

Hargadon's work (2003) on innovation processes is also built around the recognition that most innovations are about new combinations of existing resources. The main notion is that innovation is a process of recombination evolving from technology[39] brokering and connecting across networks. The dynamic view and more practical insight into managing the innovation process focus on *technology brokering* as the strategy exploiting the networked nature of the innovation process. Rather than producing fundamentally novel advances in any one technology or dominating any one industry, technology brokering involves combining existing objects, ideas, and people. Such a strategy relies not on breaking from the past but instead on exploiting it by harnessing the knowledge and efficiencies that reside in elements of existing technologies. It involves bridging distant worlds. By moving between industries, markets and knowledge domains, firms are in a better position to see when the people, ideas, and objects of one world can be combined in new ways to solve the problems of another; thinking in other boxes rather than outside the box (ibid, pp. 13, 24). Opportunities for valuable recombination emerge through technology brokering and bridging activities that result from connections between people, ideas and objects moving across divisions/groups/teams within the organisation, or on the periphery of the organisation and the technologies they might run across in their encounters in other markets or organisations. The proposition is put out

[39] Technology is defined as the arrangement of people, ideas and objects for the accomplishment of a particular goal. Such a perspective provides a way for us to consider the relationships among these three elements of technology. Technologies are unique combinations of these three elements. The objects are hardware and software, the physical objects that are tangible and relatively unchanging. The ideas are understandings of how to interact with those objects. And the people are those who know the ideas and objects. Their experiences have given them the tacit knowledge that makes the ideas and objects work effectively together (Hargadon 2003, p. 8).

that intrapreneurs and inventors are no smarter, no more courageous, tenacious, or rebellious than the rest of us – *they are simply better connected* (ibid, p. 11). Intra/entrepreneurs build connections across a wide range of disparate domains, recognize how resources of one domain can be used in another and organize solutions that combine resources across them (Hargadon 2004, p. 6). This is a relational proposition in terms of action, resources and development; and organization need to find ways to exploit the networked landscape and innovate by seeing and making connections between people, ideas, and objects across the broader landscape (Hargadon 2003, p. 11). Access to ideas, people and objects in other worlds gives people an advantage in seeing how those resources can be used in new ways (ibid, p. 88), only then to bring this inside the organisation (ibid, p. 84) and into new combinations (ibid, p. 89).

While advancing the relational and coupling aspect in recombinant innovation, Hargadon nonetheless seems to slip back into the language that maintain the sponge like image of the organisation; that is to bridge ideas, experience, resources from different domains, and then absorb and deal with it inside the four wall of the organization. For instance, when discussing the lesson of technology brokering, it is indicated that "the ability to exploit opportunities for technology brokering lies in adopting and adapting existing ideas, objects, and people (ibid, p. 184).

The conceptual resources appear to pay little attention to innovation processes, e.g. processes in a demonstration project, undertaken jointly by several organisations. Hence there seems to be a gap in the literature in terms of discussing the collaborative aspect of recombinant innovation when putting new combinations together with partners (where the people, ideas and objects/material resources reside), and where resources are collectively connected in new technical configurations in action over time. The demonstration project in my study is a site for collaboration that may highlight joint action in the social and technical process of recombination.

4 Pioneering and initiating hydrogen energy

4.1 Introduction to the company setting – Norsk Hydro

In 1905 Norsk Hydro started to utilize Norway's large hydroelectric energy resources for the industrial production of nitrogen fertilizers. In the years since, energy, in the form of hydroelectric power, natural gas and petroleum, has been the basis for Hydro's growth. Hydro at the time of my study was an energy and aluminum supplier with 36.000 employees in 40 countries. It was a large offshore petroleum operator, and the third largest integrated aluminum supplier in the world. Hydro was an industrial group based on the processing of natural resources to meet needs for food, energy and materials. Taken as a whole, Norsk Hydro expanded from its original business area (agriculture) into other fields of business investment and development (magnesium 1951, oil exploration 1965, and aluminium 1967).

As it concerns Norsk Hydro's hydrogen history, Norsk Hydro had years of experience as a manufacturer of electrolyser technology, a provider of hydrogen production systems, and as a producer of hydrogen using water electrolysis with water and hydropower as the electricity source. Hence within the Norsk Hydro organisation there was extensive experience within the traditional industrial hydrogen markets as large scale industrial gas production via water electrolysis was started in 1927. Norsk Hydro Electrolyser (NHEL), the manufacturer of water electrolysis equipment at Notodden, supplied units to the company internally because ammonia for the production of chemical fertilizer was produced using hydrogen. Hydrogen generation units were also supplied throughout the world where water electrolysis equipment and the hydrogen were used in industrial production processes. Water electrolysis in the Agri business division, however had a diminishing role as it was exchanged with technology using natural gas. Industrial hydrogen gas was produced from natural gas steam reforming since the late 1980s (Rasten 2003), which cannibalised Hydro's own electrolysis technology by wiping out internal demand and use of electrolysis technology. In 1993, Norsk Hydro Electrolyser (NHEL), the manufacturer of water electrolysis equipment, became a separate stock company owned by Hydro. NHEL was at the time in a precarious situation increasingly dependent on the external and fluctuating industrial market, and was on the look out for other applications and potential markets for their technology. NHEL was no longer part of Hydro's main business divisions (Agri, Oil & Energy, and Aluminium/Metal).

With the three main business divisions, Hydro had a plurality of business activities and areas of involvement. The predominant energy path was oil and gas exploration and production and venturing into new energy areas were deviant paths. Hydro Energy was organising to sensibly manage and administer existing assets and resources, while at the same time trying to be visionary so as to succeed if / when cleaner energy possibly take hold of the market. A balancing act of established practice with attention to existing energy markets as the current and historical spine of the organisation's energy business, and a flux of opportunities in emerging markets.

The business situation had been changing in particular over the 1990s due to knowledge of environmental impacts of current energy production and use; governmental initiatives to reduce energy supply dependence; the media coverage and knowledge of global warming and a climate in crisis as documented in IPCC reports[40]. The clean(er)[41] energy imperative had started to challenge Hydro as an energy company in fossil fuel energy. For Hydro, it was part of the game to be alert to drivers and issues shaping the energy market. Monitoring competitors, regulatory agencies and interest organisations, attending conferences and making presentations were part of information gathering and information exchanging activities that were part of the efforts to stay in tune with what was going on in energy markets and how it would affect Hydro business and existing values and resources. An additional focus was to explore how value could be created from what was going on.

Being wedded to existing technologies and resources there was no obvious answer to what emerging and potential future energy paths and technologies would mean to the organisation and whether or not new energy efforts and opportunities should be pursued. To not pursue new energy initiatives, was also an alternative; especially because being a producer of energy commodities (oil, gas, electricity), undifferentiated products of uniform quality produced and sold in large quantities geared towards large scale central production, holds a conception of purpose that was quite different from experimentation with smaller scales, demonstration of new technology combinations and system concepts, and new roles such as being involved as a technology developer and technology supplier. New energy activities deviated from the dominant lines of business and on top of it all, was less clearly defined in terms of users and markets.

From Hydro's position, what development activities should be pursued among new energy alternatives, if any? There were many technology candidates and opportunities in the new energy realm which

---

[40] The IPCC (Intergovernmental Panel on Climate Change) prepares at regular intervals comprehensive assessment reports of scientific, technical and socio-economic information relevant for the understanding of human induced climate change, potential impacts of climate change and options for mitigation and adaptation. Four Assessment Reports have been completed in 1990, 1995, 2001 and 2007.

[41] The quest for cleaner energy sources is a continuous movement where the main societal goal is that the solutions being worked on today are superior to the existing physical resources and production systems being used today – but may not be the end state.

could very well come to play a central part in the world of energy. Some more mature[42], and others less mature where reliable technical performance had yet to be accomplished. Hence some future energy solutions, hydrogen as an energy carrier being one of them, were at the time (and still is) in a demonstration period.

To Hydro, the growing challenge since the mid 1990s was to interpret the organisational context[43], handle energy trends, threats or opportunities, and to develop some kind of position or "posture" in relation to new technological fields. This involved decisions on possible roles in different development paths e.g. a passive monitoring role, watching over developments elsewhere where others shaped the development path, or alternatively to take on a pioneering role as a developer technology. In other words, a pressing issue was to set a course and decide what development activities should be pursued among new energy alternatives, if any. There was no one obvious path to embark on and create. It was a matter of orienting practice and organisational activity towards an unknown future with many possible new energy ventures.

4.2 A brief introduction to Norsk Hydro involvement in new energy

At the time of my study, Norsk Hydro Energy[44] had started to proactively position itself in new energy development. Preparing for the future while at the same time exploiting its resources in offshore oil and gas, hence Hydro had one foot in exploitation and one foot in exploration[45]. In the area of new energy, Norsk Hydro was involved in different innovation projects involving clean energy technologies at different development stages. For instance, Hydro was involved in wind power project development using technology further down the development road. Hydro's focus on 'new energy' was also channelled through Norsk Hydro Technology Ventures (NTV established in 2001), a venture capital fund denoted as Hydro's technology watch and vehicle in the energy space looking into promising energy sector-related technologies. One NTV investment area involved Hydro in the world's first commercial wave power plant development[46]. Finally, Hydro was involved

---

[42] Viable in a technical and economic sense with costs subject to calculation and a certain technological performance has been achieved as they are further down their development path and therefore some new energy options are closer to commercial application (e.g. land-based wind power)

[43] The term context refers to the situation and the entities that are related to the organisation (Håkansson & Snehota 1989)

[44] A Division in Norsk Hydro AS and later called Markets under the Oil and Energy business area.

[45] Borrowing from the language of March (1991).

[46] http://www.planetark.com/dailynewsstory.cfm/newsid/30917/story.htm

in the hydrogen energy area seeking to advance hydrogen as 'an energy carrier of the future' for different areas of use such as for mobility and stationary energy production.

There were various drivers behind Hydro's growing clean energy orientation[47]. Then chief of staff in the Energy Division[48] pointed to historical reasons: "We have been in power production for a long time and it is part of our heritage". More immediate challenges affecting Hydro were mentioned in terms of: the need for more power, the climate change challenge, new energy being profitable, and that it was "expected" that Hydro as a large company in the Norwegian economy was active and involved in this area. More long term considerations were also mentioned in terms of oil and gas resources being finite resources which in turn would require the use of present resources to build a platform for future energy activity. Finally, an external motivation was mentioned in terms of "profiling" that is to earn the company a license to operate; and an internal motivation was that employees also wished to build a future business platform. So there were several motivating drivers that encouraged Hydro's orientation towards the new energy sphere.

Although there were several drivers behind the new energy orientation, it was on the other hand also pointed out that the New Energy unit (set up in 2003) was established without a grand strategic process, and hence not the result of decision making process considering all aspects of the new energy sphere. In its infancy, the New Energy unit was meant to integrate pioneer activities that had been going on in the Hydro organisation in diverse new energy areas (e.g. wind energy, bio energy, alternative fuels) since the 1990s. The commonality in these pioneer activities was that they all related to 'the something' labelled New Energy and that these pioneer activities had no clear association or home in Hydro's organisational structure.

Activities had been initiated in the mid and latter part of the 1990s at different locations in the organisation. The period was characterised by preliminary exploration. Part of the new energy/ renewable energy initiation started for example with a visit to Danish wind manufacturer Vestas in 1995 looking into suppliers of wind technology. The wind energy development orientation focused on using available technology to do business. Wind projects were considered based on economic decisions integrating political support frameworks in project development and not as a technology development decision. Bioenergy was also explored with the purchase of a company that was later sold to Hydro Texaco due to the profile and position in the heating market (pellets, oil etc), and since it did not fit Hydro's

[47] This description is based on initial meeting and interview with assigned company liaison, Dag Roar Christensen, October 2004.
[48] At the time Dag Roar Christensen.

orientation toward larger scale production, larger scale energy carriers. As it related to fuels and the transportation sector, one of the initiators and pioneers in the hydrogen area described search like and exploratory activity as 'nosing around'. "It was a time where everybody nosed around for example into natural gas, propane, biodiesel and hydrogen". It was a time when the contours of information and growing focus on environmental issues were perceived. Hydro's New Energy unit was formally established in 2003 as a union of the former units: wind power, hydrogen and the venture capital fund, Norsk Hydro Technology Ventures (NTV).

The establishment of the New Energy unit (2003) was in a way the end of the beginning, in the sense that it was the outcome of efforts and initiatives initiated since the middle and latter part of the 1990s. It took time to move from awareness of technical possibilities, trends or threats and early ideas amongst employee pioneers to making decisions on something tangible like establishing a business unit and/or projects. In the subsequent sections of this chapter, the initiation of activities to pursue the introduction of hydrogen in energy markets is portrayed in detail. For now it is sufficient to say that moving from a stream of ideas and pioneer activities to a business unit took time.

The establishment of the New Energy unit, on the other hand, also marked a beginning where new energy paths and their profiling intensified as a part of what the Norsk Hydro organisation was doing and what it communicated about itself to the world. In a web article about renewable energy from 2003, it was written[49]: *"It's difficult to imagine a serious energy company not getting involved in renewable energy"*. In 2003, Rostrup (at the time, manager of the New Energy Unit) reflected on new energy involvement in the following way[50]:

«*We know that the development is in the direction of new forms of energy. It is important for us to be involved from the start, to build up expertise and establish a position in the new energy market, at the same time as we produce hydrocarbons in our core operation in the most efficient and environmentally friendly way…..Hydro's extensive hydroelectric power operations have provided many years of experience in delivering power based on a renewable, environmentally friendly energy source. The company has also produced hydrogen in connection with its fertilizer production for 75 years….When we add to this the many examples of the company's pioneering applications of new technology both in its aluminium and in its oil and gas operations, we see that Hydro is in a natural position to develop new forms of energy …. So far, Hydro has mainly focused on hydrogen and*

[49] Yes to renewable energy, May 9, 2003 http://www.hydro.com/en/Press-room/News/Archive/2003/May/16338/
[50] Looking ahead to the future, November 5, 2003 http://www.hydro.com/en/Press-room/News/Archive/2003/November/17290/

wind power. The company has set up Norsk Hydro Technology Ventures to support promising projects based on other forms of renewable energy such as wave power. Oil and Energy also works on solutions for handling carbon dioxide (CO2), to minimize emissions of this greenhouse gas, and on trade with CO2 quotas and green certificates»

To Norsk Hydro[51] getting involved in New Energy meant establishing the New Energy unit around initiatives in wind power and hydrogen to assess investment opportunities in renewable energy and distributed power generation, as well as realising and supporting other renewable energy projects through Hydro's venture capital fund, Norsk Hydro Technology Ventures (NTV). The New Energy unit was conceptualised as a tool to gain insight into how technologies were developing, to explore opportunities and to uncover threats to existing activities and assets. This came across most clearly when discussing NTV. NTV was described as a "watch-dog in the market" and a vehicle in the energy space looking into promising energy and energy sector-related technologies. NTV was meant to contribute to: technological development, insight into how different technologies were developing, and how to build experience, competency, and position the company for the future. NTV activity was also meant to provide insight into trends that could threaten existing business activities and assets.

«*One of the values of these projects, where Hydro's ownership interest is small, is that they give the company insight into advances in energy technologies. We don't invest in these projects solely for the financial return, but also to increase our knowledge"… A lot of research and development in this area takes place outside the major companies*»[52]

The New Energy unit was set up to pursue some technological paths among new energy opportunities. Besides wind and hydrogen energy, other new energy opportunities could very well come to play a central part in the world of energy, and it was indicated that the organisation continually pondered the question: *should they be thinking differently?* Strategy- and 'think tank' processes were going on regularly to reflect on this question, and as a result, strategy documents were revised and fine-tuned every other or third year.

In addition to the -*should they be thinking differently*- question; other questions pondered in relation to the new energy sphere concerned the challenge of defining a role and position in development activities. Illustrating dominant views in the organisation, it was mentioned that Hydro was not a technology developer, rather Hydro was to license and use technology to perform activities and bring the customer a product; that

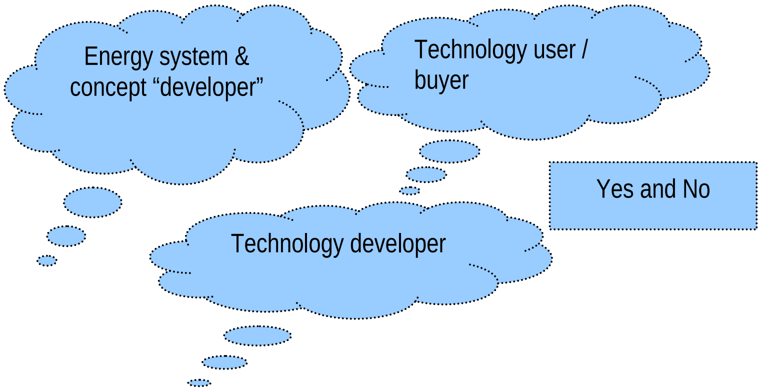
---

51 *Yes to renewable energy,* May 9, 2003 http://www.hydro.com/en/Press-room/News/Archive/2003/May/16338/

52 Interview with Dag Roar Christensen 8-10-2004.

Hydro was a supplier of energy and a professional buyer of technology from technology developers. What should be Hydro's core role? What roles were other companies taking in development processes and technology paths in the new energy sphere? Should Hydro take part in the resource, idea and concept generation phase so as to shape the energy system concept? Should Hydro develop technology? The challenge was to determine where Hydro should be positioned in development processes and with what people, and where to be in the activity chain of new energy paths.

Figure 1 Pondering roles



These questions and role pondering indicated that there was no "one and only" and obvious new energy business venture that the organisation should pursue, rather this was a subject for negotiation. The Hydro organisation was trying to make discriminating choices that fit the organisation and its circumstances. The questions pondered by the organisation also illustrated that when initiating new energy paths there was no clear facts out there which Hydro's new energy people could accurately perceive and act upon. New energy paths were in a continual flux, and emerged in interaction with the decisions of organisations like Hydro. However, initiating new energy activity provided insight and understanding into where the energy scene was moving, what ideas came up and gained strength, what were trends, what were technical obstacles, and what were other organisations doing? Developing an understanding of the new energy sphere did not only concern Hydro's own understanding, but also the understanding and actions of others. Hydro participated and started to engage in new energy projects and took on roles so as to build an understanding and experiment with how to go about this, and how to get into new energy areas in the best possible way.

With the establishment of the New Energy unit in Hydro, there was commitment to uncover the potential, performance, and value dimensions that new technologies could potentially bring to the energy market. The purpose of the New Energy unit was to consider trends, potential demand, performance attributes and then to make further decisions, deal with the residual uncertainty, and to consider in what areas and capacities Hydro should participate in order to position itself, reserve a right to play and adapt and participate in market development.

From here on, I concentrate on hydrogen energy activity. However before I describe initiation and pioneer activity in detail, I start out with a brief overview of the establishment of the Hydrogen unit, and the hydrogen energy paths that Hydro chose to pursue. This is in a way the same as writing about the end before the beginning, since the paths which Hydro chose to pursue were the effect and outcome of pioneering efforts. I choose to structure it this way to give the reader a brief overview and understanding of Hydro's hydrogen activities upfront.

4.3 Embarking on the hydrogen energy venture

In 2003, then manager of the New Energy Unit Rostrup pointed out that Hydro's hydrogen efforts in energy markets had their point of departure in three areas of competence in Hydro[53]: Norsk Hydro Electrolysers (NHEL[54]) as the producer of electrolysers for hydrogen production; research and new technology development activities – and what was technologically feasible - was primarily anchored in Hydro's Research Centre in Porsgrunn; and the commercial and strategic approach – commercial feasibility - was anchored in Hydro's Hydrogen Group in the New Energy unit under the Oil and Energy sector. The three areas of competence were said to be imperative to Hydro's hydrogen efforts toward energy markets.

4.3.1 The Hydrogen Group in New Energy under Oil and Energy

Historically, Hydro had been involved in hydrogen production since 1927. Hydro celebrated its centenary in 2005 and for most of the time it had been a major producer of hydrogen.
"After 75 years as a major producer of hydrogen, 75 years of experience in water electrolysis technology, 25 years of research in the car industry and one of the largest owners of gas in Europe, you could say that Hydro has hydrogen in its genes»[55], the Hydro home page announced. "*The use of energy may lead to climate changes. It is thus necessary to make the transition to cleaner and environmentally favourable energy carriers. Hydro is committed to this transition, and is pursuing the introduction of hydrogen in the energy markets*», Hydro's homepage continued.

---

[53] *A view to the future,* 05.11.2003
http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2003/November/17290/
[54] Name change to Hydrogen Technologies, October 1, 2006.
[55] http://www.hydro.com *Hydrogen - fuel of the future.*

In November 2001, it was decided that a Hydrogen unit should be established under Hydro Energy in the Oil and Energy business with Hexeberg as the manager starting December 2001[56]. The Hydrogen unit was established with its own Board of directors reporting to the manager of Hydro Energy. At that time Norsk Hydro Electrolysers (NHEL) also became a part of the Hydrogen unit. On the same note, hydrogen activity together with activity in wind power and Hydro Technology Ventures was subsequently merged into the New Energy Unit by the turn of the year 2002/2003, so the Hydrogen Unit with an independent Board of directors only existed for about a year, and then it became the Hydrogen Group in the New Energy Unit.

The decision to establish the Hydrogen unit was made in the end of 2001, and was accompanied with plans for how the organisation was to build up its hydrogen energy venture and with what resources. The projected hydrogen energy future could come in different shapes as there were many possible paths for making and delivering hydrogen (Appendix I). Next I will elaborate on the three pillars and particular areas of activity in the hydrogen energy effort to be pursued at the time of the establishment of the Hydrogen unit.

4.3.2 Areas of activity

Hydro decided to mainly pursue three areas: 1) stationary systems for hydrogen production from renewable energy sources and making systems that couple renewable energy sources (RES) with hydrogen production; 2) the transportation sector where there was major focus on using hydrogen as a fuel; and 3) producing hydrogen from natural gas. The main focus was the production side of hydrogen and here mainly two production methods were in focus (renewable or natural gas based). For the transportation sector Hydro also decided to pursue complete supply solutions and how production technologies could be integrated in fuelling stations. The three areas were based on Hydro's history and where the company had its strong points and it was based on pioneer activities, but the three areas were also based on what was observed to be in focus in other companies as well as in the EU. The three areas were related to concrete challenges in Norway and in the EU, in particular what the EU was preoccupied with and what the EU supported, and what the EU supposedly intended to support in the future. Pioneer activity in the interface between business development and politics had triggered ideas and produced a view of circumstances and events that affected the company. In many of the pioneer projects, pioneers had tried to create future or foresight scenarios of possible hydrogen transitions.

[56] Interview with Ivar Hexeberg 16-11-2004

4.3.2.1 The use of hydrogen in renewable energy systems

One of the perceived advantages of hydrogen was that it could make the renewable energy vision real by providing a storage function for fluctuating renewable energy sources and production, and hence make energy available where and when needed[57]. Power generation from renewable energy sources (RES) coupled with hydrogen production was chosen as a main development path for the Hydrogen unit. The focal point for this line of activity was to enable the use of renewable energy sources. Such production systems was believed to be of particular interest for regions with high levels of renewable energy production so as to better exploit the renewable energy source by converting it to hydrogen in certain periods. Normally, electric energy must be produced and consumed at the same time; however, in periods with renewable production beyond demand and/or beyond net/grid capacity, excess renewable energy production available could be used to produce hydrogen. As such hydrogen was expected to have a potential role in balancing power grids and as storage media to cope with variable power production (e.g. wind power). Hydrogen could be used to produce electricity to the grid in periods where there would be no renewable energy available or hydrogen could be used for other purposes e.g. industrial processes, use in the transportation sector. The enabling technology to go into this line of energy production systems was considered to be Hydro's electrolyser technology and competence. Hydrogen production based on electrolysis using renewable electricity (wind, photovoltaic, solar thermal, hydro) was regarded as a kind of silver bullet since it would enable close to zero emissions of greenhouse gases (GHG). Hence electrolyser technology was perceived as central to the vision of sustainable hydrogen production and supply[58].

Another perceived potential for the hydrogen and renewable energy combination, was stand-alone power systems; that is electricity systems that are not connected to a large transmission system. The Utsira project which I describe in detail in chapter 6 is illustrative of this potential for autonomous energy systems based on renewable energy sources, which was envisaged for remote areas and as an alternative to diesel. Besides addressing the specific needs of communities, such stand-alone systems were also considered as a type of living test bed for demonstrating and acquiring feedback on the coupling of hydrogen and renewable energy sources.

[57]The relevance of electricity sector's use of hydrogen depends on the existing production system. For example, the electricity sector in Norway is not expected to be in large demand for hydrogen as storage medium as the existing electricity system is hydro power based with storage potential in reservoirs and hence readily available energy storage capacity.

[58] If electrolyser technology is used with fossil fuel-based electricity, there would be greenhouse gas emissions associated with this electricity production.

4.3.2.2 The use of hydrogen in transportation

Hydrogen was also perceived as a fuel candidate for the transportation sector as a plausible alternative for gasoline. Hydrogen was considered part of to the vision of a pollution-free fuel solution with no combustion by-products as the "the ash of hydrogen is water"[59]. Pioneer activity had perceived and positioned Hydro's hydrogen venture for the transportation market. The entry ticket to be part of early markets for hydrogen in transportation was considered via electrolyser technology from NHEL (Norsk Hydro Electrolysers). Hydrogen in transport was at the time (and still is) in a demonstration period and Hydro's referral to market development was in the early stage about getting demonstration projects - the market was the demonstration projects. Yet the global potential for hydrogen in transportation was perceived as being huge as energy consumption for mobility was growing with associated air pollution and environmental challenges - CO2, particulates, sulphur dioxide, nitrogen oxide emissions - from millions of vehicles. The perceived opportunity on the transportation side was to provide an alternative fuel, and the pot of gold at the end of the rainbow was to replace the internal combustion engine in hundreds of millions of cars. However, in the transportation sector, there were technological challenges (see Appendix I) such as with the fuel cell, compact storage of hydrogen, and a chicken-and-egg problem. In other words, who will spend money on a wholly new infrastructure to provide access to hydrogen for consumers with hydrogen fuelled cars until millions of such vehicles are on the road? Yet who will manufacture and market such vehicles – and who will buy them – until the infrastructure is in place to fuel those vehicles?

The crux of the matter was that this created interdependence as Hydro's hydrogen venture was connected to solutions, breakthroughs, and development that resided with others. Trying to position the company for the use of hydrogen in the transportation sector involved analyses of how infrastructure might develop in the future, and the Hydrogen unit did not have very fixed ideas about the business model that would eventually be pursued. In the early phase, it was considered impossible to start with centralised mega hydrogen production factories with tanker trucks. It was not for Hydro to predict the eventual and future solution but to position the organisation to play a part no matter what future model of hydrogen production and distribution. Long term hydrogen was envisioned as having

[59] For the purpose of easy of a simplified understanding of the use of fuel cells in cars, one can think of the fuel cell as a "black box" that takes hydrogen and oxygen and puts out only water plus electricity and heat. Hydrogen when combined (burned, oxidized) with air's oxygen, produces only water plus minuscule amounts of oxides of nitrogen, inevitable by-products of any atmospheric burning process. (Romm 2005, Hoffmann 2002). For a discussion of the complete hydrogen production chain, please refer to Appendix I.

potentially decentral energy production, as well as central production units to get unit cost down in the production plant, and with distribution from there to the end uses, the market. At the time of establishment of the Hydrogen unit (2001), Hydro pioneers had emphasised that Hydro had a part to play in all the possible future infrastructure models.

4.3.2.3 Natural gas-based hydrogen production

The third area of activity considered at the time of establishment of the Hydrogen unit (2001) was to produce hydrogen from natural gas, which linked hydrogen energy to Hydro's oil and natural gas resources. There was a lot of history and tradition here from the Agri business with ammonia production and natural gas reforming (steam methane reforming SMR[60]) for hydrogen production. Technology used in the Agri business was not developed in Hydro but known technology purchased from others. However, the hydrogen experience in the Agri business had established a reputation of Hydro as an actor with competency in efficient and safe large scale hydrogen production and handling over decades. Natural gas based hydrogen production was also perceived as a possible decentral solution in areas with access to natural gas. Small-scale SMR was under development and could be used on-site e.g. at local hydrogen filling stations[61]. Hydro's hydrogen energy pioneers considered it relevant to know about small-scale SMR technology as it was perceived as a potential competitor to electrolyser technology. The SMR area should be monitored; however, at the time it was a question of prioritising resources and not being able to fund small scale SMR- as well as electrolyser technology development. The natural gas based hydrogen production part of Hydro's hydrogen and new energy strategy was also more about positioning the company more long-term in large scale hydrogen production. The timeline was uncertain since the hydrogen market was not there yet[62].

---

[60] SMR is a thermal process with natural gas as the feedstock. SMR plants are by far the most widely used means of producing hydrogen on an industrial scale. SMR plant have economies of scale where large plants are cheaper to build (per unit output) and are likely to command a lower price for natural gas than would smaller SMR plants e.g. on-site hydrogen fuelling stations. Another cost issue is to handle CO2, for example, global warming concerns will possibly require capture and sequestration.

[61] As to the direct use of natural gas in transport applications (Compressed natural gas CNG), with today's vehicle technology, natural gas does not significantly reduce CO2 emissions. This would require further technology development of the gas engine, which in turn depends on the car manufacturers' willingness to undertake such development. CNG also face similar problems as oil as they are based on fossil feedstock contributing with green house gas (GHG) emissions. Further fossil feedstock is finite with associated imports and security of supply concerns (see Appendix I for more details).

[62] Interview Helle Britt Mostad 18.11.2004

From here on, I focus on the initiation of hydrogen energy activity and pioneer activity in detail. At the time the initial strategy on hydrogen energy was advanced (based on which the Hydrogen unit was established in 2001[63]), it had taken several years of pioneer activity before the pioneers were asked to develop a strategy on hydrogen energy. The hydrogen energy path was initiated by pioneers working with Norsk Hydro resources from diverse settings in the organisation. *Pioneers worked in research, with the technology provider, and in business development.* The detailed description of pioneer activity and initiation of hydrogen energy activity will illustrate how the business case for hydrogen in energy markets was mobilised, and how hydrogen energy became relevant for business activity.

4.4 Pioneering hydrogen energy as part of research

4.4.1 Organising hydrogen research

The dawning interest in hydrogen was manifested through the participation in research and development projects[64]. The hydrogen area up until 2001 was foremost a research project to look into hydrogen as a future energy carrier; it was financed as corporate research to keep the option open for an integration of hydrogen in Hydro's energy portfolio in the future. As it concerned the organisational model for research, research was centralised in the sense that a Corporate Research Centre existed that served the entire Hydro organisation[65].

Up until 2001, hydrogen was foremost an internal research project to look into and get to know hydrogen as a future energy carrier. Activities particularly picked up from 1999 whereas before that it was more sporadic activities. "Bjørn Sund was the visionary"[66]. There was no hydrogen or wind business division but the Corporate Research Centre had initiated a hydrogen project where a couple of people with the necessary competence were moved from other technology areas to be responsible for projects looking into

[63]Subsequently one of the main pillars in the New Energy unit established in 2003

[64] Interview Klaus Schöffel 21-9-2005, head of the division for "Hydrogen & Renewable Energy" in the Oil and Energy Research Centre, Porsgrunn.

[65]Research was reorganised in 2001and hydrogen was placed under the Research Centre Oil & Energy The Corporate Research Centre (420 people) was divided into 4 units, with 3 areas belonging to business sectors (Oil & Energy, Aluminium, Agri) and one unit remaining a corporate research centre (CRC) serving common functions for the entire company. The objective was to close the distance between research and the users in market and business activities. With this reorganisation, focus was moved from the long-term and to more operative research closer to business activities. The Research Centre Oil and Energy working upstream in oil and gas (transport/process/separation); downstream activities in two sections included natural gas, power production; CO2 separation, as well as researchers working in hydrogen and renewable energy and with the majority working with hydrogen.

[66] Interview Klaus Schöffel (21-9-2005)

hydrogen production and distribution methods, infrastructure, costs, scenarios to develop the hydrogen society, Well to Wheel analyses to document CO2 savings, and natural gas based hydrogen production.

In hindsight, the studies from the late 1990s were described as a bit naive, the level of competence and knowledge about hydrogen as an energy carrier were at the time and in general quite low. Again, in hindsight, the complexity in the transition to hydrogen had been underrated in terms of infrastructure development, localisation and geographical specificities that were important for development in addition to political frameworks. Early work and analyses did not have or consider these nuances or their complex interplay but were more concentrated on technology. The most important result or outcome produced through early research activities contributed to information based on which alternative paths could be envisaged and communicated and subsequently plans and purposes could be advanced and debated.

The reorganisation of the Corporate Research Centre (2001 -) into research centres under the business divisions (e.g. one of them being the Oil and Energy Research Centre) added stronger commercial focus to research. Research projects needed linking and underpinning in a business strategy and a balance needed to be struck between long term projects and projects with a short term implementation horizon. Closing the distance between the business unit and research activity was portrayed as a positive development as the researchers working in the hydrogen and renewable energy section came to work closer to their 'customer' and gained a much better understanding of businesslike challenges. Further, since the eventual business success or failure of hydrogen as an energy carrier was very technology driven or technology dependent, the researchers' could be more purposeful in questions, proposing activity, and addressing the role of technology in business challenges and projects. The Research Centre also became part of the budget and planning process where ideas and suggestions could be advanced in relation to new activity. Finally, the reorganisation of research in 2001 replaced the triangular line of communication via a corporate research coordinator, the business unit, and the research centres. It put into practice a more direct line of communication between the customer (e.g. a project manager in the hydrogen business unit or NHEL when it came to electrolyser development) and the researchers in the research centre that undertook development on a particular project.

A guiding principle (since the reorganisation in 2001) was hence that research needed to be embedded with the business unit responsible for commercialisation and integration of results. This way of organising was conceived as a way out of, what one of the Hydro researcher's in a humorous tone mentioned as, the tendency of the business people to want to sell things that cannot be built by forgetting technical restrictions, and the tendency of the researcher to develop things and products that are impossible to sell[67]. Business development and research in the hydrogen area were tangled because technology development was important to achieve commercial goals. Hydrogen development could have been maintained as a research and development project because turning hydrogen as an energy carrier into business was still located somewhere in the future. However when establishing the hydrogen business unit (2001), and hence moving hydrogen energy from a research agenda to a business agenda, it added focus and interest from the rest of the company and also pointed to a stronger commercial focus in research.

Within the hydrogen business unit there was a parallel movement from a central coordination of research toward letting each business developer be responsible for the research projects associated with his or her business development[68]. The central coordination model had previously involved one person in the business unit being responsible for research activity. The research coordinator had handled the hydrogen research portfolio in terms of long term research, internal development projects, knowledge building projects (KMB projects) with the research institute sector, foresight studies, and EU projects and cooperation. Research commitments were multiple and ranged from monitoring issues and development interpreted as enablers of hydrogen energy development, and to research projects in areas interpreted as possibly relevant business areas.

The transition to a more decentral coordination of research was based on the reasoning that if research was to contribute in business-related projects and to a commercial future for hydrogen energy, then each business developer, defined as users of research and in charge of its implementation and business-related use, had to be the research's closest ally. Hence responsibilities, budgets, and project follow-up were decentralised to the business developer / project manager of the project in which research was to be implemented. Direct lines of communication were set up without a research coordinator as the go-between. Finally, research efforts were distributed among the business developers that were assigned their separate responsibilities and organised around the three pillars in the hydrogen effort (stationary systems for hydrogen energy production; the transportation sector and new energy markets, natural gas-based hydrogen production).

4.4.2 The initiation of the internal hydrogen project

Hydrogen exploration and the internal hydrogen project were initiated with the Corporate Research Centre in the 1990s. Let's go back to the visionary Director of Corporate Research. Pioneer activity and initiation of hydrogen

[67] Interview Torgeir Nakken (28/8/2007)
[68] Interview with Helle Britt Mostad (18/11/2004)

exploration was under the Director of Corporate Research (DCR) from 1998 - 2001, Bjørn Arne Sund, responsible for Hydro's research portfolio and for the coordination of research and development projects.

The DCR was mentioned as the central figure and catalyst for the early spurs in hydrogen, and a person whom the early hydrogen pioneers in Hydro sought as an ally[69]. In Hydro, Sund directed research in Oil and Energy in 1997 and the DCR from 1998-2001. Through Hydro's wide-ranging involvement in the energy business, corporate research looked at connections between different forms of energy, and was required to look ahead to picture future energy development and contemplate how Hydro's different operations and business segments would be affected. Looking into the future, and looking at trends and relationships between and across developments in energy markets, was core responsibilities of the DCR. What opportunities and threats challenged Hydro's activities and the value of existing resources? How should the company be positioned in new forms of energy? Nuclear power could experience a revival, and there were different fossil fuels available for exploration but the economics in coal, tar sand, heavy oil all depended on the perception of carbon emissions and the climate challenge. The value of existing resources would depend on how the climate crisis and challenge developed, was handled, and would affect the potential of energy alternatives as well as conventional oil and gas related business. The organisation simultaneously needed to handle opportunity and problems with existing product portfolios.

"So all the time, it is about trying to get an as balanced picture as possible. This is a balance of terror, there are opportunities and threats. Nobody can for sure say that new renewable energy sources are the solution, not for many years; other energy forms are the only sure thing right now; we cannot

[69] Bjørn Arne Sund is characterised as a grand and vigorous person by another pioneer. He is also characterised as someone with strong points of views and some one whose views are noticed and carries weight in the Hydro organisation. Sund has worked in Hydro since 1977 and has worked with the whole value chain from upstream to downstream in the oil and gas industry – exploration, reservoir studies, concept and technology development, licensing, infrastructure. On behalf of Hydro, he has been part of the Norwegian Technology Council from the middle of the 1980s into the latter part of the 1990s making plans for research funds in oil and gas. At the time of the interview he is a board member in NHEL (Norsk Hydro Electrolysers), and board member in NTNU's[69] Strategic Area for Energy and Petroleum – Resources and Environment. He is a board member in the Norwegian Research Council's (NFR) Division and initiative called Large-scale Programme. Simultaneously with Hydro's own initiatives and projects, efforts were made to create a Norwegian hydrogen focus, as well as initiatives in NFR; support NTNU and the milieu in Trondheim and Sund has worked to have the NFR support and finance doctoral- and development work in relation to new energy systems. Bjørn Sund mentioned that in the context of NFR and NTNU, he did not represent Hydro since people are appointed based on personal qualifications. At the same time, it is somehow known that it is not a bad idea with representatives from the large companies because it facilitates the creation of linkages, relations, and the creation of win-win situations because research is preferably to be transferred and embedded in business development.

know and see beyond the future so we have to position ourselves and have a balanced portfolio so that we may seize opportunities and be protected against threats»

As to the mobilisation of new projects, most new initiatives were identified bottom up and the management challenge was to be willing to keep eyes open and to have an open mind about alternatives. Then there was a whole lot of discussion about ideas and beliefs, what Hydro researcher and pioneers did and did not believe about the future.

«*Research is a lot about 'belief and hope' but it is just as much about envisioning, making approximations and creating a good picture as possible. Participating in demonstration projects is an inexpensive way to develop a platform and a backdrop of understanding on which to base your own intentions and meaning, and how to set a course of action business wise. This is very important so as to be able to use knowledge about new energy systems. There is still some time before new forms of energy will make a difference to the bottom-line, but getting involved is about preparing for what may come and happen in the future. In research it is important to maintain focus on the existing value chains as well as keeping an eye on the new things that are happening, how environmental and climate issues will affect our existing business plus positioning ourselves in products that may hold value in the future*»

Hydrogen energy initiatives were initiated and stepped up at the time of the Kyoto Agreement in 1997. Back then it was believed that there would be quick ratification of the Kyoto Agreement and decisions to reduce and limit emissions. To Hydro as an energy company it was important to get in position for a climate emissions' reduction agreement. Things were moving in the direction originally expected in the aftermath of Kyoto but it has taken much longer time than originally expected. Hence timing was indicated to be an important factor in the pursuit of opportunities and hydrogen development paths. Some initiatives had been contemplated earlier but it was around the time of the Kyoto Agreement that some initiatives appeared commercially viable since the expected cost of emitting CO2 would defend investments.

4.4.2.1 Pathway activities - fossil fuel resources

It was consideration for Norsk Hydro's oil and gas resources and the anticipation of action required to meet obligations under the Kyoto protocol that prompted activities in hydrogen as part of efforts to decarbonise fossil fuels via CO2 removal and disposal. Making hydrogen available as an alternative energy carrier was part of Hydro's strategic work facing the environmental challenges associated with particular emissions.

The Director of Corporate Research (DCR) indicated that there was an impending challenge in seeing how things were interrelated in terms of Norsk Hydro business divisions, the development of energy system solutions, the user side, political restrictions, and environmental limits related to the present energy system, and to consider commercial options for energy alternatives. The DCR pointed out that the different Hydro business segments usually worked on their separate things, also being responsible for their own research and development, and that there traditionally had been little or no focus on linking efforts. The impulse from climate change negotiations in Kyoto triggered efforts to join activities across Hydro business divisions, and a hydrogen energy initiative was mentioned to illustrate such efforts. The HydroKraft project was the first and major large scale hydrogen projects initiated in 1998[70]. The Hydrokraft project was coupled with hydrogen projected as an energy carrier of the future, and in 1998, the DCR was an important advocate for a hydrogen approach to future of energy supply. At the Energy for the Future conference in 1998, the DCR defined three challenges as part of the strategic motivation behind the HydroKraft project development. 1) Electricity production with minimal CO2 emissions; 2) the use of hydrogen in future energy supply; and 3) using and attributing value to CO2. The Hydrokraft project had several features that fitted a long term strategy towards a more sustainable electricity system based on carbon capture, hydrogen production, and using carbon dioxide as pressure support. In Norsk Hydro's Annual Report (1998, p. 15) it was written that:

«*Several of Hydro's divisions are jointly developing the HydroKraft project, which aims to produce gas-based power with very low carbon dioxide emissions. The project is also directed toward the development of a more sustainable energy system using hydrogen as the principal source of energy. The HydroKraft concept separates natural gas into hydrogen-rich gas and* CO2 . *The hydrogen-rich gas is used for power production, while* CO2 *is injected into an oil field to increase recovery*»

The project concept was to produce hydrogen from natural gas in a steam reforming process (technology similar to that used for ammonia production). The hydrogen mixture fuel gas was to be used in power production (the patent relating to the HydroKraft project described a method for producing a mixture of hydrogen, nitrogen and water which could be combusted in a commercially available turbine to produce electricity). Finally to attribute CO2 value; the CO2 removed pre-combustion was to be used for pressure

[70] Work on the project had been in progress within Hydro since the early summer of 1997. On the 23rd April 1998 Egil Myklebust, President and CEO of Norsk Hydro, held a press conference in which plans for a "CO2-free" and environmentally friendly gas power plant was announced.

support in the Grane oil field due to start operations in 2003 in which Norsk Hydro had operational responsibility[71].

Hydro management was enthusiastic about the project because of the potential ramification for technologies and commercial interests in all of Hydro's areas of activity as it created mutual benefits and synergies across divisional boundaries and different business activities (Larsen et al. 2005)[72]. The Hydrokraft project was mentioned by the Director of Corporate Research (DCR) as an illustration of efforts to join activities and combine competences across Hydro business divisions. The project involved all three operational divisions in the industrial conglomerate i.e. Oil and Energy, Aluminium, and Agri. Hydro oil and gas business was seeking alternative pressure support by means of CO2; light metal and aluminium plants in particular were seeking energy and new supplies of electricity, and the Agri segment would be able to offer its experience and competence from ammonia production and steam reforming of natural gas for hydrogen production.

The project pioneered hydrogen energy activity and was part of early efforts towards decarbonisation of fossil fuels. In 1999, the project was profiled under the title: Exploring Options for CO2 Capture and Management in a feature article in the Environmental Science and Technology Journal published by the American Chemical Society. In the article, the project description highlighted the possibility of producing hydrogen at a large scale, which could subsequently be used in fuel cells. Hence the project was associated with activity to promote hydrogen as an energy carrier and the hydrogen economy (see Appendix I).

The Hydrokraft project was mentioned as a potential starting point for Hydro's early hydrogen energy efforts. Further, when initiating activity and development projects related to hydrogen energy systems as part of corporate research; the people, experience and state of the art expertise with production, storage and use of hydrogen in the Agri segment were deemed important. Being a large user of hydrogen in Hydro's fertilizer production, the question was how to use the Agri segment's great infrastructure and

---

[71] The technological solution chosen by HydroKraft was based on available technology and involved the removal of CO2 before combustion in a gas turbine; a so-called "pre-combustion" process. In the first phase of the process carbon is removed from the natural gas and converted to CO by bonding the carbon to the oxygen from steam and air. The next phase in the process is a reaction between CO and steam in which the calorific value in CO is transferred to hydrogen while CO reacts with the oxygen in CO2. The actual patent relating to the HydroKraft project describes the method for producing a mixture of hydrogen, nitrogen and water which can be combusted in a commercially available turbine to produce heat electricity.

[72]The project has been studied extensively in the the research project CondEcol – Exploring the Conditions for Adapting Existing Techno-Industrial Processes to Ecological Premises by ProSus, and report has been published. HydroKraft: Mapping the innovation journey in accordance with the research protocol of CondEcol. Working Paper no. 3/05

experience with natural gas-based production of hydrogen to which nitrogen was added to produce ammonia for the production of chemical fertilizer. The Agri segment had a gigantic hydrogen production converting 4-5 billion cubic metre natural gas annually[73]. The challenge was to orient this expertise toward a hydrogen energy value chain and hydrogen as an energy carrier. Merging agri- and energy expertise was intended to preserve the value of Hydro's fossil fuel resources in the anticipation of action to meet obligations to reduce greenhouse gases under the international Kyoto protocol.

After a couple of years, the HydroKraft project was not moved forward and did not materialize[74]. However at the time of initiation and pioneering activity into hydrogen energy, the project was conceived as a central course of action in the pursuit of hydrogen as a prospective future energy carrier. The HydroKraft project was the most financially demanding endeavour and hydrogen related development project under the DCR's time handling corporate research[75].

The HydroKraft project illustrated early research efforts on hydrogen in energy systems that worked with Norsk Hydro's natural gas reserves to prepare for future energy and fuel markets either with hydrogen for fuel cell vehicles or for fuel cells and turbines in power production. Norsk Hydro's involvement in the CO2 Capture Project[76] (involving eight global energy companies that joined forces to research and develop technology to separate CO2 and subsequently store it in geological formations), as well as participation in the US initiated Carbon Sequestration

---

[73] In 2004 Norsk Hydro demerged or spun off its agrochemical unit Hydro Agri (now called Yara International). The former director of corporate research saw this as a potential weakening of Hydro as an energy company. The technological know-how, in terms of natural gas based competence in hydrogen production residing in the Agri segment would potentially slip away although the Research Centre in Porsgrunn would still be shared and could be a means to preserving this expertise. This, however, illustrates retrospective reflection as the interview with the former DCR was in 2005.

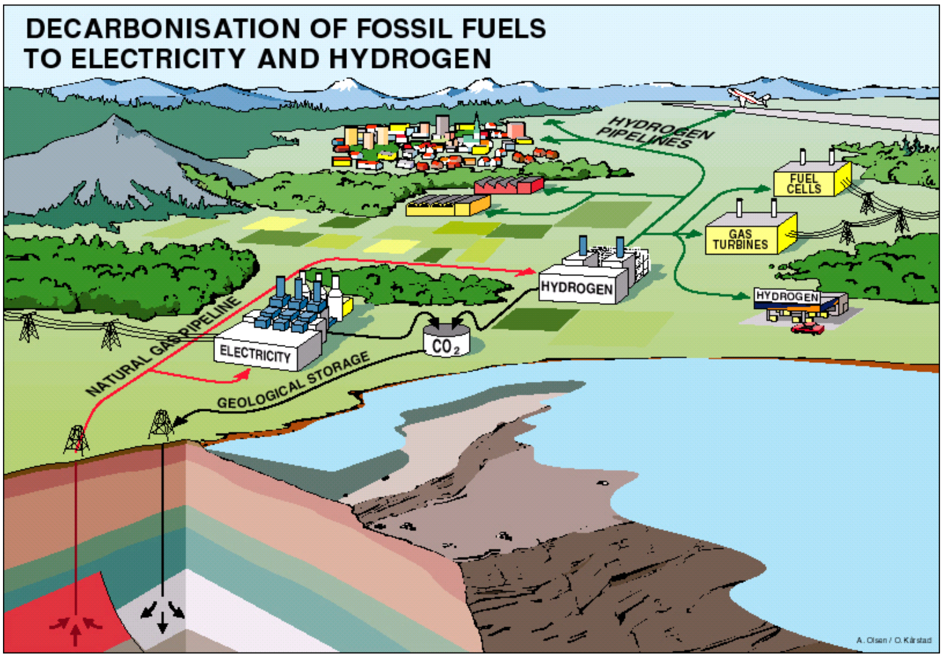
[74] See Larsen and Ruud (2005) for details on the HydroKraft project. According to the conclusions of Hofman (2006), the project failed to materialise and was ceased after a couple of years due to economic factors, and due to the presumed technical challenges of using CO2 for pressure support in the Grane oil field. The partner in the oil field, Esso/Exxon, did not perceive this technological option as realistic in such a huge project. Instead, exploitation of the Grane oil field was commenced with natural gas as pressure support. An additional hampering factor was the calculated price for the produced electricity. Electricity was supposed to be sold to aluminium smelters of Norsk Hydro, and the price was expected to be significantly lower than the commercial electricity spot market price. The project could not maximize the revenues from sale of electricity from the combustion of hydrogen in gas turbines. Consequently, the expected rate of return of the HydroKraft project was significantly reduced.

[75] The project had a budget of between NOK 30-40 million and was mainly financed by Norsk Hydro. NOK 6 million was provided in support from the Research Council of Norway (Larsen & Ruud 2005).

[76] www.co2captureproject.org

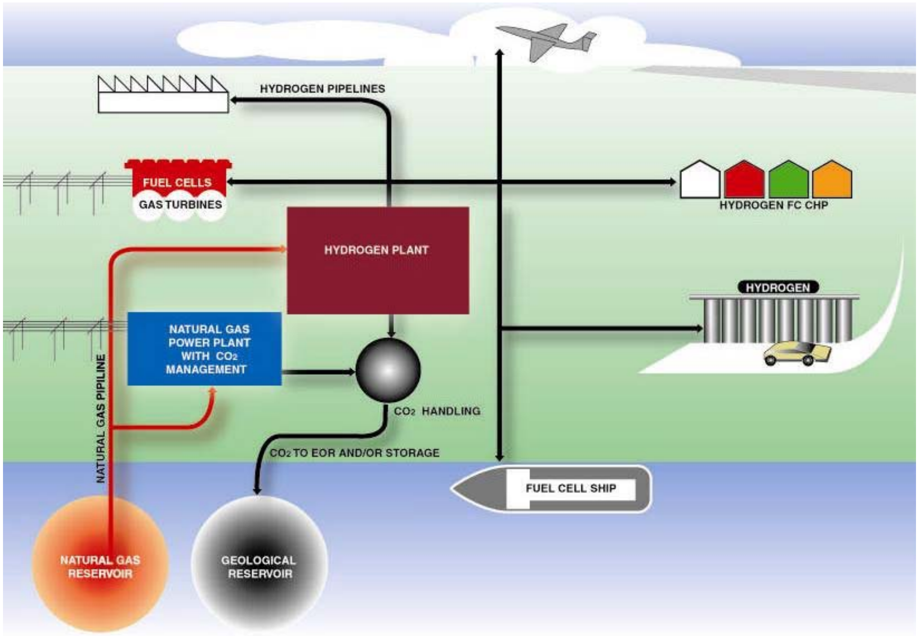
Leadership Forum (CSLF), were activities that were part of the same path commencement, namely natural gas-based hydrogen production. Hence when pioneering hydrogen energy as part of research, one focus was on efforts to decarbonise fossil fuels, with CO2 removal and disposal, in anticipation of CO2 costs on carbon containing products. Early research activities in hydrogen energy were initiated as part of strategic work to face environmental challenges associated with particular emissions so as to secure the value of Hydro's natural gas resources and make hydrocarbons 'sustainable'. This focus on hydrogen energy as part of decarbonisation efforts comes across in the illustrations below.

Figure 2 Visualisation of the decarbonisation of fossil fuels



Source: Overvik (2004)

Figure 3 Natural gas-based large scale hydrogen production with CO2 capture



Source: Mostad 12/10/2004

4.4.2.2 Pathway activities - electrolysis

When pioneering hydrogen energy as part of research actions, another focus progressively gained foothold as the Director of Corporate Research (DCR), Bjørn Arne Sund[77], became a board member in Hydro's wholly owned subsidiary Norsk Hydro Electrolysers (NHEL)[78] in 1999.

Within the Norsk Hydro organisation large scale industrial gas production via water electrolysis had started in 1927, and approximately 100.000 Nm3 H2/ hour was produced at plants at Rjukan, Notodden and Glomfjord by the middle of the 1960s from some 380 apparatuses supplied by NHEL[79]. Norsk Hydro Electrolysers (NHEL) at Notodden supplied units to the company internally because ammonia for the production of chemical fertilizers was produced using hydrogen. Hydrogen generation units have also been supplied throughout the world.

[77] Bjørn Arne Sund directed research in Oil and Energy in 1997 and was the Director of Corporate Research (DCR) from 1998-2001.

[78] In 1993, Norsk Hydro Electrolysers (NHEL), the manufacturer of water electrolysis equipment, became a stock company 100% owned by Hydro.

[79] Hydro also produced and handled hydrogen in its two chloralkali production units and it petrochemical plant at Rafnes where hydrogen was an 'excess' or by-product (Rafnes and Stenungsund). This hydrogen was used in the industrial plants.

Water electrolysis in the Agri business division, however had a diminished role as it was exchanged with industrial hydrogen gas produced from natural gas steam reforming since the late 1980s (Rasten 2003), which cannibalised Hydro's own electrolysis technology. Consequently, NHEL was increasingly dependent on the external industrial market, and therefore started to look toward other applications for its technology. NHEL was in a precarious situation with a fluctuating industrial market and was not part of Hydro's main business divisions (Agri, Oil & Energy, Aluminium/Metal); NHEL's home was in something called 'Others', an umbrella for many different activities[80].

Entering the NHEL board and this line of business, the DCR got a more direct understanding of: hydrogen production using water electrolysis; opportunities and limitations with regards to hydrogen in energy markets; status in the car industry; and fuel cell development. It was the consideration for research and the strategic positioning of NHEL business activities that led to decisions to join several international projects, the first one being a project on Iceland. The DCR approved and supported the involvement and ownership share in Icelandic New Energy (INE)[81], which was established in 1999 to manage and implement the EU supported ECTOS project[82]. This was the first commitment to deliver a technology solution to a hydrogen

[80] Hydro's core business areas consist of Oil and Energy, and Aluminium. Hydro's other activities ('Others') included: its petrochemicals business; a 68.8 percent interest in Treka AS, whose activities consist of fish feed operations; Hydro Pronova (established as the Hydro's corporate entrepreneurship vehicle in 2000 aiming to develop the non-core operations defined to have a particular potential), Industriforsikring a.s, a captive insurance company; and Hydro Business Partner, which provides service and support functions throughout Hydro. Hydro Business Partners was previously referred to as Hydro Telemark undertaking administration and management of three industry parks in Telemark, Hydro Telemark (Notodden, Rjukan, Porsgrunn). Since NHEL was located at Notodden it ends up in Others together with three other Hydro companies that were established at Notodden in 1993.

[81]The Icelandic government had announced an offensive hydrogen strategy to reshape the country's energy system and energy economy to a hydrogen economy with hydrogen as the future energy carrier. The goal was to base the country's entire energy production on renewable energy resources by 2030. INE was owned by four companies: The Icelandic Holding Company VistOrka hf owned 1/3, and VistOrka hf was a merger of the New Business Venture Fund, Reykjavik Energy, the National Power Company, the University of Iceland, the Technological Institute of Iceland, the Icelandic Fertilizer Plant, Sudurnes Regional Heating Corporations, and Icelandic Development Capital Area. The other 2/3 of INE were owned by the three multinational companies: DaimlerChrysler, Norsk Hydro and Shell.

[82] The ECTOS project (http://www.ectos.is) (Ecological City Transport System) was a 4 year project sponsored by the European commission 5th framework programme, attached to the DG Research. In Jan 2006 it was decided to prolong the Hydrogen bus demonstration using the same buses, the same fuel cells, the same hydrogen station but partially with a new agenda; Icelandic New Energy participates thereby in the Hy-FLEET:CUTE that is the CUTE follow up project.

fuelling station. In the press release[83] issued on behalf of the Icelandic Holding Company VistOrka hf, DaimlerChrysler, Norsk Hydro ASA and Shell International, Bjørn Sund as Norsk Hydro's director of corporate research expressed the following:

«Norsk Hydro has a long history of production and industrial use of hydrogen. We believe that hydrogen and fuel cells offer a great potential for future applications in energy markets, and that cooperation between the energy, automotive and other industries is essential to provide solutions to environmental challenges related to consumption of energy. The Icelandic initiative provides a good basis for further development of such cooperation»

Norsk Hydro, Shell[84] and DaimlerChrysler were international partners on the INE board. The project was carried out between 2001 and 2005, starting with a two year preparation phase and the actual trial period from 2003-2005. Inauguration was 2003. NHEL was to deliver all equipment to the hydrogen producing part of the hydrogen fuelling station in Reykjavik. The system included an electrolyser, compressor, storage and the dispensing unit, which was built and put together in Norway and sent to Iceland as a complete unit. The station was to produce hydrogen from tap water and electricity from the Icelandic renewable hydroelectric and geothermal energy sources. The fuelling station was to supply three DaimlerChrysler fuel cell busses supposed to participate in regular commercial traffic in the municipal bus company Straeto.

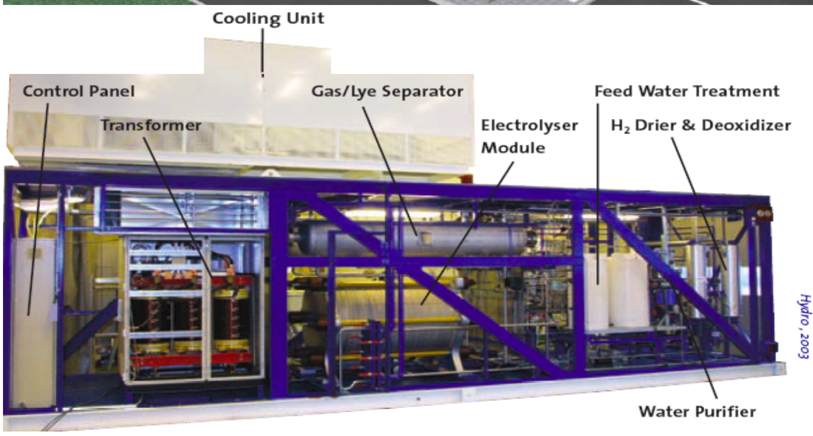
The hydrogen production and fuelling infrastructure was built by Norsk Hydro at a Shell station. It was the world's first public hydrogen station built as a pre-commercial station and integrated into the urban setting of a conventional gasoline station. Hydrogen was hence integrated in a setting very different from the typical industrial settings that were closed off to the public. The important demonstration aspect was the construction of a real-life hydrogen fuelling infrastructure for vehicles, for testing and evaluation, and to showcase an emission free energy chain. The project addressed factors such as safety, reliability, cost-benefit analysis, and infrastructural cost to society. Opinion polls addressed issues of public perception and social acceptance of a new fuel and new technology. The results and experience from operating a hydrogen infrastructure were to be used by other European cities to implement their own hydrogen infrastructures.

[83] Shell News & Library 17 Feb 1999

[84] Shell Hydrogen was set up in 1999 to pursue and develop business opportunities related to hydrogen energy and fuel cells.

Figure 4 from the fuelling station on Iceland

Figure 1. The components at the hydrogen station are: 1) Intake for water and electricity, 2) Electrolyser, 3) Cooling tower 4) Compressor, 5) Storage cylinders 6) Dispensing unit, 7) information panels



Electrolyser Unit in Reykjavik (ECTOS Project)

Source: Clean Urban Transport for Europe, Detailed Summary of Achievements, p. 23. http://ec.europa.eu/energy/res/fp6_projects/doc/hydrogen/deliverables/summary.pdf.

The Iceland project put Norsk Hydro on the hydrogen map. The opening event was linked to a conference with the title: *"Making Hydrogen Available to the Public"* and on the main speakers list was top management from Shell (Mr. Jeron van der Veer, President of Royal Dutch Petroleum Company[85]), Mr. Tore Torvund (Executive Vice President Norsk Hydro). From Norsk Hydro was also Christopher Kloed (Managing Director of Norsk Hydro Electrolysers), who spoke about present and future hydrogen fuelling stations.

In addition to putting Norsk Hydro on the hydrogen map, action and participation in the ECTOS project also linked Hydro to activities in the EU. ECTOS was the "sister" project to the EU-supported CUTE project[86] also oriented toward the use of hydrogen in transportation. The CUTE project was the first trans-European demonstration project on hydrogen of this size to demonstrate the use of hydrogen as a fuel for the transport sector. Finally, CUTE subsequently became the flagship project of the European Hydrogen and Fuel Cell Technology Platform[87], and was recognised at a global level by the International Partnership for the Hydrogen Economy (IPHE)[88].

As in the ECTOS project on Iceland, DaimlerChrysler was a central initiator and driver of the CUTE project. Due to the joint ownership on Iceland, and since Norsk Hydro pioneers had worked with DaimlerChrysler on several projects; hydrogen pioneers mobilised for Oslo to become one of the nine CUTE cities when the project was in its preparation phase in the spring of year 2000. The effort to become a CUTE city was still at a time where hydrogen energy was not a part of any formal hydrogen energy business in the Norsk Hydro divisions (e.g. Hydro Energy[89]); hence it was

---

[85] Vice Chairman of the committee of Managing Directors Royal Dutch / Shell Group of Companies (CEO of Royal Dutch Shell in 2005)

[86]CUTE (short for Clean Urban Transport for Europe) was a European Union project to develop and test three Citaro fuel cell buses each in nine cities in Europe (Amsterdam, Barcelona, Hamburg, London, Luxembourg, Madrid, Oporto, Stockholm, Stuttgart). The aim of the project was to demonstrate the feasibility of an innovative, highly energy-efficient, clean urban public transport system. The CUTE project started in November 2001 and continued until May 2006. During the first two years of the project, the busses were built and hydrogen supply chains in the nine cities were developed and commissioned. The operation phase officially started in November 2003. The actual CUTE trial ran from 2003-2005. Projects have since been continued under HyFleet Cute. The HyFleet CUTE project was to comprise the continued operation of the fuel cell buss fleet from the CUTE and ECTOS projects, the development and demonstration of a new FC hybrid pre-prototype and the development, construction and demonstration of a fleet of 14 hydrogen powered internal combustion engine (ICE) buses in regular service in Berlin including the required hydrogen infrastructure. It will be a part of the European Hydrogen & Fuel Cell platform.

[87] https://www.hfpeurope.org

[88] http://www.iphe.net IPHE Technical Achievement Award went to CUTE & ECTOS in 2005.

[89] Hydro Energy, the Energy Division in Norsk Hydro ASA later called Markets in Hydro's Oil and Energy sector.

difficult to commit to extensive funding. Hydrogen energy activities were still organised as corporate research so to become a CUTE city was a difficult decision to make, especially since the Director of Corporate Research (DCR) expressed the key belief that research and development activity had to be embedded in a business division to be moved along to commercial business. By May 2000, and in spite of the lack of formal organisation, the hydrogen pioneer (EFH) had the support of the DCR to work for Oslo to become one of the CUTE cities. However, Stockholm as an EU member city had been chosen instead.

Source: Norsk Hydro - Norsk Hydro Electrolysers supplied the hydrogen producing electrolyser technology at the Hamburg fuelling station

Nevertheless, action and electrolyser development undertaken by NHEL in partnership with German companies made a connection with the CUTE project from the spring of 2001. NHEL signed a contract with Hamburgische Electricitäts-Werke AG (HEW) as HEW was part of the CUTE city project in Hamburg, where a filling station was to be delivered fully assembled by April 2003. The coupling with HEW was facilitated by the co-ownership in the German company GHW[90], an electrolyser developer in which NHEL had purchased a share in 1998.

Norsk Hydro Electrolysers ended up delivering the complete hydrogen fuelling solution. NHEL's delivery to Hamburg became a sister plant to the one on Iceland feeding experience into the development lines of infrastructure for future hydrogen projects. By virtue of the extensive and historical experience in producing, using and handling hydrogen, Hydro research also built an expert role in the CUTE project with Hydro as a Task Force Safety and Security leader[91] making Hydro's industrial expertise available to establish working methods to provide the basis for a standard for safe hydrogen filling stations. Work was completed to develop a recommended quality and safety methodology and guidelines used when establishing future hydrogen fuelling stations[92].

[90] Gesellschaft für Hochleistungselektrolyseure zur Wasserstofferzeugung mbH" (Company for High Performance Electrolysers for the Generation of Hydrogen) in short GHW.
[91] Anne Marit Hansen, Hydro Business Development.
[92] (CUTE project deliverable # 3 published 23.3.06).

Hydro also subsequently became one of the industrial project partners[93] in the German public-private partnership: *Clean Energy Partnership* in Berlin (CEP Berlin[94]) formed in 2002, and with DaimlerChrysler once again being a central partner. The objective of the CEP demonstration project was to prove the reliability of hydrogen in everyday mobile operation and to ascertain aspects of customer acceptance. Hydro in partnership with GHW was profiled as a participant in German efforts with a leading role in the development of infrastructure and technology for a future-oriented project of pan-European significance. Hydro involvement was made possible by the ownership in GHW and Hydro delivered gaseous hydrogen to 14 of the 17 vehicles in the project produced by means of water electrolysis and renewable power (certified green electricity supplied by Vattenfall Europe).

A common denominator for the involvement in European research and demonstration projects was the linkage to Norsk Hydro Electrolyser technology, and Hydro's industrial experience in handling hydrogen. This combination was used as the door opener and offering with which to position the organisation in the emerging research and demonstration market. Activities in research projects involved efforts to relate electrolyser technology to hydrogen as an energy carrier through involvement in new settings. Actual development activity involved demonstration of on-site production where hydrogen was produced locally by using existing infrastructure of water and power, and without any transportation of fuel. With the CEP Berlin project, there was also an aim of enhancing cost efficient hydrogen production by remote control of the electrolyser from Rjukan in Norway, so as to run the electrolyser when low energy prices were available. Overall, Hydro research efforts made a contribution towards the development and integration of hydrogen energy infrastructure.

---

[93] Since the set up of the project in 2002, Volkswagen has entered the project BP/Aral, Shell, TOTAL.

[94] The Clean Energy Partnership (CEP) was formed in June 2002 by the partners Aral, BMW, Berliner Verkehrsbetriebe (Berlin Public Transport BVG), Daimler, Ford, GM/Opel, Hydro (StatoilHydro since Oct. 2007), Linde and Vattenfall Europe with support from the German government (Sustainable Energy Strategy for Germany) in combination investing a total of 33 million Euros. This cooperation is one of the largest European Projects on the road to sustainable mobility in the future with technological innovations and their implementation within a public-private partnership. The demonstration project was inaugurated and formally launched in November 2004 and will run at least until December 2007. In the CEP project, the participating automakers are to operate a test fleet consisting of passengers cars featuring hydrogen technology that are made available to customers that will operate them under everyday conditions. The automakers introduce different technologies some relying on gaseous hydrogen and others on liquid hydrogen. The fuels are made available at ordinary gasoline stations in Berlin. At a TOTAL station, liquid hydrogen is produced by Linde and delivered in tank vehicles in the form of a refrigerated liquid (opened in March 2006). At the Aral station, gaseous hydrogen is generated on-site with an electrolyzer at the station producing hydrogen on site since 2004).

4.4.2.3 *Other pioneering hydrogen research*

Other pioneering hydrogen energy projects initiated under corporate research was participation in HyNet[95] established in mid-1999, which brought together leading companies from a broad spectrum of industries and technologies. Norsk Hydro was one among 12 companies in the Core Group[96] and there were additional 30-35 companies as network participants. HyNet was funded by the Fifth Framework Programme of the EC (1998-2002 under DG Research). The objective was to initiate consensus on a vision and roadmap to build European hydrogen energy infrastructure. The more practical aspect was to propose large demonstration activities and joint projects to respond to the interest of the Commission in bundling European efforts on hydrogen energy, and to offer a joint industry position to the EU as a platform for a consensus process. The HyNet project also had a mandate from the European Commission to assist in the definition of EU's Hydrogen R&D strategy and to provide input for the High Level Group (HLG) on hydrogen and fuel cells, which was to be established subsequently[97]. A central part of the HyNet project was also to look at infrastructure synergy potential. Hence although the initial focus was hydrogen as a vehicle fuel, the project was also meant to focus on stationary use including hydrogen in

---

95 HyNet: European Thematic Network on Hydrogen Energy www.HyNet.info. The project established 5 Thematic Working Groups on: Hydrogen production and infrastructure; hydrogen applications; hydrogen safety; political and socio-economic issues; dissemination and communication. Many of the HyNet activities subsequently continued under the European Hydrogen and Fuel Cell Technology Platform and within the scope of the HyWays Project (to develop a European Hydrogen energy Roadmap in cooperation between industry and the European Commission, and to investigate the techno- and socioeconomic conditions for introducing hydrogen as a future energy carrier and fuel). HyWays, a project started in April 2004 is co-funded by institutes, industry and by the 6th Framework Programme of the EC. The partners of HyWays use the input from the High level Group on Hydrogen and Fuel Cells (HLG) and the HyNet Roadmap as a "starting vector".

96 HyNet was established, as part of European Commission's Framework Programme 5, to create a network of key European stakeholders that could provide input to high-level strategic discussion on the introduction of hydrogen energy. Core Group: NorskHydro, Shell Hydrogen, BP, Air Products, ICI, Dera, BMW, TotalFinaElf, EniAgip, Hydrogen Systems, EtaIng, CEFIC.

97 The High Level Group (HLG) was initiated by the European Commission with the objective to create a basis for focused and efficient R&D activities as well as commercialisation strategies. The HLG had balanced participation of 19 large and small/medium industrial enterprises and research institutions. It was launched in October 2002 by DG Energy and Transport, Loyola De Palacio (the Vice President of the European Commission and Commissioner for energy and transport from 1999), and Research Commissioner Philippe Busquin. Norsk Hydro's Tore Torvund, Executive Vice President of Norsk Hydro oil and energy was one of the 19 members in the HLG. http://ec.europa.eu/research/energy/pdf/hlg_vision_report_en.pdf,
http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_hlg/article_1146_en.htm

combination with renewable energy systems. The EU arena[98] was considered to be an important network for system analysis, infrastructure modelling, roadmap projects, and for watching technologies. Participation in research activities formed the informational basis for decisions in industry as well as in politics. Finally, action and efforts in the EU arena made it possible to assess entrepreneurial activity in the emerging hydrogen demonstration market.

4.4.3 Relevance and reasoning behind early initiatives in research

As illustrated in the two pathway sections, one point of departure and prime motivation for the internal hydrogen research project was the concern for the value of the portfolio of fossil fuel resources in a world with climate change mitigation and obligations to decarbonise fuels. Another point of departure for pioneering hydrogen research and demonstration projects was related to NHEL efforts to remain a leading player in water electrolysis. To pioneers working in corporate research, it made sense to sustain water electrolysis as a connection to the pursuit of hydrogen in energy markets. Research projects were supported as part of the 'mission' to envision, make approximations and create the best possible depiction and conception of future development:
«Participating in demonstration projects is an inexpensive way to develop a platform and a backdrop of understanding on which to base your own intentions and meaning and how to set a course of action business wise»

Hence pioneering hydrogen energy as part of research was an approach to "invest a little to learn a lot", which meant to invest small amounts in the early days to build, test and shape ideas from which a possible new venture could be developed. The transportation related projects were relevant to get a real world validation of components and systems, real world safety records, real world feasibility and performance from hydrogen use, which were all inputs to the process of building a value proposition for hydrogen energy.

Participation in demonstration projects, the design and construction, of hydrogen solutions were in turn part of what made these future solutions possible. Participation is research was part of the conception and creation of the future as experience and results became building blocks for further development, and were part of what proved hydrogen solutions possible. Activities fed into the formulation of a value proposition for hydrogen energy, the portrayal of potential and the role of particular technologies e.g. the electrolyser technology as part of a fuelling station, a future energy design with onsite production, and hydrogen energy as a remedy for

---

[98] Through the European Economic Area (EEA) agreement, Norway participated as a full member in the EU's framework programmes for research, technological development and demonstration activities.

problems with the current energy system like fossil fuel trafficking and energy import dependence.

Research actions aimed at demonstrating sustainable alternatives, and the outcome of the research and demonstration projects was a bid on a potential future that by itself became a resource and building block for continued activity. In the research context, project participation and partnerships aspired to involve some kind of situation analysis to get a picture of what the world looked like and what was likely to happen in the future. They were part of gaining access to keep an eye on new development, monitor progress, courses of action such as fuel cell development, possible breakthroughs and reduction in costs. Situation analysis was meant to find out how trends and development could affect existing resources and business. Research activities were to contribute to the overall objective to position Hydro with products and technologies that created value in the future. Research project participation and partnerships were also ways to shape the future and play a leadership role in energy system development as a path creator to drive hydrogen energy development in a strategic direction of Hydro's hydrogen pioneers own devising. Finally, project participation and partnerships were conceived as ways to invest sufficiently to stay in the game and reserve the right to play[99].

4.4.4 The doings of others and the importance of being hands on

Trying to predict the future was at the time (and always is) a speculative undertaking, so getting insight into what others were doing and what others believed to be likely future development was important. Information about other technology fields and enabling technology was equally important:

«When we look to hydrogen then it is what the developers of fuel cell technology think, which is important. This is the Alpha and Omega. We can supply hydrogen at a reasonable price. We look into how we can develop infrastructure and distribution; but the most critical is also to get customers and end users, that equipment is developed so that we may use hydrogen, that is an important thing to us. So again, the importance of demonstration projects where we get to be hands on»

Shell and BP were inspirational energy companies that worked with new energy systems. It was planners of Royal Dutch/Shell and their scenario projects[100] that identified a likely breakthrough in fuel cell technology, which

---

[99] See Courtney et al (1997)'s discussion of strategic postures and action under uncertainty.

[100] Shell's long-term energy scenarios go to 2050. In 1995, scenarios looked at ways to stabilize CO2 concentrations in the atmosphere, through increases in energy efficiency and aggressive increases in renewable energy. The scenarios lead Shell to invest half a billion dollars in its new core renewable energy business and to launch Shell Hydrogen. Six years later in 2001, Shell produced new and different scenarios, which highlighted the potential role

was foreseen to have a triggering effect on the use of hydrogen in energy markets and hence hydrogen market creation. This in turn caused Shell to launch hydrogen activities. BP[101] took similar steps and in parallel both companies were involved in solar energy.

Wishing to be a part of future energy markets, positioning in relation to multiple development trends was necessary. It was not clear what shares the different forms of energy would realize in future markets, but the point was that when or more importantly *if* a market with hydrogen as an energy carrier emerges, Hydro had to be prepared. Early involvement in hydrogen energy was argued to make sense for several reasons. *For one*, to be able to consider and monitor ideas, development and possible trigger events; *secondly*, to get real life experience on performance and validation of hydrogen solutions; and *thirdly*, because subsidies and government support made it relevant for business to get involved and build resources so as to be in position and be a recognised player when and if hydrogen really took off.

A final argument for getting involved in research, development and demonstration was that new energy systems were risky businesses. Replacing existing gasoline infrastructure was mentioned to illustrate uncertainty and enormous costs. Hydrogen infrastructure would be driven by the location of hydrogen production and in what form hydrogen would be stored on board hydrogen vehicles. To avoid stranded investments, building new transportation infrastructure was mentioned as something that should preferably not be done too often:

«*It is clear that this is the big challenge for energy companies. An energy system has incredible large start-up and massive infrastructure costs, just look at the chain of gas stations if you have to replace this with a new distribution system of energy. Replacing infrastructure is a giant investment and that is why this needs to be thoroughly worked through so that it is done only once, into THE future system. You cannot go several rounds. Costs are so enormous and this is why it is necessary to be part of development and demonstration projects. Another reason to be part of development and demonstrations is that we need a license to operate and this means that to have credibility in the eyes and minds of authorities, politicians and the public, we need to be an active participant in handling the challenges and problems with our present energy system*»

---

of hydrogen and renewable energy in reducing greenhouse gas emissions (Romm 2005:134-140).

[101] In 1997, Sir John Browne, chief executive officer of British Petroleum said, “The time to consider the policy dimensions of climate change is not when the link between greenhouse gases and climate change is conclusively proven but when the possibility cannot be discounted and is taken seriously by the society of which we are part. We in BP have reached that point.” BP started a voluntarily reduction of its emission towards 10 % below 1990 levels and expanded its photovoltaic company, BP Solar, and launched major efforts to produce hydrogen (Romm 2005:134).

4.4.5 Top management orientation and involvement in hydrogen

Working actively with environmental challenges was multifaceted. The former Director of Corporate Research (DCR) mentioned Hydro's participation in the World Business Council for Sustainable Development (WBCSD), an industry arena profiling "the business case for sustainable development", and an expert arena also with an eye to the consideration of opportunities as well as threats.

The purpose of participation in industry arenas such as the WBCSD was multifaceted. Building credibility in relation to important stakeholders; to look at development and get status on state of the art technology development e.g. for mobility and fuel cells and prospects for mass production, cost reduction, the competitiveness of different technologies; looking into opportunities for light metal / aluminium e.g. with car manufacturers and in light hydrogen vehicle production. In general this was an arena for considering how sustainability issues and environmental challenges would influence existing businesses.

Hydro's CEO Myklebust[102] was the chairman of the WBCSD in 1998-1999, and the attention of the CEO to new energy and environmental challenges, set a general direction for the organisation and focus on particular endeavours. The issues being debated in international arenas, like the WBCSD, was said to heighten internal focus and efforts to get involved in new energy projects. Further, the media profile and attention was mentioned to be high when the CEO fronted projects:

The former Chief Executive Officer in Hydro (Myklebust until May 2001) was mentioned to have had a constructive influence on hydrogen initiation with ideas that allowed pioneers to pursue their work. Hence with top management priorities and supportiveness, new energy issues and hydrogen projects gained relevance.

«*It is important that top management has an open mind and demands certain directions and endeavours. The organisation delivers what is being demanded, so whatever is in focus amongst management is part of what will be delivered by the organisation*»

The uncertain timeline in the possible transition to hydrogen energy, however, was indicated to require Hydro to take stock and have regular evaluations of commitment:

«*The hydrogen area has had a slower development than expected. It has taken longer time e.g. the break through for fuel cells has taken longer than we thought and hoped. So that is why it is necessary to adjust the hydrogen*

[102] Egil Myklebust Norsk Hydro Chief Executive Officer from 1991-2001. Chairman of the Board from 2001-04.

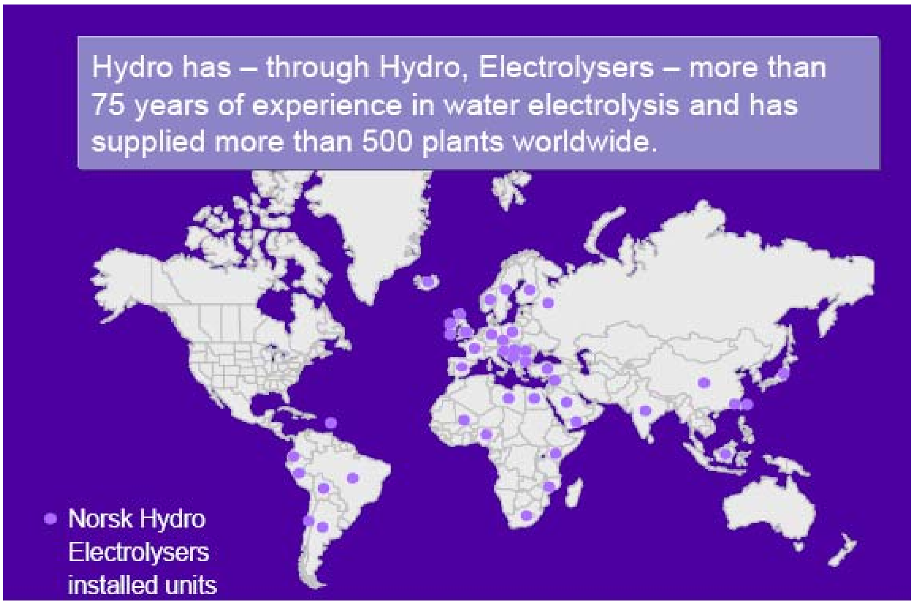
venture and range of activity to face facts and reality. But this is how it is when it comes to development. You try, fail, adapt and adjust, as long as you keep it going»

Top management's assessment and the importance of issues (e.g. the significance and connectedness between energy and environmental issues) had influenced and defined priorities, and thereby shaped action. Hence top management was mentioned as a strong motivator of research initiatives in hydrogen energy.

4.5 Pioneering hydrogen energy as a technology provider

4.5.1 A brief introduction to NHEL history

In the previous section looking into pioneering hydrogen energy as part of research; Norsk Hydro Electrolyser (NHEL) was mentioned several times when initiating and participating in research activity. In section 4.3, I also mentioned that the manager of the New Energy Unit (Rostrup) in 2003 stated that Hydro's hydrogen efforts in energy markets had their point of departure in three areas of expertise in Hydro, one of them being Norsk Hydro Electrolysers (NHEL) located at Notodden. As a supplier of water electrolysis equipment, NHEL had supplied some 500 hydrogen generation units throughout the world.



Source: Mostad presentation (2006)

However, water electrolysis had a diminished role in chemical fertilizer production in the Agri business division. It had been exchanged with petrochemical-based ammonia production where hydrogen gas was produced from natural gas steam reforming since the late 1980s (Rasten 2003)[103]. Consequently, NHEL was increasingly dependent on the industrial market, and since the 1980s, external industrial customers[104] had become increasingly important. The expertise in technology research and development located at Notodden was sustained by selling services and technology to other purposes and applications in an international market (Andersen et al 1997).

NHEL's main purpose was to develop, produce and deliver large water electrolysis equipment and complete hydrogen generation units for industrial applications. The traditional product line was relative large somewhat lumpy apparatuses placed in large industrial spaces where size did not matter. Focus was on splitting water into its components with the least energy use possible. Yet having only one product outlet - selling electrolysis equipment for hydrogen production to industrial applications and purposes – made NHEL vulnerable to market fluctuations. Selling electrolyser equipment to industrial markets was selling proven technology and equipment with a long life and durability (electrolysers were marketed with a useful life of 30 – 40 years provided that the maintenance schedule was followed). It was a small market and customers did not come running after 3 years saying they wanted another one; comparable market situation to a shipbuilding yard, where you either get the job building the ship or you do not.

In 1993, NHEL became a stock company as part of a larger restructuring process[105]. NHEL was established to sustain the competence in

[103] Almost all of the 40 million tons of hydrogen used worldwide came from natural gas though a process called natural gas steam reforming. Natural gas is made to react with steam, producing hydrogen and carbon dioxide. Why natural gas takes such a large share is related to the fact that natural gas has traditionally been priced low and electricity high in most countries which makes electrolysis more expensive as the use of energy is a central cost component. In water electrolysis as a rule of thumb approximately 2/3 of operational costs are from the use of energy (Kruse et al 2002). In the future however a main challenge for natural gas based hydrogen production is cost-effective handling of CO2. Only about 4 percent of hydrogen gas production worldwide was produced by water electrolysis to costumers demanding the purest commercially available grade of hydrogen.

[104] Hydrogen is used in ammonia manufacture for fertilizer production, in refineries in the refining of petroleum, as a coolant in large electricity generators, in the production of hydrocarbons from coal, and in the chemical, metals industries and food industries for the hardening of vegetable or animal oils (i.e. to convert them into saturated fats which are solids). http://fuelcellsworks.com/JustthebasicsonHydrogen.html.

[105] In 1991 CEO Egil Myklebust took over. A main organisational initiative was Hydro Pluss from 1993 with focus on efficiency enhancements - Hydro 2000 - initiated in the latter part of the 1980s. Attention was directed at traditional areas; Norsk Hydro was to do what it does

electrolysis owned by Hydro. At the time, the company was in serious crisis as the internal sales of electrolysis equipment had withered away. Managing director Christopher Kloed[106] started to work at Notodden in 1993. Kloed came to NHEL to help get the company back on track. NHEL was in crisis, the market was dry, and the organisation needed a tune up. Kloed recalled that he was not brought to NHEL to be creative and innovative but to make money; that is to focus on the existing business and products in the industrial markets. NHEL was in a "back against the wall" situation as there was little interest in this area of business in the Norsk Hydro organisation at large. Kloed stated that they were given one year to turn the business around otherwise NHEL's fate in the Hydro organisation would be uncertain.

The fragile position of NHEL may be reflected in NHEL's position in the Hydro organisation, where it was shuffled around during the 1990s. When Kloed started in NHEL, it was an activity under the 'Other' business umbrella. Since NHEL was located at Notodden, it was geographically a part of Hydro Telemark, the assembly of the industrial parks in Telemark (Notodden, Rjukan, Porsgrunn), linked to management of Hydro Telemark and Hydro Service[107] and manager Jan Løkling in particular. That NHEL became subordinated to this management was very context specific since Løkling at the time was chairman of the board in NHEL, and at the time NHEL was established in 1993, there was no obvious place for or interest from other parts of the Hydro organisation.

In the late 1990s, with the planning of the establishment of Hydro Business Partner, there was a renewed discussion about a suitable position for NHEL. This was after NHEL's closer cooperation and linkage to corporate research, and with assistance from the Director Corporate of Research (section 4.4), it was decided that NHEL should be part of Hydro

---

best. Strengthen core competence as the agricultural-, light metal and petrochemical business segments were embellished with optimism (Andersen et al 1997; 297).

[106]Kloed was the President/ Managing Director of Norsk Hydro Electrolysers AS for 11 years (1993 through August 2004). Some of his merits mentioned by hydrogen colleagues and others in the Norwegian hydrogen milieu are that Kloed has been central in putting hydrogen for energy markets on the industrial and public agenda in Norway. He was a central driver behind the establishment of the Norwegian Hydrogen Forum in 1996, a central figure in advocating the use of hydrogen in transportation launching a forerunner project to the national project HyNor, and he was the early idea pioneer and project initiator on the Utsira project in Hydro.

[107] Hydro Service administrating joint activities, service and support functions, is later turned into Hydro Business Partners. Hydro Business Partner was established in 2000 as Hydro's internal, commercial supplier of support and services. Hydro Business Partner delivers services in the following product areas: IT/IS, maintenance and refractory work, offshore, accounting, office and HR administration and communication. Hydro Business Partners was previously referred to as Hydro Service under which the administration and management of the three industry parks in Telemark, Hydro Telemark (Notodden, Rjukan, Porsgrunn) was also located. Since NHEL was located at Notodden it ends up in 'Others' together with three other Hydro companies that were established at Notodden in 1993.

Pronova. Like research, Hydro Pronova was a corporate function under the business category 'Other Activities'. Pronova was Hydro's corporate entrepreneurship vehicle trying to develop the non-core operations[108]. Hence although electrolyser production was an old historical activity, the crisis and precarious situation with fluctuating demand, meant that the electrolyser activity got shuffled around. With new and hitherto unknown ventures, a company through trial and error usually come to a suitable form of organising. In a time of transition and crisis, the same was the case with NHEL aspiring to renew the association with the Hydro organisation[109].

When NHEL became a stock company in 1993, a period followed with layoffs and down sizing and surviving the one year given to turn the business around. Yet being against star spangling the role of managers in general, and to avoid accrediting his own management efforts too much glory, then managing director Kloed, indicated that he had good people working with him, and that they were quite lucky in terms of market cycles and temporary fluctuation in the beginning of his time with NHEL. From 1993 – 1998 there was an upward trend in demand, orders were coming and annual reports showed that NHEL ran at a profit[110].

4.5.2 Vision building and orientation towards hydrogen energy

After having "its back against the wall", and surviving the initial year to turn around business, NHEL in a way was allowed to live its own life with decisions and discussions among management and the board without interference from Hydro at large. Due to the fluctuations in the market with industrial applications, then managing director (Kloed) became increasingly oriented towards "not having all your eggs in one basket", and the

---

[108] Pronova's main task was to take care of the diversity of ideas developed in Hydro, to provide the necessary help at the inception stage, and to develop defined projects for commercialising. In the annual report from year 2000, it is indicated that Pronova is Hydro's incubator for projects and activities at the periphery of the company's core business areas with the mission to develop businesses. In Norsk Hydro Annual Report (2000:26), 12 activities were listed there among electrolysers for the production of hydrogen.

[109] From Pronova, it is not until the end of 2001 that a decision is made to integrate NHEL into the Hydrogen Unit in the Hydro Energy business division.

[110] This was followed by a downward trend from 1998 to about 2003.The downward trend was already anticipated in the annual report from 1998. Annual reports from 1999-2002 show deficits; in the 1999 report, it is explained by unrest in the world economy in 1997-98 that hit hard and made an impact in terms of fewer orders in 1998/99. In the reports from 2000 – 2002 it is indicated that the company is extremely dependent on exports to distant markets and that the industrial markets are showing little or no signs of growth: they are experiencing price pressure in the industrial market; a weak order reserve and that fear of war in the Middle East push purchasing decisions out in time. Participation, preparation and work up on new applications and uses for hydrogen are mentioned in the annual report from 1999 and development costs are mentioned from 2001 and 2002. In the 2002 report it is mentioned that the development costs are part of a long term strategy agreed between NHEL and Hydro Energy. Annual Accounts from 1999-2002 Brønnøysundregistrene, http://www.brreg.no

importance of finding new market segments or applications for NHEL technology. By the end of 1994, they started paying attention and looking outward and started to notice that hydrogen was of interest to others than the traditional industrial users.

There were talks, development initiatives and visions about fuel cells and fuel cell cars. These inputs originated from development activities and projections from car manufacturers; hydrogen associations, the hydrogen programmes and R&D initiatives in several countries e.g. the US, Japan, Germany, and Canada; and the activities of competitors in the 1990s that started to pursue hydrogen energy with electrolytic hydrogen production on site[111]. Competitors were on the move signalling efforts to advance water electrolysis and hydrogen generation equipment in energy markets.

The main motivation for exploratory activity was to seek new activities so as to stabilize demand. When hearing about hydrogen as an energy carrier used as a fuel or in stationary energy production, Kloed started taking an interest, looking for opportunities, read more, attend conferences and seminars, and having points of contacts with environmental groups around the world, so as to learn more about energy system visions in which hydrogen was projected to be a part. In the 1990s, limited energy-related hydrogen initiatives were on the way in Norway. Hence international milieus and government agency backed initiatives in other countries were by far the most important forums for information, surveying the situation and to create a broad outlook on a probable future for hydrogen as an energy carrier.

Ideas and visions matured by having a large circle of acquaintances or points of contact as it related to technology, research, politics, and interest

[111] As to competitors, the key competitor in water electrolysis technology over the 1990s was Canadian Eletrolyser Corporation that founded Stuart Energy Systems Corporation in 1997, a company dedicated to the supply of hydrogen for energy use and hydrogen infrastructure solutions. Their focus was to approach the energy market through electrolytic hydrogen energy stations, and the company pioneered the design of hydrogen filling stations using on-site hydrogen production systems. From the end of the 1990s, the Belgium-based Vandenborre Technologies also entered the stage to manufacture and sell hydrogen generation systems based on advanced alkaline water electrolysis. Vandenborre also worked to development on-site water electrolysis hydrogen generation equipment for energy systems. Vandenborre was acquired by Stuart Energy in 2003 and became Stuart Energy Europe. Canadian Hydrogenics, a global developer of clean energy solutions working to commercialize hydrogen and fuel cell products purchased Stuart Energy in 2005; and Teledyne Energy Systems, a subsidiary of Teledyne Technologies Incorporated, was active on technology solutions for electrolysis and PEM fuel cell systems and worked with the US Department of Energy on high efficiency PEM fuel cell power systems. Another US Technology company Proton Energy Systems (later Distributed Energy Systems) also initiated research and development in proton exchange membrane (PEM) electrolysis technology and worked on electrolysis-based hydrogen fuelling stations for automobiles and other mobile applications. Proton Energy worked from the basis of the PEM electrolysis concept developed by General Electric in the early 1990s.

groups. Hydrogen had advocates in multiple circles in the US in national laboratories under the Department of Energy, Europe, Canada and Japan; and hydrogen advocates had their point of departure in major environmental policy controversies. Environmental challenges like urban air pollution, greenhouse gasses, and dependence on finite conventional fossil fuels. Concerns over security of supply and dependence on geopolitics in fossil fuel regions, the vulnerability and many choke points in central production and distribution systems (pipelines, refineries, transit routes, and terminals) making them easy targets for e.g. terrorist attacks. Hence from this information, the managing director (Kloed) as the initial pioneer, started to build visions that related to a probable future with hydrogen as an energy carrier. Hydrogen energy and hydrogen technology were envisioned as means to handle the before mentioned concerns, as well as to enable a more decentral, independent and local supply of energy.

Looking outward and having a large circle of acquaintances allowed the manager to get in touch with ideas and establish a sense of direction in terms of technological development, and possible hydrogen applications. The manager participated in conferences, meetings and seminars where hydrogen as an energy carrier was in a process of being defined by politicians, researchers, economic agents, industry representatives, and engineers.

4.5.2.1 From crisis to exploration

NHEL's managing director managed to convince his immediate management, (Jan Løkling in Hydro Service/Hydro Telemark and at the time also the chairman on the NHEL board 1994 – 1999) that hydrogen as an energy carrier was possibly relevant and interesting for NHEL activities. This was the internal sales pitch since management was mostly concerned with the existing product line and the traditional market outlets. Kloed was also of the impression that his advocacy of applications for hydrogen in energy markets was considered too vague. Further, if initiating new activities toward hydrogen in energy markets, the company would become somewhat schizophrenic. On the one hand, there would be NHEL's traditional market as the lifeblood and means of support of the company. On the other hand, NHEL would have to relate to a new sphere with multiple initiatives and abundant directions, which would require attention, attendance and most importantly, decisions as to how to respond.

Although the details of a transition to hydrogen energy were neither clear nor available, Kloed was entrusted and given the opportunity to initiate new things. It was agreed with the support of the Board that Kloed, as the managing director, should devote parts of his time to orientation (conceiving and configuring information and ideas on technological development, applications and markets) so as to create a scope of action and an option for the future. Other than that, the NHEL organisation was to be shielded to concentrate on existing activities and markets.

4.5.2.2 Relevance building in society

NHEL's managing director was an early pioneer in the effort to mobilise interest for hydrogen as an energy carrier not just within the company but also with a broader scope in Norway. Kloed and pioneers working in research made Hydro a vocal industrial actor according to the chairman of the Norwegian Hydrogen Council, researcher Steffen Møller-Holst[112]. Møller-Holst indicated that Hydro representatives[113], since the middle and latter part of the 1990s, were the most outspoken and visible Norwegian company on hydrogen energy. Hydro had visionary personalities that advocated hydrogen energy in a very pronounced manner even though this was not core business for Hydro. Over the years, the names of the people changed but Hydro representatives took the lead in putting hydrogen as an energy carrier on the industrial and political agenda. Further, there were Hydro representatives dedicated to work e.g. in the Norwegian Hydrogen Forum or on expert committees and work groups constituted by the Norwegian government to publish Norwegian Official Reports.

Pushing and mobilising the industrial and national attention[114] in parallel with pushing initiatives internally in NHEL and research, there were pioneers marking Hydro's involvement in hydrogen energy. Møller-Holst recalled that in the late 1990s, Hydro's director of corporate Research (Bjørn Sund see section 4.4) played an important role in putting hydrogen on the map and was an inspirational source to the Norwegian research milieus. As an illustration of national agenda and relevance building activities, Kloed with NHEL, together with University of Agder (then Høyskolen in Agder) and representatives from Institute for Energy Technology (IFE) in hydrogen

[112] Steffen Møller-Holst has worked with hydrogen since the early 1990s working on his doctoral thesis on fuel cells at NTNU from 1990-1996. He worked at Los Alamos from 1997 through 1999 and was part of their publication *Fuel Cells Green Power.* He is the research manager at SINTEF Materials and Chemistry and since 2005 he has been the chairman on the Norwegian Hydrogen Council that guides the research, development and demonstration activities of the Norwegian Hydrogen platform www.hydrogenplattformen.no . Recent Council's activity chaired by Møller-Holst concerns the mandate to develop and provide input to an action plan for the work of the Hydrogen platform. The Action Plan was presented December 2006, and makes recommendations for activities between 2007-2010.

[113] Christoffer Kloed, Elisabeth Fjermestad Hagen, Elisabeth Baumann Ofstad, Bjørn Arne Sund, Helle Britt Mostad, Ulf Hafseld are some of the people mentioned by Steffen Møller-Holst.

[114] The public and political attention that started to materialise in 2003/2004 was triggered by the early industrial initiatives in the hydrogen area. Norwegian authorities for long adopted a sort of 'sitting on the fence' attitude waiting 10 plus years after other national governments started to dedicate funding to the hydrogen area.

research established the Norwegian Hydrogen Forum in 1996[115]. The main motivation was to bring industry, environmental organisations and research institutes together to discuss hydrogen in relation to government and authorities. Kloed was the first President of the Hydrogen Forum, and recalled that the attention it got from diverse parties and the joining by energy companies and research institutes (Statoil, Statkraft, Agder Energi, Lyse Energi, Sintef, NTNU, Institute for Energy Technology (IFE), Grimstad's National Centre for Renewable Energy (Energiparken) and other research milieus) provided a renewed impetus since it indicated that they were interested in hydrogen. In turn this strengthened the belief among NHEL and Hydro's hydrogen pioneers that there indeed was something to the vision of hydrogen as a future energy carrier.

4.5.3 New applications considered by NHEL

Early NHEL initiatives were motivated by the prospect and belief that new applications, associated with hydrogen in energy markets, could lead to deliveries of hydrogen production equipment from NHEL. Different paths were envisioned in stationary energy and in transportation.

4.5.3.1 Stationary energy system applications

As hydrogen re-emerged as a future energy contender and low carbon energy solution[116], the modern idea[117] for stationary energy systems combined

---

[115] Norwegian Hydrogen Forum (NHF) was founded in 1996. NHF is a non-profit organization to promote the advantages of hydrogen as an energy carrier. The members come from Norwegian industry, universities, research institutes and other organisations interested in hydrogen. The forum is to distribute information on Hydrogen in Norway Seminars and workshops; publish a newsletter; and encourage and stimulate R&D on hydrogen technology.

[116] The 1980s were described (Appendix I) as a decade where interest waned, until environmental challenges spurred by global environmental deterioration such as acid rain, ozone layer depletion, and the threat of irreversible climate change re-entered the energy debate since the late part of the 1980s. The climate conventions in the 1990s and the emissions reduction negotiations in Kyoto (1997) generated a renewed focus on greenhouse gas emitting activities, which in turn established a new rationale for hydrogen as an energy carrier spurring research and development activities.

[117] Experiments with hydrogen dates back centuries. In 1766, hydrogen was first identified as a distinct element. In 1800, English scientists William Nicholson and Sir Anthony Carlisle discovered the ability of electrolytical water splitting that is applying electric current to water produced hydrogen and oxygen gases. This process was later termed "electrolysis." In 1839 the fuel cell effect, combining hydrogen and oxygen gases to produce water and an electric current, was discovered by Swiss chemist Christian Friedrich Schoenbein. In 1894 Danish scientist Poul LaCour worked with the idea to use the DC-electricity from his wind turbine to electrolyse water into hydrogen and oxygen, to store the two gases in big gas containers and use them for room lighting at Askov Folk Highschool (between 1895 to 1902). A central disadvantage of LaCour's plan was that he had to replace school windows several times due to hydrogen explosions when too much oxygen entered the hydrogen volume. http://www.windpower.org/da/pictures/lacour.htm

hydrogen with renewable energy sources in stand alone energy systems. This combination was advanced in articles in the International Journal of Hydrogen Energy. In 1994, an article reported on the German / Saudi HYSOLAR[118] project working with isolated electrical energy systems with photovoltaic and wind energy, and a system design including an electrolyser, hydrogen storage, and a fuel cell (Dienhart et al 1994). Hofmann et al (1998) wrote: “electrolysis is the important energy transformer in a world of sustainable energy… in order to balance supply and demand, for storage purposes and to meet the specific requirements of the different end users; we need powerful energy transformers in both directions – fuel cells and electrolysers”. The same article identified requirements (high efficiency, low cost, intermittent operation, large range of operation, immediate response control, and built-in safety) that an electrolyzer had to fulfil to be a powerful, simple, efficient and cheap energy transformer. The article also mentioned GHW[119] (Company for High Performance Electrolysers for the Generation of Hydrogen) with the development of a prototype of a pressurized alkaline electrolyzer to meet the demands of hydrogen production for the envisaged energy market. As already mentioned in the discussion of research, and I will come back to it again, NHEL purchased a share in GHW in august 1998.

The spring 1997 newsletter from the National Hydrogen Association (NHA) wrote about: “renewable, hydrogen based energy for isolated communities worldwide as the US Department of Energy had identified isolated communities as a viable site for demonstrating the practicality of integrated, renewable, hydrogen-based utility power systems” (Ramback et al. 1997). In the end of the 1990s, NHEL and managing director Kloed also got inspiration from the World Hydrogen Energy Conferences where system concepts were advanced with design variables in isolated renewable energy-hydrogen systems[120]. There was also a linkage of this type of system conception and developments in the EU. The White Paper *Energy for the future: Renewable sources of Energy* included a focus on the integration of renewable energy in 100 Communities. These communities were to be operated 100% by renewable energy with different sources and technologies,

[118] The HYSOLAR project was carried out by the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) and the University of Stuttgart in cooperation with three Saudi universities (King Saud University – Riyadh, King Abdulaziz University – Jeddah, King Fahad University of Petroleum and Minerals – Dharan) and the King Abdulaziz City for Science and Technology (KACST), Riyadh. Phase I of the program which started already in 1985/86 and which lasted until the end of 1989 had a total financial commitment of about 40 million DM, brought up by the Saudi and German partners http://www.hyweb.de/Wissen/autarke.htm

[119] Gesellschaft für Hochleistungselektrolyseure zur Wasserstofferzeugung mbH (Company for High Performance Electrolysers for the Generation of Hydrogen) in short GHW, a company owned by Linde AG, MTU-Friedrichshafen and HEW.

[120] Studies referenced in Energy Development 1999.

and with adaptation to local conditions at the specific locations to secure reliability and continuity (EU Commission 1997). Renewable islands were conceived as one type of pilot location suitable for the exploration of distributed renewable energy supply.

Hence, a new area of activity and application for hydrogen as an energy carrier involved ideas and system concepts for *stationary applications* with hydrogen used in combination with renewable energy. This combination was envisioned to replace diesel systems and batteries and be able to supply: a) communities / isolated areas without central station supply and distribution systems; b) islands without a sea cable connection to a mainland grid; c) islands at a time of investment in a sea cable replacement; or d) in developed energy supply systems as a grid balancing tool and a storage medium for variable renewable energy production.

The managing director in NHEL (Kloed) was the communicator and carrier of these ideas, and also the central project initiator of the Utsira project illustrating the stationary application. The idea, that after several years became the Utsira project, matured over time. As a system concept it was discussed in encounters with other organisations e.g. in the Norwegian Hydrogen Forum (NHF). On the NHF board there was representation from the Norwegian company, Energy Development AS[121], an early project inventor/ developer/idea generator. It was through the acquaintance and collaboration in NHF that Kloed was approached with the idea to a feasibility study on a wind - hydrogen system on a Norwegian island, Orten (outside Molde) in 1998. The proposed feasibility study would involve an imagined wind-hydrogen system on Orten and was part of the initial concretization of a renewable energy (wind) / hydrogen system. Equipment and components including hydrogen production estimates would be based on NHEL electrolyser technology.

Around the same time, an analysis was published on existing hydrogen activity, research, and opportunities in the "hydrogen society" for Norwegian industry. Several research communities participated in a 'hydrogen working group' (May 1999) exploring system analysis and the hydrogen chain (production, storage, transport and end use). Further, a

[121] Interview with Ove Christian Bugge, 20/5/2008. Energy Development is a project development firm founded in 1975 and specialising in energy project focusing on identification, facilitating and financing energy projects. Focusing on hydrogen energy projects, Energy Development AS worked toward individual firms trying to advance their project ideas both in the area of mobility that is hydrogen in transportation including hydrogen buses for the Greater Oslo Public Transportation Company (Stor-Oslo Lokaltrafikk AS) as well as hydrogen coupled renewable energy sources in stationary energy system. Studies on Norwegian islands were conducted on: Wind –hydrogen system on the island of Orten (1999), Wind-hydrogen system for Utsira Havstuer (2000), Feasibility study: wind-hydrogen system on the island of Røst (2001), and a Wind – Hydrogen system on the Faroe Island (2003).

national opportunity study was carried out from November 1999 through April 2000 on hydrogen as a future energy carrier (Norwegian Research Council 2000). The opportunity study (Kvamsdal et al. 2000) concluded that Norway had special conditions for industry development related to hydrogen as an energy carrier. This was related to Norway as a natural gas nation but also based on existing competence in industry and in the university – and research institutes in terms of hydrogen production from electrolysis[122].

Another initiative linked the research institute IFE[123] with Norsk Hydro Electrolyser. Over the 1990s, IFE carried out theoretical and practical research in the area of autonomous or stand-alone power systems (SAPS) with renewable energy sources (RES) and hydrogen technology[124]. IFE took part in the International Energy Agency's hydrogen programme (1999-2001)[125], where one case study used a wind park and an electrolyser-based hydrogen fuelling station as the basis for the modelling. The study explored the integration of wind energy in combination with hydrogen production on remote locations. Hydrogen was to be used in buses operating the public transport, and hydrogen was also conceived as an attractive alternative for the operation of ferries at a later stage. Kloed with NHEL was a contributing author on a paper written for the World Hydrogen Energy Conference in Montreal in 2002 (Glöckner R et al 2002).

Hence technical projects, system concepts as well as intrapreneurial ideas were conceived, generated and emerged through processes of interacting with others. Visions and ideas to the Utsira project (more details on the Utsira project in chapter 6) circulated since the early and middle part of the 1990s.

4.5.3.2 Mobility and transportation applications

Another area of application envisioned to potentially lead to deliveries of hydrogen production equipment from NHEL was within *mobility and transportation.* Hydrogen fuelling stations and hydrogen used to fuel zero emission fuel cells in hydrogen vehicles or with a possible transition via hydrogen used in an internal combustion engine.

[122] The purpose was to map research needs, existing research institute and university competence, industry and trade interests and possible technological and market areas to be prioritised in particular. The project was conducted in a joint effort between SINTEF (project manager), the Norwegian University of Science and Technology (NTNU), IFE (Institute for Energy Technology) and the University of Oslo (UiO). As part of the study a workshop was arranged with 100 Norwegian participants and foreign speakers from Germany, England and Iceland.

[123] IFE (Institute for Energy Technology)

[124] In 1999 joined the International Energy Agency Hydrogen Programme (IEA/H2) Annex 13 Design and optimization of integrated systems

[125] Annex 13 Design and Optimization of Integrated Systems. www.hydrogems.no

The national project targeting hydrogen use in transportation that initially profiled hydrogen in Norsk Hydro involved the Norwegian demonstration of a DaimlerChrysler's hydrogen bus visiting Oslo in 1999. Albeit initially driven by NHEL and fronted by Kloed, the project was realized with the aid from pioneers in Hydro's Refining and Marketing division. The bus demonstration in 1999 was linked to a process set out in 1995, where the before mentioned Norwegian consulting company, Energy Development AS[126] was involved in the idea and conceptualisation phase of a transportation project with hydrogen on behalf of Oslo and Follo Buss Trafikk (OFB) [127] running bus routes for SL (Stor Oslo Lokal Trafikk[128]).

An initial evaluation (Automarine as 1995) had contemplated ideas and opportunities related to hydrogen as a fuel, and recommended a project with 4 hydrogen fuelled busses put into test operations and in so doing to push Norway to pioneer the use of hydrogen technology. The report mentioned relevant partners for a pilot project there among Norsk Hydro Electrolysers (NHEL) to supply electrolyzer technology to produce hydrogen locally.

A pre-project study was phase one in the recommended bus project and was conducted on behalf of SL[129] in 1996 (report was published in January 1997). The purpose of the pre-project was to plan and concretise the technological and economic aspects of the proposed project with 4 hydrogen fuelled buses with cost estimates and detailed tenders for the supply of all components covering production, buses, and fuelling plant. The study was financially supported by six project collaborators including NHEL[130]. Participating in this early transportation project initiative was supported by Kloed / NHEL as part of the effort to obtain information about new uses and applications for hydrogen to find new sources of business opportunities to create value for NHEL technology.

A phase two followed the pre-project undertaking a test of a hydrogen bus during a two week operative demonstration period. This was the initial project in the transportation market that profiled hydrogen energy not only in NHEL but also in Norsk Hydro in cooperation with partners.

[126] In 1995 Energy Development AS was named Automarine AS.

[127] OFB routes were integrated into NorgesBuss AS in 1998 that was also contracted with bus route operations for SL.

[128] Stor Oslo Lokal Trafikk responsible for the planning and coordination of public bus transportation in Akershus and between the counties Oslo and Akershus.

[129] In SL's environmental report from 1997, hydrogen was mentioned as part of the effort to consider alternative fuels both renewable and fossil-based in order to reduce air emissions in the Oslo region. At the time there was little operational experience with hydrogen as a vehicle fuel, and to have SL's contracting bus companies participate in pilot projects were mentioned as a means to enhance competence and boost the prospects alternative fuels.

[130] NHEL, Oslo & Follo Busstrafikk, Raufoss Technology AS, Akershus Energiverk, Ulstein Bergen AS and Stor Oslo Lokaltrafikk.

Pioneers in Hydro's Refining and Marketing division wished to learn more about hydrogen as a fuel for the transportation sector. Other partners were Bertel O. Steen (representing the bus producer Daimler Chrysler in Norway), and Stor-Oslo Lokaltrafikk (SL) running the public bus transportation in the region. Daimler Chrysler delivered the fuel cell bus, and the NEBUS (new electric bus[131]) was in Oslo for a 2 week demonstration and operation period between 16/8/99-27/8/99 running in ordinary traffic between Oslo and Bærum outside Oslo[132].

Norsk Hydro Electrolysers developed the fuelling station for the demonstration period and supplied the hydrogen, which was transported to the station. Hydro also contributed to a safety study and market analysis conducted on experiences from the first operations including reactions and views from passengers and the driver. The project was profiled not only as NHEL activity but also as a part of Norsk Hydro activity. This was illustrated with the picture of Norsk Hydro's former CEO, Egil Myklebust, pictured in the project brochure with former Oil and Energy Minister Anne Enger Lahnstein in the hydrogen bus with a sample of the bus' only emission, namely a bottle of pure H_2O - water!

[131] Based on a Mercedes-Benz 0 405 N regular-service bus, the NEBUS ('new electric bus'), was a result of research carried out by Daimler-Benz towards a fuel cell suitable for automotive application and NEBUS (New Electric Bus) was to demonstrate the feasibility of using fuel cell drive for a city bus. On a single hydrogen tank filling, NEBUS has an operating range of 250 kilometres and thus had no difficulty in covering the normal daily schedule for a regular service bus. With an output of 250 kilowatts, the fuel cell drive unit powered the bus to a top speed of 80 km/h. NEBUS demonstrated its operational viability in line service in Oslo, Hamburg, Perth, Melbourne, Mexico City and Sacramento.

[132] SL's conclusion from the project was reflected in their environmental report from 2001 (2001a) indicating that the safety, economics and technologies of alternative fuels had been explored in projects undertaken within the scope of funding from the Ministry of Transport and Communication. Due to the positive experience with the two week demonstration, SL wanted a more comprehensive period of demonstration and operation under Norwegian conditions and over a longer period of time. As busses were not commercially available, a transition to hydrogen busses was indicated to be a long term initiative to get emissions down.

Source: Stor-Oslo Lokaltrafikk a.s. (2001b)

The work with a hydrogen bus project Oslo included the before mentioned pre-project analyses, the two week test operation as well as reporting from the project's phases in 1999 (SL brochure 1999) and again concerning the period 1999-2000 in 2001 (SL brochure 2001b). The core partner group, mentioned previously, were central to the demonstration's realisation and the project was communicated as the outcome of collaboration between the energy sector, the transportation sector and public authorities. The brochure from 1999 elaborated on the relevance of the project by pointing out the urgent need for environmentally friendly fuels and - vehicles in urban areas due to emissions from traffic. Further, as the introduction of new infrastructure would be demanding resource wise, the brochure pointed to the significance of starting with vehicles with large fuel demand that could share a joint fuelling station. Hence the relevance of bus projects that in turn could pave the way for other hydrogen fuelled vehicles.

The brochures (SL brochure 1999, 2001b) profiled the project's realisation in terms of roles, components, activities of the core partners as well as project reporting on experience gained through the project. Multiple team players had brought in diverse expertise to document the relevance of the project in terms of environmental benefit calculations (noise and air quality compared with diesel), advice on policy issues to further zero emission vehicles, analysis to handle risk and safety issues related to hydrogen as a fuel, storage issues on the bus, advise and co-financing from the Norwegian Public Roads Administration. Hence one aspect of the hydrogen bus project in Oslo was to undertake and subsequently communicate about the actual technical realisation and test operation.

Another central aspect of the bus project's activity that came across in the project brochures was to communicative purpose in terms of the relevance of the project. This related to the "what is and why hydrogen". Brochures simultaneous communicated about the project while also communicating why hydrogen energy was relevant. This involved communication about hydrogen's attributes as an energy carrier, enabling technologies like fuel cells and the time horizon including projections from the car industry about technology and vehicle availability supposedly by 2005. It involved communication about environmental benefits locally and globally; the opportunity space in terms of value creation and business opportunities; projections on user groups and initiatives that would trigger market development. Project brochures also pointed out that if there was political and economic will to advance cleaner and more energy effective technology; the project partners could carry out the practical realisation (SL brochures 1999, 2001b).

As far as continuation of this work in the area of hydrogen for mobility and transportation, the preparatory phase and the operative test demonstration was an early investment into a possible future venture; exploring new solutions through collaboration and relationships as part of building a new venture platform. The project fed into a sorting through and relevance building process. As seen from a Norsk Hydro perspective, albeit initially driven by NHEL interested in supplying the hydrogen and primarily fronted by Kloed, the project was realized with aid and project coordination from pioneers in the Refining and Marketing Division in Norsk Hydro interested in hydrogen as part of explorative activity to get a status on new fuels[133]. Plans for a continuation of demonstration and operation of busses[134] under Norwegian conditions were planned provided that public authorities would take on a financing responsibility (SL brochure (2001b, SL's environmental report from 2004-2006).

The proposed continuation efforts were subsequently channelled into the HyNor joint industry initiative[135]. HyNor became the key project for Norsk Hydro's pursuit of hydrogen in transportation, and with the main emphasis and pursuit of HyNor, other initiatives were abandoned. One such project idea that never materialised, and was abandoned altogether by

[133] For Stor-Oslo Lokaltrafikk (SL), the preliminary work exploring hydrogen as a future fuel was part of exploring a long-term transition to emission-free public transportation. Environmental reports from 2002-2006 are available at http://www.slnett.no

[134] A geographical suburban area with a dense commute into Oslo (from Fornebu, Lysaker, Skøyen) was suggested as suitable route. Further, the year 2005 was projected as the year when busses and vehicles would become commercially available.

[135] The HyNor project was established in 2003 with the objective of a broad market demonstration of hydrogen for transportation in Norway along one of the major national transport corridors along a 580 km long road – "The Hydrogen Highway of Norway". A joint industry initiative launched "seven nodes in a southern necklace" to demonstrate real life implementation of hydrogen energy infrastructure by establishing local nodes with diverse technical concepts. Each node constituted its own project with local/regional partners. Each node was to plan for setting up at least one hydrogen station, identify vehicle users and optionally plan for a local hydrogen production facility http://www.hynor.no.

2005[136], was a local demonstration project called Green Hydrogen Notodden. This project had been planned and profiled by NHEL since the latter part of the 1990s. NHEL had a pioneering role and Kloed was quite vocal and visible in the media (Bellona 2000, Dagbladet 2000, Folkevett 2000.

However, when NHEL became part of the Hydrogen Unit[137] in Norsk Hydro, some of NHEL's early initiatives were abandoned due to lack of support and competing project concepts (e.g. HyNor was chosen with a broader focus on distribution of hydrogen and different hydrogen production concepts[138]).

4.5.4 International efforts pioneering hydrogen energy

Since official and coordinated hydrogen programs were not pursued in Norway until the beginning of the new millennium; international development activities were the major sources of inspiration to NHEL's pioneer activities in the middle of the 1990s.

The International Energy Agency conducted work under the HIA (Hydrogen Implementing Agreement program since 1977) focusing on collaborative research and development of hydrogen energy technologies and information exchange. Japan's WE-NET (World Energy Network), with international cooperation in research and development of clean energy systems and emphasis on hydrogen, was initiated in 1993. Public R&D and interest in fuel cell and hydrogen technologies in Canada[139] had picked up since the 1980s with the industrial potential of the work of Dr. Geoffrey Ballard[140] and his research team, and the pursuit of the commercial potential of hydrogen fuel cell technologies. Development was on the way with car

[136] After years trying to establish funding, it was granted a much lower amount than was applied for. In 2003, the manager of Norsk Hydro's Hydrogen group suggested the preference for building demonstration projects with a larger national perspective, that public authorities had to partake in such a venture, and that the project would not be realised without financing from the National Budget. Although efforts were made to re-launch the project as an associated project to the national HyNor project in 2004, Norsk Hydro pulled out of the project in 2005, and the project was terminated in 2005 due to a lack of funding. With the previous visibility and vocal support of the project, Norsk Hydro was left vulnerable to critique and after abandoning the project Norsk Hydro received harsh criticism[136] in particular from environmental organisation Bellona indicating that this was a reoccurring pattern and a let down after the proclamation of support.

[137] This was after the decision to establish the Hydrogen Unit (in November 2001) under Hydro Energy (later Markets) in the Oil and Energy division, and hence after it had been decided that hydrogen should be pursued as a business venture.

[138]The distribution and production side of hydrogen and the versatility in the HyNor nodes are the force of the project showing that hydrogen may be produced using local resources and hence bringing another core idea to the fore, namely energy independence due to decentral energy production. Interview with Christopher Kloed 8/9/2005

[139] Public support of hydrogen and fuel cells were $200 million from 1982–2002 and additional $215 million in the period 2003-2008.

[140] http://en.wikipedia.org/wiki/Geoffrey_Ballard_(businessman)

makers in the 1990s. Carmakers DaimlerChrysler (then DaimlerBenz / DaimlerChrysler merger in 1998), Ford, General Motors, Honda, Mazda, Nissan, Renault, Toyota and VW all presented hydrogen vehicle prototypes in the 1990s, and there were projections on expected commercialisation of hydrogen vehicles from 2003/2004[141]. In the US, there were publications from the National Renewable Energy Laboratory as well as from Los Alamos National Laboratory. The National Hydrogen Association (NHA) was formed in the US in 1989 with ten members (in comparison it held more than 100 members in 2008), and NHEL together with the Norwegian Hydrogen Forum became members in 1998 with managing director Kloed as the point of contact.

In Europe, both Iceland and Germany were central to NHEL's pioneer activities. Iceland captured world attention in 1999 when it declared a national goal to convert its economy to hydrogen energy by 2030 with collaboration from DaimlerBenz and Ballard Power System[142]. The bold Icelandic vision was linked to the government's efforts to reduce imports of fossil fuels[143] and to research and development initiatives that went years back[144]. In addition there was extensive experience with hydrogen used to produce ammonia for fertilizer production.

Efforts in Germany were linked to efforts on Iceland. As early as 1990, the researchers at the University of Iceland had meetings with German industrial companies including Hamburgische Electricitäts-Werke AG (HEW). This meeting was the result of many years of research on hydrogen energy on Iceland, which other countries had started to notice (Andersen 2006). In Germany, DaimlerBenz (DaimlerChrysler merger in 1998) that began its serious assessment of fuel cell technologies in 1990, which was

---

[141] http://www.hyweb.de/index-e.html DaimlerBenz presumed to enter the market with fuel cell propelled series vehicles by year 2000, GM indicating the production of hydrogen fuelled, fuel cell vehicles to be ready by 2004 and Toyota by 2005. HyWeb Gazette http://www.netinform.net/H2/ GM 12/1/1998 and Toyota 30/10/97, http://www.hyweb.de/Politics/bavaria.htm#With%20new%20energy%20into%20the%20future%201997 26/6/1997.

[142] In 1997, the Ministry of Industry and Trade had created a committee for national fuel production to develop guidelines for policy and commitments in the development of a hydrogen strategy.

143 Since the oil crises in 1973/4, Iceland sought to replace fossil fuels – oil – with renewable energy sources especially hydro power and geothermal energy. Since year 2000, an official policy existed on renewable energy and hydrogen on transformation to a sustainable hydrogen economy before 2030. Policy and planning have resulted in the world's largest share of renewable energy in primary energy use (72%). The remaining energy use came from imported oil products where half was used in fishing boats and the other half in road transportation. Electricity production was carbon-free as fossil fuels had been replaced for heating purposes by geothermal energy (Andersen 2006).

[144] The University of Iceland, Reykjavik had produced hydrogen at a laboratory scale and the historical steps to Iceland's hydrogen efforts can be traced to 30 years of research under Professor Bragi Arnarson and colleagues at the Science Institute.

part of an evaluation of hydrogen and alternatives to the conventional internal combustion engines. A Daimler representative[145] held a lecture on hydrogen applications in city busses in 1992, referring to experiments with hydrogen vehicles since the mid 1980s, which was the foundation for their 1994 introduction of the world's first fuel cell vehicle, NECAR 1 (New Electric Car)[146]. Work with Canadian fuel cell manufacturer Ballard Power Systems continued with several prototypes introduced over the 1990s[147].

In Iceland, DaimlerBenz was also an initiator of market preparation activities to create an arena for their vehicle testing and demonstrations. In 1997, DaimlerBenz contacted the Icelandic ambassador to Germany and asked if researchers at the University of Iceland would come to Germany. The firm wanted information about Iceland's strategic hydrogen plans and the ambassador together with professor and researcher Bragi Arnarson went to at meeting in Stuttgart and presented information and plans to convert Iceland to a hydrogen economy[148]. A basis for cooperation was discussed since actors on Iceland were already producing the fuel (Andersen 2006). To demonstrate the performance and safety of hydrogen propulsion, concrete plans for a hydrogen fuelling station in Hamburg were reported in 1997 by the German Hydrogen Association[149]. Further, the German project was linked to a second phase with a pilot project Wasserstoff-Energie Island-Transfer (W.E.I.T.) with hydrogen production in Iceland by means of electrolysis using hydropower and the use of hydrogen in transportation.

4.5.5 Linking NHEL to international efforts

How international influences and initiatives were picked up and translated into Norsk Hydro Electrolysers' (NHEL) and Hydro's organisational context were very individual and context specific. Through NHEL's electrolyser

---

[145] Dr. Hans-Ulrich Huss (1992) Hydrogen Applications in City Busses, lecture held at The European Conference on New Fuels and Vehicles for Clean Air, Amsterdam 1992.

[146] NECAR 1 was basically a mobile laboratory. A converted Mercedes-Benz van, in which the fuel cell system / the power unit and performance-monitoring equipment took up so much space that there was just enough room left for the driver and front passenger—the fuel cell power unit alone weighed more than 1760 pounds (800 kg)

[147]The Fuel Cell – Drive for the Future
http://www.daimlerchrysler.com/Projects/c2c/channel/documents/102771_broschure_e.pdf.
Karl-Heinz Schlaiss, Fuel Cell Technology for Transportation, Engineering and Technology for Sustainable Development, August 28, 2002 http://www.daimler.com/

[148] Icelandic New Energy envisaged a stepwise plan with 5 phases for the transition to a hydrogen economy on Iceland. Phase 1: Demonstration project with hydrogen fuel cell buses in Reykjavik, the ECTOS project (Ecological City Transport System). Phase 2: Gradual replacement of the Reykjavik city bus fleet and possibly other bus fleets with hydrogen based fuel cell busses. Phase 3: Introduction of hydrogen based fuel cell cars for private transportation. Phase 4: Fuel cell vessel demonstration and evaluation projects. Phase 5: Gradual replacement of the present fishing fleet by fuel cell powered vessels.

[149] Hydrogen Mirror 6/97 http://dwv-info.org/e/news/mirror/wss/wse976.htm#Islandprojekt

activity, Hydro became linked to and part of activities on Iceland. In 1998, the German Hydrogen Association[150] reported that Iceland was the forum for the introduction of hydrogen. A working group consisting of members from industry, research, and authorities was concerned with ways to introduce hydrogen energy in transportation. There were negotiations with DaimlerBenz and Ballard about the operation of fuel cell buses in Reykjavik. The long-term objective was to convert mobility of the whole Icelandic society to hydrogen fuel and a first agreement about this with German partners was made as part of the Hamburg demonstration project W.E.I.T. Due to the plans from the Icelandic authorities to realize a hydrogen based energy economy, Iceland was a promising site for a hydrogen based fuel project and a platform to get experience, test and put together turn key solutions for a future hydrogen infrastructure.

NHEL had historic business relations on Iceland. The fertilizer factory (Aburdaverksmidjan) on Iceland, with a large electrolysis-based hydrogen plant, was originally delivered by NHEL and in Kloed's time as the managing director there had been orders for upgrades. In September 1998, Kloed invited members of the NHEL Board to Iceland and arranged a hydrogen seminar. The seminar discussed different energy related topics (hydrogen techniques for the future, geothermal power, investments in energy utilizing industry, the future hydrogen economy on Iceland) with presentations from Icelandic experts. The days of local fertilizer production at the factory were numbered and Professor Bragi Arnarson (at the University of Iceland) had advocated using the electrolysis production to produce hydrogen for methanol production (at the time, DaimlerBenz still contemplated vehicles using methanol with onboard reforming to hydrogen). Daimler and Icelandic researchers had found a common interest in this pursuit[151].

After the Board of NHEL's trip to Iceland and the hydrogen seminar (September 1998), NHEL was invited to join the ongoing partnership discussions involving DaimlerBenz, Shell and Icelandic interests represented by VistOrka. Hence NHEL participated in a meeting concerning cooperation on a concrete development project. The three internationals would work with Icelandic actors. Kloed considered this a golden opportunity for NHEL. Kloed thought that by entering the partnership, NHEL could land the opportunity to supply a fuelling station to Iceland based on on-site electrolysis. Negotiations started in 1998 and as it turned out to be difficult

---

[150] Hydrogen Mirror 3/98 http://dwv-info.org/e/news/mirror/wss/wse983.htm#Island

[151] In the mid 1990s, it was thought that producing hydrogen "on the go" would be an interim step between the hydrogen fuelling infrastructure and the coming of the hydrogen powered vehicles. However, the environmental and energy security benefits of the strategy would be modest and nearly all manufactures have abandoned the idea due to technical complexity which seems not to be compensated by the advantages that no hydrogen infrastructure would be needed.

to coordinate activities, a jointly owned company Icelandic New Energy (INE) was proposed to coordinate the project. NHEL was to supply all the electrolyser technology for the production of hydrogen at the fuelling station including compressor, storage and dispenser system, which were to be built in Norway and sent to Iceland as a complete unit. Domestic geothermal and hydro-powered electricity was to be used as the electricity source.

Participating in the partnership on Iceland and becoming a shareholder in the company was a major step to consider for NHEL. This was before Norsk Hydro had any kind of strategy on hydrogen as an energy carrier, but the invitation to become a part of the ECTOS project (see 4.4.2.2), and subsequently a joint owner in INE was more like "now there is an opening, we have to do something". Embarking on the development project was undertaken in parallel with efforts to initiate hydrogen energy inside the Hydro organisation.

«*In the beginning, there was no formal strategy and no budgets to support NHEL development initiatives. It was messier in a way. When NHEL at Notodden was invited to be part in the project on Iceland, the opening was there and now we had to do something. There were big discussions as to whether or not to do this. We knew it would be costly and we knew that if deciding to do this, it would mean taking NHEL technology as the starting point and develop it into something else, as a first step in a new development path. We were a small company and we knew that we did not have the money for the whole effort. So to the company board, I had to argue that this was so exiting that we had to do it. We initiated the project knowing that there was a long road ahead where a lot of people needed to be convinced. That took time and for a while all our equity was used to handle the new development*»

The Iceland project was a concrete delivery of equipment in one of the new areas of application. As part of research activities, the project was relevant to get insight into the status on fuel cell development and work in the car industry. In the fall of 1998, Kloed had advanced the idea and Icelandic opportunity to Hydro's director of corporate research (DCR) Bjørn Sund and Elisabet Fjermestad Hagen (also working on research projects and originally a part of the Refining and Marketing division), and both were enthusiastic about the project. Research activity was oriented towards the development of future energy; hence there was an accord between Kloed and Sund.

«*Sund understood much more of this than I did and was willing to support initiatives as part of a research project and as part of considering hydrogen as an energy carrier, Sund was in a central position in the Hydro organisation from where he could advance the area into the organisational limelight*»

The project and partnership investment were advanced by the DCR before Hydro's corporate management team at the end of 1998. Kloed and NHEL were applauded for a constructive initiative with the establishment of important business relations and contacts. A go ahead signal was granted and Norsk Hydro became part owner of NyOrka/Icelandic New Energy (INE) established in February, 1999[152]. The DCR became a member of the INE board and Kloed from NHEL also attended meetings with the INE partners. With Shell and Norsk Hydro's commitment to the project, INE's focus was shifted toward production of hydrogen via water electrolysis and on board storage of compressed hydrogen. Work on the EU application for the ECTOS project was filed February 2000.

The decision point to enter into the development project and the ownership on Iceland was an important point of crossing between the early pioneers operating from diverse settings in the Hydro organisation (NHEL, Corporate research, and the Energy Division). It added momentum to work with hydrogen as an energy carrier.

«*Iceland made an impression. I remember, I was in a meeting with Corporate Management at the end of 1998, this was when the Icelandic New Energy was being established and they wanted to know… former Hydro CEO Myklebust wanted to know "who came up with this"? Then it was nice to be able to say that it was at Notodden that this opportunity was created... It was almost like a catalytic process… through the work of a select few individuals …. Slowly but surely it starts to grow and becomes something bigger… little by little it started to get noticed*»

4.5.6 Creating organisational links between pioneering efforts

Another point of crossing between Hydro's energy division and Norsk Hydro electrolysers was the appointment of members to the NHEL board. This was in connection with NHEL's transfer to Pronova[153] in 1999. Kloed had conversations with Pronova manager Kjell Ramberg (subsequently also the director of the NHEL board) expressing that the entry of Bjørn Sund and Dag Christensen (Hydro's director of corporate research and chief of staff in the Energy Division) would be constructive. They both entered the NHEL board, year 2000. The exchange and interaction with representatives from

---

[152] http://dwv-info.org/e/news/mirror/wss/wse991.htm#Island "The first "hydrogen economy" of the world will be created on the north Atlantic island. A joint venture called "Icelandic Hydrogen and Fuel Cell Company Ltd." was founded on February 17. in Reykjavik. Half of the capital of 1 M$ is held by the Icelandic consortium Vistorka hf. (EcoEnergy Ltd.), the other at equal shares by DaimlerChrysler, Norsk Hydro, and Royal Dutch Shell. The new company will investigate various applications for hydrogen fuel cells and hydrogen carriers. A first substantial project might be the use of buses running on hydrogen in Reykjavik", Hydrogen Mirror 1/99 News from Hydrogen and Fuel, German Hydrogen Association.

[153] Pronova was Hydro's corporate entrepreneurship vehicle, and was a corporate function and located under the business category 'Other Activities'.

Hydro's corporate division and Hydro's energy division was important to tap into the Hydro organisation so as to make hydrogen important beyond its relevance to NHEL's context and electrolyser technology. Christensen, who at the time was the chief of staff to the manager of Hydro's Energy division, had an important communicative role in terms of selling the potential relevance of hydrogen as an energy carrier of the future, and became another early collaborator and sponsor from the Hydro energy division. Christensen was open-minded towards hydrogen energy activities.

«*In Hydro you always hear the notion: core business, deal with core business. Dealing with new things is very dependent on individuals. Some are enthusiasts; others are more neutral and middle-of-the-road saying lets stick to what we have got. I needed some checks and balances, to see if I was the only one thinking that this hydrogen as an energy carrier was interesting or merely wishful thinking. Fortunately I was not alone*»

Sponsors were needed to advance a hydrogen energy venture in the Hydro organisation. Further, to Hydro hydrogen pioneers, a group of people was also needed to bounce ideas back and forth, reflect and to conceptualise relevant action and development paths. An organisation and boards without visionaries could have put out these ideas, thinking it was a waste of time and too deviant to deal with. Sponsors and collaborators were important to communicate the significance of the innovative area of activity, in this case hydrogen as an energy carrier; to create new mental models and an understanding in the organisation of why development activities were relevant[154].

4.5.7 Communication and argumentation in relevance building and commitment making

Translating ideas into value propositions, NHEL and Kloed's argumentation for the initiation of development activities was built on three pillars[155]. *Firstly*, components of the past like historical achievements and company experience with technology and electrolysis (NHEL as a world leader in water electrolysis with low energy use). The achievements of the past were argued to be central building blocks in the creation of future hydrogen energy solutions. NHEL technology and experience was conceived as a solid starting point for technological development activities with a conviction that NHEL could maintain its technological leadership in electrolysis and development efforts. *Secondly*, the argument was advanced that hydrogen

[154] Instead of pouring knowledge into people's heads, you need to help them grind a new set of eyeglasses so they can see the world in a new way. This involves challenging the implicit assumptions that have shaped the way people in an organisation have historically looked at things (Brown 2002).

[155] Interview with Christopher Kloed (13-1-2005)

energy and hydrogen technology could serve many countries' interest in emissions reduction, securing energy supply and thereby realizing political goals. The Kyoto Protocol and urban pollution had lead to the initiation of several politically driven programmes advancing alternatives to fossil fuels with these backed by political will and funding e.g. in the EU, Japan, and in the USA. Project ideas were profiled as environmental projects to reduce emissions of greenhouse gases, and to reduce local air pollution due to emission of particles NOx, and SO2. The argumentation incorporated an imagined future state where transportation was possible without pollution. International hydrogen projects indicated that it was technically feasible to create hydrogen infrastructure; develop low emission vehicles among car manufacturers; and international regulatory initiatives like the Clean Air Act in California set percentage targets for zero emission vehicles that was expected to accelerate the development of hydrogen fuel cell cars. *Thirdly*, hydrogen energy was sketched as golden opportunity to become a supplier of the full spectre of energy and an exporter of technology.

This was relevant for NHEL, as well as for Norway, with solid knowledge about the production and utilisation of hydrogen, and a supplier of equipment and technology for the production and storage of hydrogen. There was the expected challenge in terms of decarbonising fossil fuel resources by reforming natural gas resources, and to supply Europe with large amounts of hydrogen while depositing CO2. There was hydro power and renewable energy that could be exploited by using electrolysers developed by NHEL to produce hydrogen in periods where electricity production from renewable energy sources did not coincide with the demand for electricity. *Hence the third pillar in the argumentation was that this was a business opportunity.* If hydrogen in energy markets took off, it would be a substantial business opportunity.

What was (still is) uncertain in the third pillar in the argumentation was the timing issue. Arguing for funding and allocation of resources to development, the first and second arguments were rather solid with an undisputable history to support them. But when confronted with the question: "You want to spend all this money on the development of new technology, but when are we going to break even or make a profit"? That was the tough nut to crack and respond to.

«Well besides getting sweaty and a bit shifty-eyed, what I tried to do was to leave no doubt that this is coming. You acknowledge that it is uncertain WHEN this is coming but given this uncertainty, can we afford to lean back, wait and see and do nothing? Or do we have to get started to be sure that when this comes, then we are ready to be a part of it. And the answer, as I see it, is simple. There can only be one simple answer. You cannot lean back. If you do so, you are not paying attention and then you don't know how others are positioning themselves and bringing out new technologies. So

when you enter the war, then you have to start anew and get acquainted with everything. Then you realise that you do not know anything about the situation, that you have not paid attention and you are not qualified to play a part. In a way, you have to be a part early on. However, after the question about when we are going to make a profit, then comes another question: yes but how much should we put into this, how heavily involved and how much money should presently be staked on hydrogen?.... Well, we have chosen to get heavily involved and I hope and believe it is the right thing to do. For NHEL, we know that there is the market for industrial applications. It is not a huge market, but it is large enough that those who develop good technology will have sales. So we are not totally dependent on the materialization of hydrogen in energy markets. This seems to be why Hydro has chosen to say that it is sensible to spend money and to start out»

Annual reports[156] from NHEL mirror the orientation toward new applications. The 1999 report mentioned new hydrogen applications that were worked on to supplement traditional industrial markets, and the company was running a deficit. In 2000, NHEL participated in work on several new areas of hydrogen energy, which combined with a growing interest in environmentally friendly hydrogen was meant to put the company in position for new business opportunities. The annual report from 2001 showed that hydrogen energy activities resulted in high development costs and deficits in 2000 and 2001, which were handled using the company's own equity, as well as with contribution from Norsk Hydro Corporate. 2002 was referred to as a year with little activity in traditional markets and large development costs. It was the initial production year of the first fuelling stations for hydrogen in transportation. High development costs from 2002 were expected to continue in 2003 as part of the company's venture into hydrogen as an energy carrier. Long term strategic plans had, at that point in time, been worked out, and large sums were being transferred from Hydro Corporate to NHEL. In the next sections, the focus is on the technological development processes initiated at NHEL.

4.5.8 Commitment materializing into development paths

NHEL's and managing director Kloed's orientation into new ideas quickly took on a material path. There was little compatibility between the existing technology and product-line of NHEL and the visionary ideas related to hydrogen in energy markets. The existing technology was not suitable for the type of production conceived of and emerging as opportunities in the new energy markets. The old product line consisted of somewhat lumpy apparatuses usually placed in large industrial spaces where size was of little or no concern at all. Further, the electrolysers' performance and efficiency

[156] Annual Accounts from 1999-2002 Brønnøysundregistrene, http://www.brreg.no

depended on continuous operation. Hence alterations were needed to access the research and development market for projects exploring hydrogen as an energy carrier. A new generation of electrolysers needed to be developed.

The challenges associated with NHEL's existing electrolyser technology came across when mentioning[157] the advantages associated with the two development tracks that were embarked on. Key words for the product development initiatives were flexibility and effectiveness. When oriented toward the market for fuelling stations, the requirement for a hydrogen production plant was that it had to be able to produce enough hydrogen to serve bus and car fleets without taking up too much space. Developing more compact solutions and producing the same or more on a smaller footprint was a main challenge.

Flexibility was also a major concern. The existing product line serving the industrial market was build for continuous operation and did not handle production variations well. With the old product line, exploiting a high percentage of max capacity was required; otherwise it was necessary to shut down completely. Shutting the old type electrolyser on and off however, brought about a whole new set of problems. First of all, when stopping production in the old product line of alkaline electrolysers, it took a long time from stop to restart to being ready to produce. With every start and stop, for security reasons, the apparatus and compartment volume had to be purged, and nitrogen had to be injected at a certain pressure (5-6 bar) so that all gasses were squeezed out thereby creating a nitrogen atmosphere which was inert[158]. Frequent starts and stops required extensive use of nitrogen, which added cost, yet for security reasons this was alpha omega.

With the use of hydrogen at fuelling stations and in autonomous renewable energy systems (with electricity generation from renewable sources coupled with hydrogen production and storage), flexibility was central. In these types of hydrogen systems, production requirements were by nature variable and tied to demand at the pump (fuelling station) and consumption on the user side, which combined with storage capacity, would determine the need for hydrogen production. One had to be able to scale production up or down and switch from a low to a high percent utilization in a short period of time. Further, in order for electrolysis to produce low cost hydrogen, low cost electricity had to be available. Hence flexibility was valuable for using off-peak electricity with lower tariffs from the grid and intermittent renewable energy sources such as wind or solar power.

---

[157] Based on interviews with Christopher Kloed (13.1.2005) and Ivar Hexeberg (16.11.2004).

[158] An inert gas is any gas that is not reactive under normal circumstances e.g. nitrogen. There is no reaction between nitrogen and hydrogen yet mixing hydrogen and oxygen is potentially very explosive as it creates explosive gas, hence the most important thing when working with hydrogen is to avoid mixing with oxygen (the critical residual hydrogen content must be well below the explosion limit of 4 % by vol.). These processes are patiently explained to me by researcher Torgeir Nakken at the Research Centre in Porsgrunn.

With NHEL's orientation towards hydrogen energy applications, NHEL had to develop something to be a part. To create an opportunity space or scope of action through participation in projects that explored hydrogen energy, a more compact and flexible electrolyser needed to see the light of day. Development activity was agreed to by NHEL management and board, and was commenced around the turn of 1995/96. Feasibility studies to find out what to do and where to direct development was undertaken, and some funding was landed through the Norwegian Industrial and Regional Development Fund (SND) and the Norwegian Research Council for a development period from 1/1/96-31/12/97[159].

Building on the conventional area of competence in alkaline electrolysers (see appendix II), an alkaline high pressure electrolyser (HPE) was developed as opposed to atmospheric electrolysers that were NHEL's traditional product. The HPE 15 model and technology was built on existing technology with conventionally known components assembled at NHEL with a new core component the electrolytic cell block - the heart of the electrolyser - coming from a Chinese supplier (Peric, an electrolytic equipment manufacturer). The apparatus HPE 15 (15 bar(g) pressure) was the initial apparatus in the HPE series. It was presented at the joint presentation of hydrogen technologies with fuel cell applications at the Hannover Fair, April 1998[160]. The term «pressurized» means that hydrogen (and oxygen) gas generated by the electrolyser is at pressure. Electrolysis at pressure would increase efficiency and use less energy by skipping a compression stage, and the main advantage of the HPE path was that the electrolyser became smaller, preserving space and hence had a smaller footprint.

The HPE series were marketed as the most compact and the best choice for applications requiring smaller hydrogen volumes (nm3/hour)[161]. Although the HPE 15 was developed for applications with hydrogen as an energy carrier; the apparatus also opened up doors to new customers with lower demands for hydrogen in the conventional industrial market. This was not planned for, but the new model allowed NHEL to tap into other industrial segments where the large apparatuses could not make an entry because they were too big. With the conventional apparatus it was physically

---

[159] Hydrogen production from water electrolysis - Energy efficiency. NFR no. 33031

[160] http://www.netinform.net/H2/Aktuelles_Detail.aspx?ID=2520 Norsk Hydro Electrolysers AS of Notodden, Norway, presented its new line of small alkaline electrolysers ranging from 10 to 60 Nm^3/h of hydrogen production. With a power consumption of 4.8 kWh/Nm^3 this corresponds to electric input powers of 48 to 288 kW_e. The hydrogen is delivered at a pressure of 16 bar (a), higher pressure levels up to 31 bar (a) being possible on request for smaller models. The gases are produced at purity levels of 99.8% for hydrogen and 99.2% for oxygen at production rates of 50% to 100% of rated power.

[161]Capacity in ranges from 10 Nm3/hour to 65 Nm3/hour as contrasted with the conventional atmospheric alkaline electrolyser for capacity ranges at 50 Nm3/h – 485 Nm3/hour.

possible to produce smaller hydrogen volumes, but the apparatus took up large space and capital expenditures and surrounding equipment would then make up a disproportionately high share of the hydrogen price.

The initial development and construction of a new pressurised electrolyser, was part of the steps to explore hydrogen as an energy carrier. NHEL's experience and technology was something concrete and existing technology to build something new around, which made it possible to explore new paths. It allowed NHEL to present themselves as a technology partner candidate to participate in the early research and development market for hydrogen projects that emerged during the latter part of the 1990s. HPE 15 ended up being used to get into the ECTOS, CEP and CUTE projects (mentioned in section 4.4). The technology was also used in the Utsira project, the first wind/hydrogen project in Norway (chapter 6).

Technology development and alterations in conventional technology was important because with the conventional atmospheric electrolyser, it would be difficult to profile the company as future oriented within hydrogen energy system applications. HPE 15 sales continued to industrial customers, yet although the HPE 15 apparatus made participation in early hydrogen demonstration projects possible, it was not as load flexible as expected and needed for energy market purposes (it could only be run optimally with gas production volumes at a range from 50 – 100% of maximum capacity[162]). Hence the internal NHEL development of the HPE 15 model was conceived as a midway or a bridging solution until technology, more suitable for swing load operation and attributes in energy system applications, could be developed.

A next generation in electrolyser development was therefore pursued with two different technological development paths. One is in alkaline water electrolysis and the other is in PEM electrolysis technology (see Appendix II)[163]. The former project was mainly handled and coordinated by NHEL, and the latter by the Research Centre in Porsgrunn. Both paths were intended to handle swing load and a variable production range from 0 – 100% capacity; and central to both technology paths were effort to increase energy efficiency[164].

---

162 http://www4.hydro.com/electrolysers/library/attachments/Brochures/49444_Productsheet_1.PDF

163 They differ in technology and in size that is capacity (volume production), PEM is one type of technology and is for applications with smaller hydrogen demands; and the HPE/PME (high pressure electrolyser/pressurised module electrolyser*)* path is in alkaline electrolysis technology for larger demands. PME development involves electrolysers with outlet pressure of the hydrogen at 15 bar g, and another at 30 bar g where the latter is undertaken within the GHW partnership. The GHW apparatus is also expected to replace or substitute the conventional alkaline electrolyser in the industrial markets.

164 The art of electrolysis is to increase hydrogen production while keeping energy consumption down. Historically there has been continuous work in this area as the hydrogen

In the following sections, the focus is on the process and materialization of technology development. *Emphasis will be put on the HPE path as this was initiated as part of pioneer activities before Hydro had decided to pursue a hydrogen energy venture.* HPE development was initiated by NHEL during the latter part of the 1990s prior to Hydro's pursuit of hydrogen energy. PEM development, on the other hand, was initiated as a Hydro internal project at the end of 2001 with the hiring of researcher Rasten. Hydro's Hydrogen unit had been established in November 2001 under the Hydro Energy division. It had also been decided that NHEL should be integrated in the Hydrogen unit. Research and development money to NHEL was part of the budget of the Hydrogen Unit. PEM development was neither part of pioneering activity nor pre-venture mobilisation; hence it is not included in this section on pioneering activity that pertains to relevance building and commitment to a hydrogen energy path. Rather PEM development is described in appendix IV because PEM development is mentioned in the chapter on the Utsira demonstration project. Hence appendix IV is additional and optional reading.

4.5.8.1 HPE in the GHW partnership

One path of electrolyser development is within Norsk Hydro Electrolysers (NHEL) and Hydro's historical competence in the area of alkaline water electrolysis. A research and development project was initiated with German partners for a new generation high pressure electrolyser suitable for future fuelling stations and on-site hydrogen production.

The HPE (high pressure electrolyser) development initiative, and Hydro's involvement in it, was handled by NHEL with development support from the Research Centre in Porsgrunn. Involvement was initiated when NHEL entered a strategic partnership on July 31. 1998 by purchasing a 40% share for DEM 100.000[165] in the partnership: "Gesellschaft für Hochleistungselektrolyseure zur Wasserstofferzeugung mbH" (Company for High Performance Electrolysers for the Generation of Hydrogen) in short GHW[166]. GHW's purpose was to create key technology for electrolyser-based fuelling stations, and the project was referred to as HPE 30 (high

---

volume determined the ammonia volume, which in turn set the limit for the company's fertilizer production. A major challenge was to increase hydrogen gas production /output without increasing electricity input.

[165] Accounting Register Brønnøysund. Annual report 1998 Norsk Hydro Electrolysers AS. On July 31st, 1998, the Norwegian company NHEL of Notodden has acquired a 40% share of GHW-Gesellschaft für Hochleistungselektrolyseure zur Wasserstofferzeugung mbH of Ottobrunn near Munich, Germany. GHW is a subsidiary of MTU Friedrichshafen GmbH and Hamburgischen Electricitäts-Werke AG (HEW).

[166]http://www.netinform.net/H2/Aktuelles_Detail.aspx?ID=2503

pressure electrolyser delivering hydrogen at 30 bar pressure) [167]. To NHEL, becoming a strategic partner was a way to get into development of a new generation of alkaline water electrolysers. Partners in the project were MTU Friedrichshafen GmbH (40%), a subsidiary of DaimlerChrysler and a manufacturer of high-quality propulsion systems including fuel cell activities. Hamburgische ElectricitätsWerke AG (HEW with 20%), a large energy utility in Europe, researched the use of hydrogen as an energy carrier wanting to take on a role in the field of hydrogen technology[168].

The German partners and the project had already been initiated, and NHEL purchased a 40% share that had previously been owned by Linde. As a result of a previous project connection, HEW made contact and offered NHEL to take over Linde's share in the GHW partnership[169]. The investment decision was made independently at Notodden, supported by NHEL management and the board. The selling point and argumentation by managing director Kloed was that this was a way to get a head start on new technology development with large industrial players on the hydrogen scene. It was considered a relatively minor expense to become part owner in a development already advancing and well into actual development projects. GHW had a 20 nm3/h prototype, was making a delivery to the Munich Airport demonstration project (H_2ARGEMUC), and had started developing the next generation high pressure electrolyser. GHW had 7 employees and was located at the MTU facilities with production- as well as lab equipment.

---

167 http://www4.hydro.com/electrolysers/en/products/product_development/index.html Some of the project specifications are that hydrogen will be delivered at 30 bar without the need for a compressor; cell-stack, gas-separation and lye circulation system within a single vessel; high energy efficiency and excellent gas quality; working range from 10 to 100% of full output, very short response times. It was to be manufactured in different output categories with a working range up to 500 Nm_3/hour and it newness among other things consist of load flexibility.

168 Since 1989 HEW had been involved in the application of renewable energy with "The Energy Concept – Future" (a cooperation with the City of Hamburg); and dealing with system integration and being a potential user of electrolysers, HEW also researched the use of hydrogen as an energy carrier by being active in hydrogen projects. One step in this direction was the participation of HEW in GHW.

169 The partnership opportunity came up due to the acquaintance between NHEL representative Andres Cloumann and a HEW Board member that knew each other from a previous study conducted in the early 1990s looking into green hydrogen from Norway and its potential use in Germany (NHEG Norwegian hydro energy in Germany). NHEG abstract: Transfer of renewable energy from remote areas to energy-intensive industrial regions might be of prospective importance. The case study NHEG considers a system where Norwegian hydro-energy is exposed to Germany as hydrogen or electricity. The goal was to evaluate the technical and economical feasibility of a demonstration project, paving the way for larger commercial projects in the future. Primarily, hydrogen is considered as the energy carrier. Liquid hydrogen is produced in North Norway, shipped to German ports and distributed to specific cities. Three alternatives are studied. The reference case is based on 100 MW hydro-power, the two others on 20 MW

The interior of the GHW electrolyser

To NHEL and Norsk Hydro, being a partner in GHW turned out to be a bridging strategy and catalyst for contact and collaboration with German authorities and political and industrial initiatives on hydrogen as an energy carrier. It was due to NHEL's ownership share in GHW that Norsk Hydro pioneers from the energy and corporate research division were invited to participate in a German initiative in July 1999 with the intention to couple public authorities, private industry partners (MAN a producer of busses, BMW and Daimler), and the research institute Ludwig-Bölkow-Systemtechnik (LBST) with extensive research on hydrogen conducted since the late 1980s. The focus of this public / private initiative was an energy- and transport-related goal to develop cleaner fuels based on renewables and other resources.

The German owner- and partnership in GHW was the entry ticket to get invited into this dialogue and planning process. It was also through the GHW ownership that NHEL/Hydro got involved in EU and German research and development projects like the contract signed with Hamburgische Electricitäts-Werke AG (HEW) to supply a complete hydrogen fuelling station in Hamburg, as part of the CUTE demonstration project[170]. A GHW electrolyser was part of the hydrogen project in the Munich airport, and it was through GHW that the linkage to the German project CEP (Clean Energy Partnership) Berlin arose, as the partners agreed that GHW should show an interest and participate in preparatory meetings on the CEP project. Hence participation in market preparation activities, testing and demonstration arenas emerged unexpectedly out of NHEL's

[170] Clean Urban Transport Europe demonstration project using hydrogen as fuel in 27 buses in nine European cities.

involvement on Iceland and investment in the GHW technology development partnership. Hydro, through NHEL technology, had a building block and something concrete to offer that created an entry and an opportunity to embark on new paths. Demonstration projects were undertaken in parallel with GHW development of new electrolyser technology.

Development, however, did not materialise as quickly as intended, and because there was no finished HPE product from the GHW partnership, the HPE 15 electrolyser apparatus ended up being used in the German projects in Hamburg (CUTE) and Berlin (CEP), in Reykjavik (ECTOS), and subsequently it was also used in the Utsira project (chapter 6). Hence the first NHEL electrolyser technology for new applications with hydrogen as an energy carrier came to use as a bridging solution, and was the outcome of development activities at NHEL, initiated to get in position for hydrogen energy.

The HPE 15 was build as an interim apparatus and bridging solution, which NHEL knew was not the perfect configuration for the future because of lack of flexibility. It was launched and built as part of pioneering activities so as to stay in the game and get experience from politically sponsored projects and experimentation with hydrogen solutions. Project participation exploring hydrogen in energy markets then ran in parallel with technical development, and insight and experience were fed into the development projects.

4.5.9 Communicating electrolyser development across organisational boundaries

Since an important aspiration and element in the NHEL strategy was to sustain its position as a world leader in water electrolysis, and development activities had been initiated, an important activity was to communicate these efforts and make one's presence known to potential partners also working towards hydrogen in energy markets. Project participation was about exploring and connecting to the competence of others and turning combined resources into something new. At the same time, projects were also a form of communication as they signalled that NHEL was extending and redirecting its resources and competencies toward new business opportunities (hydrogen as an energy carrier). The redirection was initially shaped around the immediate resources at NHEL's disposal – the conventional electrolyser technology.

Projects and involvement in new development paths were mentioned in NHEL's communication. A Hydro Electrolyser brochure, *Hydrogen starts with …. Hydro,* pointed to electrolysers as paving the way for hydrogen infrastructure and promised the delivery of efficient electrolyser-based fuelling stations producing hydrogen locally to supply hydrogen that were just as convenient as fuelling today's gasoline and diesel vehicles. NHEL's position, as a reliable player and supplier of hydrogen producing technology to energy market applications, was presented by relating to history. 75 years of historical achievements and experience in the production of hydrogen.

«We are additionally building on our 75 years of experience producing hydrogen, and currently cooperate with other leading companies in testing future energy supply at pilot facilities in Iceland and Germany» (Norsk Hydro's Annual Report 2002:17).

Being a reliable supplier of hydrogen producing technology to energy applications was communicated by relating to the characteristics of NHEL's conventional product (the atmospheric electrolyser) with a well documented design, reliability in operation, low maintenance costs and low energy consumption. The credence of history and heritage was mobilised in full and conventional product characteristics were indicated to have been retained in new development, albeit the new electrolyser apparatuses in reality were being developed without certainty as to their eventual capabilities.

Details on technical attributes could not be specified at the outset of pioneering activity and development projects. Simply put, it was impossible to communicate the specifics of an invention before it was invented. What could be communicated and specified initially, were the strategic visions of the organisation, targets for technology development, and the core of the development projects. The core idea in the projects sketched the hydrogen energy applications that the electrolyser development was oriented towards. Further, when sketching project ideas, it included a problem orientation/definition, which in turn showed the importance of technology development and pointed to the NHEL organisation as a supplier of solutions. To illustrate the communicative aspect, NHEL, in 1999, participated in an EU project oriented towards hydrogen use in stationary energy systems with energy storage to optimise renewable energy[171]. The project signalled the intent to demonstrate wind power and energy storage to help reduce the need for new fossil fuel-based generation or increased grid capacity. The project signalled a direction toward hydrogen energy, where NHEL would be capable of supplying the hydrogen production system. Another illustration is the GHW (electrolyser development in the German

171 http://cordis.europa.eu/data/PROJ_FP5/ACTIONeqDndSESSIONeq112362005919ndDOCeq661ndTBLeqEN_PROJ.htm: ESTORE's objective is to develop a demonstrable combination of energy storage and wind power to produce a low cost, renewable generation source. E-STORE will enable wind power be deemed firm capacity. It is designed to solve the problem of using energy storage for cost effective network stability and to create longer bridging times for renewable energy systems and to be an integral part of a growing hydrogen economy. EU's Fifth framework programme (1998-2002), project reference: NNE5/20234/1999

partnership) project description issued in the context of EU's Fifth Framework Programme (FP5)[172]. Here it was indicated that:

« New energy markets require efficient, low cost, small size electrolysers in the MW power range for the macro storage of renewable electric energy, for load management and frequency control of the power grid, the build up of a hydrogen infrastructure for hydrogen fuelled vehicles….The load variable 30 bar HPE electrolyser is meant to become a stand alone unit for on site hydrogen production with a variable and disposable load to stabilize the electric power grid (frequency control, load/power management), especially for grids to which a large fraction of renewable energy production facilities are connected like wind, solar etc. …. The results of the project will have strategic impact on energy markets, namely those of renewable energies, of fuel cell markets for stationary and mobile applications…. Establishment of a hydrogen infrastructure for fuel cell vehicles will move closer towards realisation by developing the ability to produce cost efficient electrolytic hydrogen directly where hydrogen is required. For the transport of the electric energy, the existing power grid is used. One of the advantages of electrolytic hydrogen fuel production is that the very same installations are equally suited for operation with conventionally produced electric energy, for renewable electricity and for a blend of both enabling a smooth transition to a sustainable and increasingly non-fossil fuel energy supply structure »[173]

The need for electrolytic hydrogen production was pointed to in the project description both as an enabler of renewable electricity development, enabler of load management and grid balancing in areas with large fractions of renewable electricity, as well as an enabler of hydrogen infrastructure development and a decentral onsite production structure. The development of the electrolyser was pointed to as a central piece in this type of energy system vision and the solution to several needs, which in turn was a projection of value. Development was shown to be relevant due to the characteristics of the natural resources in this type of energy system vision, namely variable renewable energy production, but also by incorporating the characteristics of the use / application / market in terms of the development of fuelling stations with hydrogen fuel production onsite. The energy system

[172] The project was part of the EUs fuel cell and hydrogen projects from 1999-2002, and supported development and testing from 2003-2006 under the project acronym HyStruc Project Reference: NNE5/525/2001, start date: 1/2/03-31/7/06, Development And Testing Of An Innovative 30 Bar Low Cost, Small Size Pressure Module Electrolyser (PME) In The MW Power Range For The Cost Efficient Production Of Electrolytic Hydrogen

[173] http://ec.europa.eu/research/energy/pdf/efchp_hydrogen1.pdf Low-cost, high capacity PME electrolyser for the energy hydrogen market. The project was also part of the European Fuel Cell and Hydrogen Projects from 1999-2002. European Communities, 2003 ftp://ftp.cordis.lu/pub/sustdev/docs/energy/sustdev_h2_european_fc_and_h2_projects.pdf

vision carved out the relevance for the organisation's resources and technology offering (electrolyser technology) by specifying it as a technical solution to advance the potential for hydrogen energy, renewable and distributed energy systems, and to harvest the synergies between hydrogen and renewable energy.

In addition to company brochures and project participation, international technology fairs also signalled the organisation's involvement in hydrogen energy, and to make the organisation's presence known to potential partners. Participation at one particular fair may be mentioned as NHEL participated in the Hannover Hydrogen + Fuel Cells Fair (Arno A. Evers Fair) an annual event since 1996. The exhibit stand reflected that pioneering activity with NHEL was fronting electrolysis technology. In 1996, NHEL participated as 1 among 16 exhibitors with a corner stand to the right.

Source: Hannover Fair http://www.fair-pr.com/other/hm96/impressions.php

In 2001 under the title: *On the way to a Hydrogen Economy*, NHEL signalled the diverse applications of NHEL technology. NHEL projected the relevance of electrolysers in hydrogen energy applications by mentioning concrete NHEL activity and achievements in year 2000:

«Market introduction of the new high pressure electrolyser for small to medium size capacities; participation in the first wind/hydrogen project in Norway; and a development programme initiated with German partners, for a new generation high pressure electrolysers for future fuelling stations»

As 2001 news, NHEL pointed to participation in the fuelling station in Reykjavik, Iceland[174]. Further, with concepts combining wind power for hydrogen production, electrolyser technology and fuel cells for power production; NHEL was portrayed not only as a supplier of electrolysers but also as a supplier of complete package plants including hydrogen fuelling stations and distributed energy system. NHEL was promoted as offering solutions to hydrogen fuel demand.

«The necessary infrastructure for an emerging new era of hydrogen-driven vehicles can be nurtured using e.g. electrolysers. They are compact and need only water and electricity to produce hydrogen. NHEL provides a feasible solution for hydrogen needs in new energy markets until the hydrogen fuel market is significant enough to justify large scale hydrogen production. Hydro has vast experience producing electrolysers and handling hydrogen. The company's first electrolyser was made in 1927. Hydro has been in the business ever since with continuous research and development»[175]

International industry fairs were forums for discussion of the technological, financial and strategic challenges of new technologies and the path from research and development to commercialisation and acceptance by users. It was also a setting where hydrogen energy system visions met. Fuel supply and infrastructure solutions for hydrogen - the "fuel of choice" - were discussed in combination with argumentation for likely applications and users. To illustrate with the Forum discussions at the 2001 Fair, international speakers explained steps in industrial production of hydrogen, and discussed the use of renewable energy in the production of hydrogen. Kloed, from NHEL, participated in the discussion and envisioned the energy system with hydrogen as an energy carrier, and the potential for a cleaner energy supply by using hydrogen. Electrolysis was highlighted as an integral part of using renewable energy:

«We should use existing resources on natural gas more environmentally friendly through reforming into hydrogen. Our natural gas will last approximately 10-15 years and the necessary unit for using it with hydrogen are already here. Of course this process should take place together with the use of renewable energies. To reach this target we should do more research and development concerning electrolysis ….. Hydrogen fuel is more environmentally friendly and safer than existing fuels, and Norsk Hydro Electrolysers AS is participating in many demonstration programmes in order to show its usefulness to the public and to the government»

[174] http://www.fair-pr.com

[175] http://www.hydro.com/en/Press-room/News/Archive/2002/April/16134/

Visions of potential supply solutions encountered visions of application areas that in turn were projections of future markets e.g. independent power supply (your power unit at home); back-up systems for electric power (using fuel cells); and developing countries in regions without connection to the electrical grid. Together with projections on use in the transportation sector, various application fields were projected:

«The first applications for fuel cells ready to merchandize will be back-up systems; the technology is prepared to provide electric power in milliseconds …. In several years micro fuels cells will push portable applications for hydrogen technology with ten times higher capacity. These devices will be cash cows due to their longer time of use. At present mobile phones, laptops etc. are already high-tech units, so the consumer will pay for this new technology…. There will be a large market for bicycles and wheel chairs»[176]

Industrial fairs in this sense were arenas for joint envisioning experiments, where actors and their respective organisations took part in a process of defining likely development and business opportunities. NHEL communication illustrated that the organisation proactively sought to describe and project a future energy system vision suitable to the organisation's competence and technologies.

[176] http://www.fair-pr.com/h2fair/e/hm01/kongress-print.html

4.6 Pioneering hydrogen energy as business development

4.6.1 Project initiatives and actionable first steps

> "In the breast of one who wishes to do something new, the forces of habit raise up and bear witness against the embryonic project"
> (Schumpeter 1934:86)
>
> "Innovation isn't some big bang thing. It's something that people do every day by challenging the system"
> (Keith Yamashita, CEO and Founder, Stone Yamashita Partners)

Looking to pioneering activities as part of business development in Norsk Hydro Energy, will show how three areas of competence[177] and work at diverse locations in Hydro came together and intersected. It will illustrate the path from hydrogen as a research project to a strategic business initiative.

Business developer, Elisabet Fjermestad Hagen, was a pioneer and vital to initial ideas and to winning hearts and minds[178]. When initiating exploration into hydrogen energy, Hagen was working with assisting colleague Vera Ingunn Moe in the Refining and Marketing Division focusing on developments in retailing and downstream marketing. Their position in the organisation was the Refining and Marketing Division until 1999 when Norsk Hydro was in a merger process with another Norwegian Oil company, SAGA[179]. In connection with the merger, the R&M division was closed down at the turn of the year 1999/2000, and Hagen and Moe were officially transferred from the Refining and Marketing Division to the Strategy group in Hydro Energy[180] from January 2000. At that time, Elisabet Fjermestad Hagen had also worked on hydrogen related projects under the director of corporate research (Bjørn Sund) where hydrogen activity was anchored.

[177] 1) Norsk Hydro Electrolysers (NHEL) as the producer of electrolysers for hydrogen production. 2) Research and technological feasibility and development anchored in Hydro's Research Centre in Porsgrunn. 3) The commercial and strategic approach, commercial feasibility, anchored in Hydro Energy, and later in the Hydrogen group in the New Energy division under the Oil and Energy sector.

[178] Hagen was a long term Norsk Hydro employee, 20 years in the aluminum division before entering Hydro's Refining and Marketing Division, Hydro Energy, and subsequently the Hydrogen Unit and then the Hydrogen Group in New Energy. Hagen opted for an early retirement package with the merger of StatoilHydro (October 2007).

[179] Norsk Hydro bought Saga in June 1999 and the two companies merged during the second half of 1999 with a total integration of Saga into Norsk Hydro and the establishment of a new organisation effective as of 1/1-2000 (http://www.scanweb.no/forening/nopef/fusjon.htm)

[180] Hydro Energy was a Division in Norsk Hydro AS and responsible for Hydro's commercial operations relating to electricity, crude oil, gas and NGL products. Hydro Energy was also responsible for Hydro's power production and refinery operations, in addition to the transport of oil and gas, and Hydro's initiatives regarding new forms of energy. Hydro Energy was renamed: the Markets Sector in Norsk Hydro's business area Oil & Energy.

Hence at the time of the integration of Refining and Marketing into Hydro Energy, Hagen had been temporarily transferred to work in corporate research and had one leg in research as well as one leg in Hydro Energy, which was illustrative of the bridging path ahead.

In the latter part of the 1990s, Moe and Hagen's work involved explorative activity and participation in diverse projects without being formalised in any kind of agreed pursuit of business activity. *"It was a time where everybody nosed around for example into natural gas, propane, biodiesel and hydrogen"*. Looking into alternative fuels was part of business development and evaluations in relation to new fuels. The guiding question was: what are trends and what are contestants to the products of the refinery and marketing division? As far as fuels, Hagen and Moe explored natural gas, hydrogen and biodiesel. Focusing on hydrogen, analyses and presentations were written on various topics such as the projected market situation for hydrogen and technology status such as fuel cells.

The explorative activity into fuels in the Refining and Marketing Division crossed Norsk Hydro Electrolysers and Christopher Kloed's activity with hydrogen as a possible new energy carrier. An initial contact from DaimlerBenz to Norsk Hydro had been made in the middle of the 1990s, and the Oslo project had been in the works since 1994. To move along from evaluations and pre-project studies on hydrogen as a potential fuel for busses and transportation, Kloed and Hagen's work joined and continued from around 1997 in different work groups and in the preparatory work for the 2 week demonstration to operate[181] DaimlerBenz's NEBUS[182] (section 4.5). Combined Hydro contributed with the supply of hydrogen, financing, and got permission from the Oslo municipality to let them use the Oslo Town Hall to support the opening of the event.

As part of looking into alternative fuels, another mobility oriented project was the Norwegian H2-ferry project[183]. This was a pre-study

---

[181] The test run took place between 16-8-99 through 27-8-99

[182]The NEBUS was the result of continued development of the CITARO-busses of Mercedes; and Daimler wanted to build and deploy about 20 of these busses worldwide to get feedback for further development and as part of their initial launch and marketing. The goal was to demonstrate its suitability for regular-service operation and demonstrations were run in Oslo, Hamburg, Perth, Melbourne, Mexico City and Sacramento. With a single tank filling of hydrogen, the NEBUS had a range of 250 kilometres, well in excess of the distances typically covered by a regular-service bus in the course of a day's operation. With a power rating of 250 kilowatts, the fuel cell drive unit made for a maximum speed of 80 km/h. http://www.h2mobility.org/2_busdata/b009.htm

[183] Norsk Hydro, IFE, NTNU, Marintek, Vegdirektoratet, Ecotraffic Norge AS 2001: Hydrogen and Fuel Cells in Ferryboats, a feasibility study by "The H2-Ferry Project". The purpose was to reduce NOx and CO2, demonstrate new technology and environmental and safety aspects associated with the use of hydrogen and fuels aboard ships. In the projected demonstration hydrogen was to be produced ashore and stored in metal hydrides on board. The study proved that a demonstration could be carried out without great safety risks, but a

conducted in 2000 to explore the technical challenges and conversions related to the use of hydrogen in marine transport. In addition to work on hydrogen for mobility purposes, Kloed and Hagen also shared ideas on possible wind / hydrogen development combinations with concept studies and evaluations on various energy storage solutions since 1998.

Working from the Refining and Marketing Division in Norsk Hydro, the initial motive behind participating in exploratory hydrogen activity was to learn more about hydrogen as a fuel for the transport sector, and as an energy carrier in general. For Kloed the motivation was looking to prospective markets for NHEL's hydrogen production technology. As NHEL was organised under Pronova, there was little attention to the electrolysis supplier in Hydro's energy business, and Kloed approached Hagen knowing that her work related to alternative fuels. Collaborators were needed to assess the significance of development efforts into hydrogen energy, and to generate and communicate an understanding in the organisation at large as to why activity was relevant.

Very few people in the Norsk Hydro organisation at large were oriented towards hydrogen. The main support came from the managing director in NHEL (section 4.5), and an important ally was the director of corporate research (section 4.4), who supported participation in different hydrogen related projects to establish an understanding of what was going on in hydrogen energy. The director of corporate research was in a central management - and organisational position to elevate and boost hydrogen as a future and possible energy carrier[184]. When initiatives in the area of hydrogen were advanced in front of the research director, they were met with interest and an open mind, whereas in the Marketing and Refinery division, initiatives usually received a rather lukewarm response as hydrogen was beyond the current scope of business.

Being the entrepreneurial type, Hagen indicated that she always tried to shape and to define the contents and scope of her activities. "This was exiting and challenging and what else was I supposed to be doing?" suggested this quality. Without a basis in a business strategy and division, Hagen used her operational budget to make early activity and projects possible. This was how a pre-project study was conducted by the consulting company, Energy Development, on the economics and technical aspects of a

---

more detailed analysis would be needed. Cost estimates indicated relatively high costs of a one year demonstration, approximately 75-100 million NOK. Since is was expected that fuel cells were approaching commercialisation, technology was being developed with high speed with an expected cost reduction, it was projected that costs would have fallen significantly before an eventual demonstration project in 2-3 years time.

[184] To illustrate, Sund fronted and supported involvement in the ECTOS project and investment in Icelandic New Energy (INE) and brought the matter in front of Norsk Hydro Corporate Management in the end of 1998 (INE/NyOrka was established February 1999). See section 4.4.

wind-hydrogen system on the Utsira Island (published December 2000). For activities with industry funding and co-funding from the Norwegian Research Council, Hagen outlined a Hydro share taken from her budget and could then apply for support to double the budget. To get funding to explorative activity was hence a dual process working inside out and outside in. *Inside-out* in the sense that Hagen's own budget was used and project funding also came from corporate research. *Outside-in*, in the sense that if sufficient funding was not available from within, for instance due to scepticism and hesitancy on a proposed activity, then project support and money had to be raised from external sources (e.g. the Research Council of Norway, the Norwegian Water Resources and Energy Directorate (NVE) or the Norwegian Pollution Control Authority (SFT) as possible sources). If financing could be raised from external sources, it in turn facilitated acceptance and a "go through with it" mode to realization. If it could be added that other large companies e.g. car manufacturers and/or oil and energy companies were interested and part of an activity or project, then it indirectly supported the venture. This was the case with the ECTOS project on Iceland where Daimler and Shell were key actors, which in turn could be advanced in front of Hydro management to argue the activity as relevant and worthwhile. The efforts and orientation of others helped build legitimacy as it generated a point of reference, attention, and a shared meaning, which created a basis for action.

4.6.2 Initial exploration and industrial point of departure

Norsk Hydro's industrial experience with hydrogen production (natural gas reforming) was the industrial starting point for research and development efforts in corporate research, and the key motivation was to secure the value of natural gas resources. Research and development efforts and projects commenced in the latter part of the 1990s were driven by the motive to decarbonise fossil fuels in anticipation of CO2 costs so as to make fossil fuels 'sustainable'. Activities related to this orientation and technology path were the initiation of the HydroKraft project (the power plant concept generating electricity from natural gas derived hydrogen with decarbonisation); involvement in the CO2 Capture Project[185], participation in the US initiated Carbon Sequestration Leadership Forum (CSLF); and the AZEP project (Advanced Zero Emissions Power Plant)[186] cooperating with multiple partners.

[185] www.co2captureproject.org. Eight global energy companies joined forces to research and develop technology for separating carbon dioxide (CO_2) and subsequently storing it in geological formations.

[186] http://cordis.europa.eu/data/PROJ_FP5/ACTIONeqDndSESSIONeq112362005919ndDOCeq

Linking to this orientation and focus on decarbonisation, and while undertaking early explorative activity on fuels and demonstrations, Hagen started her work and affiliation with The International Energy Agency (IEA)[187] and the Hydrogen Programme in 1998 and 1999. Hagen was the proposed Task Development Leader with support from the Research Council of Norway, and this concerned the preparation and development of a future task, for which she subsequently became an Operating Agent, Hydrogen from Carbon- Containing Materials HIA Annex 16 2002-2005[188]. The IEA fronted the initiative to get into dialogue with existing industrial users and producers of hydrogen to discuss research efforts that could facilitate an increased utilization of hydrogen. The idea was that an increased market share for hydrogen in industrial arenas could lead to expedited infrastructure development, which was a necessity for the advancement of hydrogen energy. During 1998 and 1999, there were workshops and questionnaire activity with industry representatives to identify research needs and the scope of future work. Hydrogen production technologies from fossil fuels received great industrial interest, perhaps not surprising since about 95% of the hydrogen produced was coming from carbon-containing raw material, primarily fossil in origin. With growing awareness of the impact of greenhouse gas emissions on the climate, there was a drive to reassess conventional approaches and a growing international interest in integrating carbon dioxide capture and storage with conventional steam reforming of fossil fuels to achieve 'clean' hydrogen production. Biomass, as a carbon-neutral source of renewable hydrogen, was also evaluated.

Participating in the definition, planning and execution phase of the IEA task lead to activities in the area of communication. Communicating the participation in IEA activities were an offshoot from the practical involvement. Showing author and organisational affiliation, Hagen co-authored papers on the topics of international collaborations to advance hydrogen energy technologies, and IEA efforts to advance hydrogen energy. Papers were communicated at the World Hydrogen Energy Conference (Elam et al 2002) and in the International Journal of Hydrogen Energy (Elam et al 2003). Efforts were also made to link IEA activity to national activity.

102ndTBLeqEN_PROJ.htm
http://www.co2captureandstorage.info/project_specific.php?project_id=54

[187] http://www.ieahia.org/pdfs/1999_annual_report.pdf

[188] The work resulted in the definition of three subtasks to be researched and explored from 2002-2005 under Hydrogen from Carbon- Containing Materials (Hydrogen Implementing Agreement HIA Annex 16), and this was the first Task to be led by industry with operating agent, Hagen and with several industry participants. The three subtasks in HIA Task 16 - Hydrogen from Carbon Containing Materials were: A) Large-Scale Hydrogen Production, B) Biomass to Hydrogen and C) Small Stationary Reformers. Industry participants were Haldor Topsøe, IGS Mahler, Gastec, BP, Texaco, ENI, Gaz de France, Norsk Hydro, PanCanadian, Shell, Statoil and Suncor http://www.ieahia.org/pdfs/2001_annual_report.pdf , http://www.ieahia.org/pdfs/2002_annual_report.pdf

The Clean Energy for the Future programme with the Research Council of Norway (NFR) supported Hydro's IEA task coordination[189].

The original involvement in IEA activity was started before the establishment of a hydrogen energy business venture. At the time of commencement (1998/1999), participation in IEA activity was primarily motivated by the interest in large scale natural gas production with CO2 capture, and an interest in cooperating with IEA's Greenhouse Gas programme. The diverse IEA sub-task areas provided access to best practice information. For instance one subtask focused on small scale stationary natural gas reformers, and created unique insight into the main competition to NHEL's electrolysis technology.

IEA activity was initiated when this was an area of interest and not an area of business. How it would prove relevant for a possible future business pursuit was hence unclear at the time of initiation. Besides putting the organisation's name out there amongst hydrogen energy constituents, a central advantage of participating was the informational basis that was constituted. It provided a basis for evaluating participation in different technological areas. However the information's relevance in relation to a hydrogen energy strategy and/or business pursuit was not knowable at the time, as both were non-existing.

4.6.3 Hydro Energy and the linkage to international hydrogen efforts

Efforts initiated in the late 1990s relating to hydrogen in transportation systems, were rooted in corporate research. These included the Iceland project based on NHEL's technological experience with electrolytic hydrogen production, and activities branching off to other transport related projects and infrastructure development (sections 4.4 and 4.5). Especially German development initiatives were positive indicators of hydrogen energy visions and were picked up by Norsk Hydro Electrolysers (NHEL), the Corporate Research Centre, and Hagen and Moe working in the Refining and Marketing Division (and subsequently in the Hydro Energy division). In Germany in 1997, it was announced that the Bavarian State Government would spend 50 million DM (US$ 29 mill.) to foster hydrogen energy technologies[190]. Reference was made to international competition to get into a leading position in hydrogen energy technologies with Japan, the USA and Canada, which had increased their funding to hydrogen technologies. The

[189] At a later date, NFR came to sponsor an information related project in 2006 where Hydro wished to conduct an information programme adapted to NFR wishes and possible continuation and planning of continued IEA activity on hydrogen from hydrocarbons. The information package was based on the content of the work on Annex 16 with the communication of reports, presentations and seminar activity in coordination with the Research Council for interested Norwegian parties. Project numbers 156455, 168444, and 174045 http://www.forskningsraadet.no.

[190] http://www.netinform.net/H2/Aktuelles_Detail.aspx?ID=2599 (26.06.1997)

Bavarian State Ministry for Economy, Transportation, and Technology supported the hydrogen project at the Munich International Airport[191], launched in 1997 as a pilot project to demonstrate fuelling stations with two "paths". One of them gaseous with hydrogen generation on site, and the other liquid hydrogen, and both were intended to serve passenger cars and airport buses. GHW with which NHEL entered a strategic partnership (mid 1998) was responsible for the electrolysis plant (the high-performance pressurized electrolyser) in the Munich project.

The Bavarian State efforts were associated with German national efforts. The TES initiative (Transport Energy Strategy), pursuing energy and transportation goals, was launched in 1998[192]. This was a joint initiative with German authorities (the Federal Ministry of Transportation), vehicle manufacturers and energy suppliers (BMW, DaimlerBenz, MAN and VW as well as Aral, RWE and Shell) in order to secure and extend German industrial technological leadership in the area of alternative propulsion and energy technology. The TES initiative was also to identify and develop a future and sustainable fuel for road transport produced from renewable energy / non-petroleum based clean energy sources[193]. Projects likely to appeal to the general public were to be carried out with fuel cell vehicles and vehicles with an internal combustion engine using hydrogen. The production and transport of fuel as well as fuelling infrastructure were to be tested, and the first step was to launch the Clean Energy Partnership CEP in Berlin with the support of the Federal Government, and European corporations were also encouraged join the initiative.

The German TES initiative inspired Norsk Hydro's initiation of hydrogen energy. This was previously mentioned in the section on NHEL (the GHW electrolyser being part of the hydrogen project in the Munich airport, the delivery of an electrolyser to the CUTE project station in Hamburg, and participation in preparatory meetings on the project Clean Energy Partnership Berlin CEP pursued via GHW). However, the linkage to German activity expanded to the Hydro Energy division in July 1999, when invited to participate in the German energy dialogue under TES. Norsk Hydro Energy representatives, also associated with corporate research, were invited to participate as a result of the strategic partnership between Norsk Hydro Electrolysers (NHEL) and the German electrolyser company, GHW (discussed in section 4.5).

[191] http://www.ieahia.org/pdfs/munich_airport.pdf

[192] http://www.netinform.net/H2/Aktuelles_Detail.aspx?ID=2527

[193] By the end of year 2000 (and from a broad spectrum of ten potential alternative fuels and over 70 methods of production), the TES project group selected three fuels for further consideration: natural gas, methanol and hydrogen. Further, after narrowing down the choice of possible fuels to hydrogen, natural gas (liquefied) and methanol in 2000, the TES dialogue (June 2001) signalled that for industry, hydrogen represented the most promising option in the long term.

Analyses and projections on hydrogen fuelling infrastructure presented by Ludwig Bölkow Systemtechnik (LBST) also supplemented the inspiration from the TES initiative. Germany's national initiatives were supported by LBST, a leading German technology and strategy consultant company in the area of sustainable energy- and transport systems. LBST emphasised the role of hydrogen as a transport fuel, and hydrogen as an energy carrier in a renewable energy economy[194]. Studies from LBST, on greenhouse gas reduction potentials and the mapping of planned and concrete hydrogen activities worldwide, provided a timeline for hydrogen vehicles and infrastructure development. Projections through year 2020 were presented, and the build-up assumptions e.g. in Germany and Europe were supported with referral to politically planned activity. Political initiatives (the White Paper from 1997 with actions designed to achieve a doubling of the renewable share of EU's total energy consumption from 6 % to 12 %[195]; work under EU's Energy, Environment and Sustainable Development (one of four thematic programmes in the Community's Research Fifth Framework Programme 1998-2002); the EU Commission's Green Paper "Towards a European strategy for the security of energy supply"[196] setting out a target of 20 % for fuel substitutes in road transport by 2020; and the Commission seeing a potential in hydrogen development to a level of 5 % or more of the total automotive fuel market by 2020[197]). The build-up assumptions were also supported by the strategies of car manufacturers planning commercialisation by 2003/2004 and mass production by 2010, but car manufacturers also emphasised that early infrastructure build up would be necessary to start mass production[198].

---

[194] LBST has supported numerous projects as a coordinator and also with technical expertise. EQHHPP – Euro-Québec Hydro-Hydrogen Pilot Project, 1989-1999, EIHP – European Integrated Hydrogen Project, 1998-2004, HyNet – The European Thematic Network on Hydrogen, 2002-2004, HyWays – European Hydrogen Energy Roadmap, 2004-2007, HyLights – Coordination Action to accelerate the Commercialisation of Hydrogen and Fuel Cells in the field of Transport in Europe, 2006-2008, HFP – Secretariat of the European Hydrogen- and Fuel Cell-Technology-Platform, 2004-2007.

[195] White Paper Energy for the future: Renewable Sources of Energy for a community strategy and action plan, COM(97)599 final (26/11/97)

[196] Green Paper-Towards a European strategy for the security of energy supply / COM/2000/0769 final. 20/10/2000.

[197] COM(2001) 547 final 7.11.2001

[198] LBST, Reinhold Wurster; *Pathways to a hydrogen refuelling infrastructure between today and 2020 – Time scale and investment costs*, Fuel Cell Teach-in European Commission DG TREN, Brussels. For Europe, LBST projected that a 5 % substitution of vehicle fuels would mean a conversion of at least 15-20% of all refuelling stations to the new fuel, and the estimate for Europe was 15-20.000 refuelling stations by 2020. The estimated cumulative investment costs for a European hydrogen supply and refuelling infrastructure were 53 billion Euros for 15.000 stations by 2010 and 213 billion Euros for 60.000 stations by 2020. Calculations on the case of Germany alone projected that more than 700 stations would be in place by 2010 and a total of around 6200 by 2020 or half of all refueling stations

LBST also conducted a well-to-wheel study in 2000-2001[199] (in collaboration with General Motors/Opel BP, ExxonMobil, Shell und TotalFinaElf) to document the cleanest and most environmentally sustainable source of energy for future mobility. Complete energy chains were analysed from primary energy in fuel production to the actual consumption of the fuel in vehicles i.e. from the well to the wheels of the vehicle. The aim of the study was to evaluate total energy consumption as well as the total greenhouse gas emissions from fuel production to final use in an automobile. The well-to-wheel study showed that fuel cell vehicles could greatly reduce greenhouse gas (GHG) emissions from passenger cars. Further if hydrogen was produced from renewable energy sources (electricity to water electrolysis and hydrogen in a fuel cell[200]), it would eliminate GHG emissions entirely.

Norsk Hydro acquaintance with LBST also evolved through joint EU initiatives where Norsk Hydro started to participate in the HyNet project in the middle of 1999 (see section 4.4.2), where LBST carried the coordination responsibility. Activities involved hydrogen value chain analysis; seminars and working groups; position papers; and initiation of project proposals to the 5th research framework programme. The purpose was to create a network of key European stakeholders that could participate in the definition of a European hydrogen energy roadmap. It had a mandate to assist the development of a hydrogen energy research, technology and development strategy in the European Union, and to provide input to the High Level Group (HLG)[201] launched in October 2002. The more practical aspects were to propose joint and large demonstration projects to respond to the interest of the European Commission in bundling European activities on hydrogen energy. Hydro sustained the European linkage through participation in the HLG, which subsequently formulated a collective EU vision[202] with agreed recommendations on the contribution that hydrogen and fuel cells could make to the realisation of sustainable future energy

---

[199] http://www.lbst.de/gm-wtw

[200]Electricity produced with renewable energy is used in electrolysis of water (using electricity to split water molecules to create pure hydrogen and oxygen), and when hydrogen is used in a fuel cell (using an electrochemical process) where hydrogen is recombined with oxygen to create water, heat and power.

[201] The High Level Group (HLG) was initiated by the European Commission with the objective to create a basis for focused and efficient R&D activities as well as commercialisation strategies. HLG balanced participation of 19 large and small/medium industrial enterprises and research institution. It was launched in October 2002 by DG Energy and Transport, Loyola De Palacio (the Vice President of the European Commission, and Commissioner for energy and transport from 1999), and Research Commissioner Philippe Busquin. Norsk Hydro's Tore Torvund (Executive Vice President of Norsk Hydro, and CEO of Hydro oil and energy) participated in two meetings in October 2002 and April 2003.

[202] HLG work was compiled and formulated with the assistance of the High Level Group members 'sherpas' and technical writers.

systems (Hydrogen Energy and Fuel Cells – A vision of our future, June 2003).

4.6.4 Relevance building through partnering and participation

International hydrogen efforts and the work of LBST, in terms of the projected development of hydrogen energy, supported the optimism of Hydro's hydrogen pioneers trying to advance hydrogen activity from research and analyses to business development in Hydro Energy. Prospects in transportation markets, in particular, were integrated in vision building activities and were communicated inside the Hydro organisation. In addition to participation in the TES dialogue, there was also Hydro participation in brainstorm meetings, early into the new millennium, with representatives from the car, oil and energy industries (there among Daimler, BP, Shell and Hydro). The intention was to pull together and discuss a common way to develop infrastructure in Europe so as to facilitate the projected mass production of vehicles. Here the point of departure was a "chicken-egg" type stance with industry arresting each other. The oil and energy industry saying "yes we shall build infrastructure if you build the cars", and the car industry's position being that they wanted to be sure that hydrogen fuelling stations were built, and that this was not just a strategic stunt of publicity and profiling on the part of energy companies.

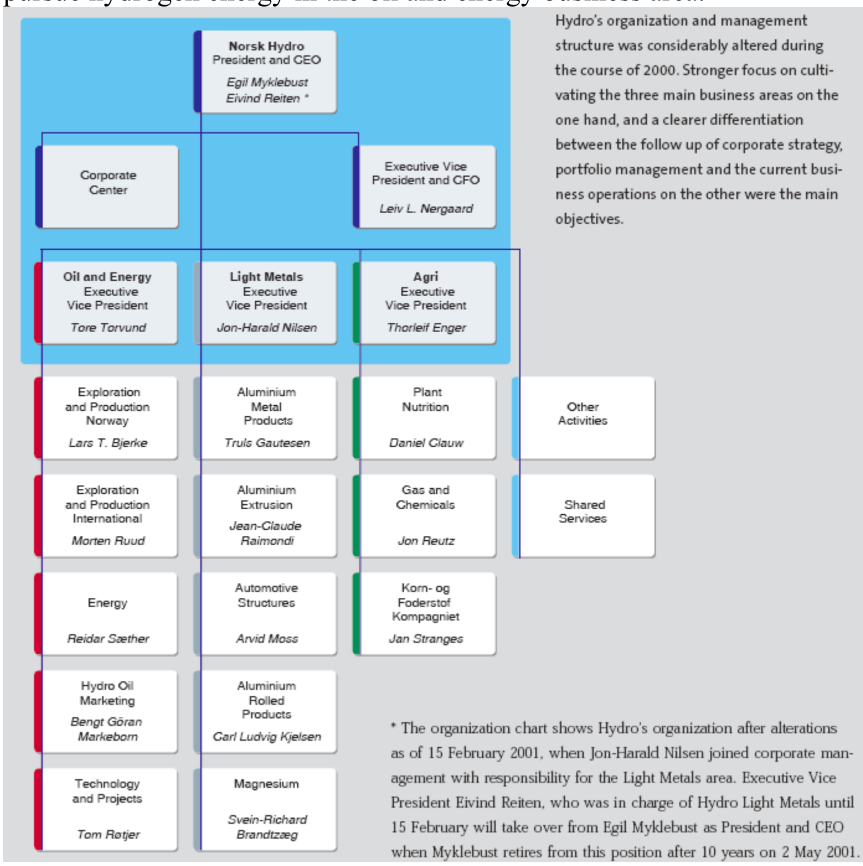
Yet regardless of the issues being debated behind closed doors, participating and partnering in projects and explorative activity, had multiple purposes. *For one,* for hydrogen energy to be developed there was a need to do research, analyses, demonstrations for products and technology to develop and improve, and for applications and a market to develop. Such activities required funding from the EU Commission and/or national support programmes. One purpose of showing that industries (car and energy companies) were pulling together in hydrogen energy efforts was to convince that this was to be prioritised and funded. It was also a way to reduce risk and spread costs of the initial hesitant baby steps in the advancement of hydrogen energy. *Secondly*, cooperation and partnering helped legitimize the hydrogen venture inside the company. Cooperating with large energy companies worked to support the initiation of a hydrogen venture that is to say if Shell and BP thought something was okay, then it assisted and supported the argumentation advanced in front of Hydro management. *Thirdly*, the motivation behind participating in e.g. International Energy Agency (IEA) work, and Hagen being the first Operating Agent coming from industry, was to break a tendency of doing research on specific solutions that were far down the time line and realization, which had been pushed mainly by operating agents coming from technical university and research milieus. Participating in IEA was one way to look at what could be done in the near terms that would be of use and interest to industry. This involved coordination of projects and efforts to address the question of when production technologies would be ready for use and integration, which in turn helped facilitate the prioritisation of research projects. IEA involvement was an attempt to move the time horizon of hydrogen technologies towards the here-and-now, and thereby make it more interesting for industry to get started. By focusing on possible combinations of resources in the present, activities and resources were assessed and linked, and actionable steps could be taken.

Participating in international initiatives and concrete development projects was vital to pioneering exploration. Pioneers connected with activities outside the company, which was central to build an understanding of opportunities, and to build visions of possible future hydrogen energy systems. Being a participant in more visionary activity like conceptual road map studies also allowed Hydro pioneers to influence ideas. However, having built understanding and visions of future states with hydrogen energy, the pioneers still needed to embed such visions in their own organisations. The dynamics inside the Hydro Energy organisation to establish a hydrogen energy venture is described next.

4.6.5 From relevance to strategy development

The Hydro organisation was both an enabler of and a possible constraint on the initiation of hydrogen energy initiatives action. Pioneers or technology path breakers involved in hydrogen energy business building had forces acting upon them like strategy documents, annual budgets, and decision making hierarchies. Project evaluation methodologies provided common language in the planning and execution of investments, and in establishing common decision making requirements. Such processes and methodologies governed existing business activities and said little about how hydrogen business area was decided upon and established in the first place. The focus in this section is on how management was linked to hydrogen initiatives and ideas bubbling in the organisation, and the mobilisation behind the establishment of the hydrogen energy business venture.

This chapter, focusing on initiation and pioneer activity, illustrate that a window of opportunity opened with multiple initiatives to create a new venture platform. Pioneers or path breakers participated in international arenas and brought home experience and visions. The visions were used to consider existing organisational activity, opportunities and possible participation in hydrogen as an energy carrier. Visions allowed pioneers to reinterpret assets in different contexts, to take stock of what the organisation had and then consider how new opportunities and unchartered territory could be explored. The process of gaining support for hydrogen projects was linked to interpreting what was going on in energy markets (technological developments, threats and opportunities). However, it was also linked to convincing and 'selling' this 'inside' to the organisation at large. Those who wanted to pursue projects had to persuade those with authority to allocate resources to them. Below, a chart of the organisational structure is included, which may be used as a reference when reading about the decision process to pursue hydrogen energy in the oil and energy business area.



Source: Hydro management and organisation, Hydro Annual report 2000 http://www.hydro.com/upload/Documents/Reports/Annual%20reports/ann_rep00_e.pdf

Having participated in international forums and projects with impulses and information, this was not information that everybody in the Hydro organisation had, and it had to be packaged similar to a sales job. Hagen discussed efforts in winning heart and minds and the initiative process from idea to the pursuit of business:

«If an idea is not in a strategy, then the idea must be very good and acceptable to rise up, otherwise you have to struggle… And it is usually a struggle because rarely are ideas so acceptable or obvious; there are always uncertainties - great uncertainty in everything that has to do with hydrogen, both market- and technology wise. So you have to work on it, believe in it, work the system in every possible way by offering information, pushing information, you have to work to convince, you need good argumentation and some calculations»

Elaborating on the transition from actionable first steps to integration in strategic thinking, one remark on the initiation period was:
«What happened is that I worked for quite some time to be allowed to put together a hydrogen strategy»

Hagen explained that the period of working on hydrogen as an alternative fuel in the Refining and Marketing division and hydrogen projects linked to corporate research was also a period where:

«I worked to have management of the Hydro Energy business division say that we needed to have a strategy worked out for the hydrogen area»

The objective of the different projects, research and exploration activities were to eventually trigger interest and to try to communicate hydrogen as a contender to new energy markets so that a strategy process would be called for. Research activity needed to be anchored in a business division to be moved along and the mandate while working in corporate research was to make this so interesting that the question would come up: "don't we need a strategy for this work". With the publicity and 'noise' stirred up by participation in HyNet, the Iceland project, the planning of the CUTE project, the SL initiative with the Oslo bus demonstration also publicly fronted by CEO Myklebust, the question came.

By the summer of 2000, Hagen was asked to gather a group of people and work out a proposal for a hydrogen strategy for Hydro Energy. That was the mandate coming from the manager of the Hydro Energy Division and the main idea was to ponder the questions: *why is this interesting, what may Hydro do in this area and what does this have to do with our business?* From the summer of 2000, the group (mainly Hagen and Moe) worked to put together information and to sharpen the argument to try to get the message across. The first presentation to Hydro Energy management was held in November 2000.

«I presented my arguments before the management team in the Hydro Energy division. This consisted of managers responsible for the diverse business areas under Hydro Energy e.g. trading power, trading gas. And what can I say, none of them seemed to think too much about this, questioning the relevance, rather neutral and borderline indifferent as this did not concern nor have an effect on their business areas. This was new business and it received a lukewarm reception. But then it so happened that within a few weeks time, the Hydro Energy division's entire middle management team from across Europe had its annual meeting, and I was asked to present this again. The funny part was that there was such an enthusiastic response after the presentation, so the Hydro Energy division management team seemed to say hmmm, maybe this is interesting after all. Here they seemed to be thinking that 'this is new and exiting but what is the rush', no great enthusiasm could be traced, but the thing that so many reacted so positively speeded things up. But I couldn't have counted on that. It was a total coincidence that this meeting came right after, so I considered that as luck»

This was the beginning of a lengthy decision and approval process. In December 2000, a second presentation of a strategy proposal was made to the Hydro Energy management team. Next more details on the strategy proposal are presented.

4.6.6 The strategy proposal of December 2000

The presentation of the December 2000 strategy proposal mentioned the whole host of industrial actors associated with hydrogen as an energy carrier (industrial gas companies, hydrogen generating equipment suppliers, fuel cell developers, component suppliers, system suppliers, utilities, vehicle manufacturers, and oil and gas companies), and the importance of identifying and developing partner alliances was emphasized.

4.6.6.1 Risk, opportunity and timing

Risks associated with a long term market perspective were recognised in terms of uncertainty of future profitability, uncertainty of product development, uncertainty with regards to market acceptance of products, dependence on strategic partners, dependence on key personnel, and the management of growth. Risks specific to hydrogen as an energy carrier were associated with the market for hydrogen fuel, new products, technological change and competition from alternative fuels. *As a counter measure to the depiction of risk was the portrayal of commercial potential.* Here the projected size of the transport market was presented using Germany as the example (projected 300 stations by 2005); alternative path scenarios for hydrogen penetration in the European transport market projected by 2015; and estimates were presented with profits and income potential. Hydrogen growth in other markets were also projected e.g. the increased use of hydrogen in refineries for cleaner fuels / new product quality requirements, and the use of hydrogen for distributed power was projected with hydrogen produced from natural gas reforming.

The initial strategy proposal presented a broad array of large scale supply alternatives e.g. to use existing ammonia facilities, use hydrogen from refineries and petrochemical plants or hydrogen from new, large scale combined hydrogen / power plants. This was done to outline the flexibility of hydrogen supply in the transition period and also pointed out the capacity to match future large hydrogen markets at low cost. The sourcing of hydrogen fuel was expected to be dependent on market size with small on-site generation units or trucking from regional production facilities in the build-up phase, and future bulk market opportunities with commodity supply projected in 10 years ++. *The timing* of large scale CO2 free hydrogen production was presented as being dependent on market development in terms of hydrogen volumes and infrastructure for energy markets in transportation and power production (distributed versus central solutions); hydrogen production technology choices and their costs; the location of production plants; CO2 separation and storage; and hydrogen storage.

The timing issue was difficult to address with the pathway to a new energy society being uncertain in terms of market, technology development, politics and environment. However an attempt toward *concretization of progress included sketching a timeline*. The timeline projected European preparations on new fuels and technology development; preparation of demo projects between 2000 and 2003; actual demos and early adopters in stationary applications in the period 2003-2005; and projections on decisions from the car industry on series production of fuel cell vehicles in the same time period. By 2005-2008 series production of busses and vehicle fleets were projected coupled with commercialisation in stationary applications and demand growth in refineries, and series production of passenger cars was projected between 2008 and 2015. *Hence a conceptual transition* was outlined with milestones during the time frame (2000 – 2015) involving priorities on clean fuel developments in Europe (as part of the German Transport Energy Strategy process and the European HyNet processes); decisions on serial production on fuel cell vehicles; sufficient infrastructure solutions; and regulations on greenhouse gases and local emissions.

4.6.6.2 Envisioning alternative paths

Given uncertainties three paths were envisioned: 1) the option of doing nothing, 2) a reversible strategy without excessive upfront expenditure that would position the company for future market development, or 3) to take a strong proactive role with investments to secure commercial rights and growth opportunities. Path two was recommended among the pioneers. Given the substantial uncertainties, a central part of the strategy process was to propose a development plan suitable for managing risks. The proposed plan combined *business development, production and technology development, and marketing*.

4.6.6.3 Business development activities

What the pioneers referred to as *business development* was far from a straight forward linear sequence of "identify demand and market supply", rather a multitude of activities to develop business and sales opportunities to construct a basis for business were proposed. Business development incorporated activities from analysing profitability, to identifying and monitoring market development and early applications, and getting a position in these. Other business development activities were analysis of indicators in relation to uncertainties (markets, fuel choice, technology development and costs, politics and environment). To do so alliances, demonstration projects, and networking were launched as key activities. Identifying partners, forming partnerships and establishing relationships with relevant companies; and prioritising demonstration projects also with partners as well as developing networks with industry, research and authorities. Building alliances and partnerships were projected as a way to diversify risk by sharing costs of demonstration projects and research activity[203]. Alliances and partners were to be identified and developed further in the pre-commercial period and were also seen as planting a seed for possible joint ventures and access to best technology at a later period of development.

Building on the actions and experience gathered hitherto in research projects, and the participation status already worked up on Iceland, bus demonstration, CUTE, H2 Ferry, and the Utsira project signalled that activities would hit the ground running. Referring to European activities was also a way to portray Hydro as being in a strong position with significant contacts in relation to energy companies, auto manufacturers and the EU

[203] A distinction was drawn between alliances with other market makers (e.g. automotive industry, utilities) and stakeholders with regards to demos and positioning the company; alliances and technology partners to explore technical feasibility (equipment like compressors, reformers, storage, system suppliers, fuel cells); and partnership building with governments and authorities for support.

Commission. Being in a strong position were aimed at meeting certain goals e.g. becoming a central player for on-site hydrogen production, leading in electrolyser business, and also positioning the company as a large scale hydrogen producer.

4.6.6.4 Planning production and technology development

As it concerned production and technology development, the objective was launched to develop the technological basis for Hydro to become the preferred supplier of hydrogen. Both improvement and cost reduction of electrolysers and small scale hydrogen production based on natural gas, ammonia and methanol were fronted candidates. An R&D focus on safety, hydrogen storage issues, monitoring of hydrogen production technology, and fuels cells was launched. An outline of a development plan for Norsk Hydro Electrolysers was presented to be in the lead of electrolyser business. The argumentation for this was supported by the previously projected sourcing of hydrogen fuel, which in the build-up phase was expected to be small on-site generation units or trucking from regional production facilities.

4.6.6.5 Marketing activities

Marketing activities were linked to both technology - and business development activities in terms of marketing actual production systems from Hydro Electrolysers for on-site hydrogen production, but also to market Hydro as a competent partner and innovative organisation. In sum, opportunities were projected to arise from activities in business development with demos, research and development, NHEL technology development and partnership formations. Organisationally, it was proposed that all hydrogen activities should be placed with Hydro Energy also with the integration of Norsk Hydro Electrolysers (NHEL). It was also proposed that a new Hydrogen Unit should be established to handle the activities described in the strategy proposal.

From this presentation of the strategy proposal to the Hydro Energy management team in December 2000, the strategy proposal was adopted. The general recommendation was that although there was substantial uncertainty with respect to timing and volume of initial hydrogen energy markets, the search for sustainable energy solutions was pointing towards an increased use of hydrogen. Hydrogen had the potential to become a major business for Norsk Hydro, but to grasp this opportunity; significant financial and human resources were needed. The central argument was to build on present strengths to become a central player in on-site hydrogen production as well as develop a position as a large scale hydrogen supplier from natural gas resources including CO2 sequestration. Both implied launching activity to build technical and commercial expertise also to allow Hydro to enter other parts of the hydrogen business value chain as opportunities would arise.

4.6.7 From strategy to business plan

The strategy proposal was adopted by Norsk Hydro Energy (NHE) management in December 2000, and Hagen was asked to prepare a business plan to be presented in spring 2001 if the hydrogen energy strategy was approved by management over the Hydro Energy division. Two presentations were held in January 2001 and March 2001 to the management team of the Oil and Energy Business area (in which the manager of Hydro Energy was also a part). The strategy proposal was presented twice because of reservations and several concerns. Concerns on what other energy companies were doing in the hydrogen area, concerns over the coupling between hydrogen and natural gas resources and existing competence on hydrogen from natural gas reforming in the Agri/industry gas segment. Elaboration on the role of Norsk Hydro Electrolysers (NHEL) was also needed since this technology sales and not energy sale.

Hence closer attention was paid to strategies of other energy companies and their focus areas (e.g. technology development, market making), their actions (investments, alliances, demos, subsidiaries) and resources committed. Reference was made to other energy companies being well into hydrogen energy activities so as to provide a sense of urgency. The long term goal for Hydro was to be positioned in large scale value chains with hydrogen production based on natural gas resources with CO2 handling. However in the near term, hydrogen was expected to be produced on-site and as Hydro had electrolyser technology, it was suggested that Hydro should take a pro-active role as a hydrogen production systems supplier so as to build up a market base. It was further suggested that Hydro Energy should take ownership of Norsk Hydro Electrolyser, which at the time was part of Hydro Pronova (Hydro's corporate entrepreneurship vehicle trying to develop the non-core operations).

The strategy proposal was adopted by Oil and Energy management in March 2001, and the outcome of the initial strategy process narrowed development activities to three main areas: 1) hydrogen for mobility to get established in the transportation sector with hydrogen fuelling stations using electrolysis technology as the entry point; 2) stationary use in stand alone systems, and 3) large scale hydrogen production plants based on natural gas with CO2 handling, and possibly also use of hydrogen gas in combined heat and power production (CHP).

«The main point that sold it to Oil and Energy seemed to be the projection of the long term objective that this would enhance the value of our natural gas

resources via processing and conversion into hydrogen. That was the long term goal. The short term objective was to get started with activity via our electrolysers. Then we did not really have a good answer on how to get from the short term to the long term objective, which we in a way still do not have»

Oil and Energy management approved the strategy whereas the concrete business plan was subject to approval in the business division. Hence the matter went back to the business division (Hydro Energy), and a business plan needed to be developed. Hydrogen pioneers proceeded with the development of a business plan with more details than the overall strategy document. This included resource commitment in terms of how much money was to be put into this and why; positioning and working on target business areas and activities; working with whom including prospective alliances and partnerships; and business goals, costs and profit estimates. With this process came a sharpening of the strategy, where the commercial positioning and the target areas for entry and positions in the value chains were sharpened and specified further.

4.6.7.1 Management commitment to the business plan

A business plan proposal was developed during spring of 2001 and presented to Hydro Energy management in June 2001. At this point Hydro Energy management had not been updated on hydrogen since December 2000. Hence the attention span and interest in hydrogen had not been nurtured in the management group, and the enthusiasm from the November and December (2000) presentations had withered. Hydrogen pioneers were given the thumbs down.

«They were no longer enthusiastic. Here I came with my business plan… looking back I see that it was a bit optimistic all the curves moving upwards, but we had made calculations and based on what the car manufacturer were saying … well, it is easy to show profitability in a market that has already taken off… the point was to show that once this became a market, it would be profitable. But here I was, almost flat out rejected, and I remember I was exhausted, pissed, and very angry with the whole company ….. I went on vacation and upon my return I was called to the manager of the Hydro Energy division, who seemed to acknowledge that the interest in hydrogen in the management group had not been sustained … In a way it was a bit embarrassing to Hydro Energy management because Oil and Energy Business management had approved the strategy, and left it to Hydro Energy to take on business development. This kind of stumbling was not acceptable when a strategy had been adopted; Oil and Energy had approved the strategy so there was a shortcoming in terms of not moving this along»

To move things a long, a full day work seminar was arranged for the Hydro Energy management group, September 2001. Everything was examined thoroughly, discussing the strategy and the business plan, and why this should be pursued. The final decision to go ahead was taken and a Hydrogen Unit was to be established. One of the pioneer's reflects on the commitment making process:

«Hence it turned out to be a rather strange process: where it was moving upwards to seek the support of the director of corporate research and working on multiple projects; then I went downwards to gain support among the 'audience' (the European middle management team); it was then accepted and the division's management team asked me to prepare a business plan. Meanwhile I also had presentations for the top management layer above the division's management team, which gave it a positive response. But when I came back to the division's management team – they had forgotten all about it and the 'sales processes' had to be started anew with an internal hydrogen seminar before it was finally decided that a hydrogen unit should be established in the oil and energy sector. Weird process when I come to think of it»

4.6.7.2 Commitment through the reinterpretation of company resources in relation to hydrogen energy

The business plan was to pursue a dual strategy targeting business in small as well as large scale value chains. In the early stages of a hydrogen economy, the target was on-site markets (fuelling stations in transportation) and to build up a role by supplying technology with smaller scale hydrogen production systems (electrolysers). The transport sector was the main focus area. Another ambition was to take smaller scale hydrogen production technology to systems labelled: hydrogen for stationary power; hydrogen/fuel cell system as backup for autonomous energy systems; distributed power / hydrogen and fuel cell applications. Business potential was also envisioned for hydrogen in flexible energy supply / energy management by combining electrolysers, hydrogen storage and peak power.

Concerning large scale, the projection was that the use of hydrogen in energy markets eventually would require large scale CO_2 free hydrogen supplies. To target this, the company had natural gas resources, power, and deposition opportunities for CO_2, hydrogen production - and handling experience, and experience with production and energy sales. The focal business areas gave rise to overarching business goals and visions to establish the company as a leading system supplier of small scale hydrogen generation systems in Europe and use the position in on-site hydrogen production to develop markets. Other overarching business goals was to be in the lead of electrolyser business and flexible systems for hydrogen generation, to be positioned for power and gas supplies in new energy markets in Europe, and to be positioned to enter distributed power markets. The business plan targeted a dual track and a stepwise approach where the link from small scale to large scale opportunities would have to be developed.

There was a sense of urgency in getting started so as to secure a presence in an emerging market and build alliances to facilitate hydrogen introduction and market development. First choice alliance partners were mentioned among energy companies and car producers for hydrogen generation systems for the transportation market in Europe. Partner choices in other parts of the world would depend on the local situation. The experience gained from the actionable first steps in pioneering project initiatives shaped the preferred partner orientation. With regards to hydrogen for flexible stationary energy supply, alliances with fuel cell producers / integrators, and system suppliers needed to be explored as it was too early to point to any one preferred partner constellation.

4.6.7.3 Enabling activities to build commercial activities

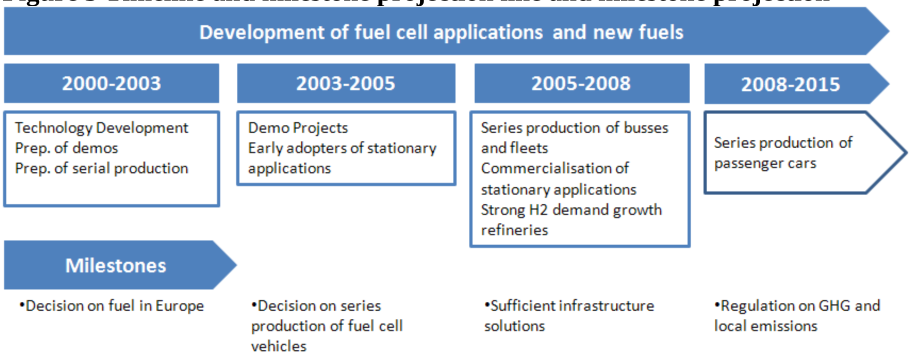
The business plan included a development plan for research and product development efforts for NHEL with turnover and profit estimates. It also included networking in relation to private and governmental stakeholders, funding efforts, profiling, competitors, market and cost analyses; and it included internal resource and competence development. A central part of establishing presence and building a commercial position was to participate in demonstration projects.

Demo projects were pointed to for multiple reasons. *Firstly*, to build competence in Hydro through practical experience in small scale production technologies, experience with the flexibility of production of these technologies, energy flows, and storage. Demos would provide practical experience with different applications and energy market segments, and give insight in market development and the feasibility of technologies. *Secondly*, to establish ties with authorities and decision makers, and build a public perception of hydrogen as reliable in terms of safety and operations. *Thirdly*, to profile Hydro as a competent and innovative partner and hence facilitate partner alliances. *Fourthly*, partnerships and alliances around demos were considered as ways to monitor the market, to access customers, access technology, to share costs of research and development with other private companies, as well as in public-private partnership with governmental support. Reference to pioneering activity and demo participation signalled that hydrogen energy activities would hit the ground running.

External milestones and conditions for commercialisation were projected in a timeline to support involvement in hydrogen energy, R&D

activity and the costs of business development. The timeline indicated the conceptual understanding of hydrogen energy and supported the strategy and business plan.

Figure 5 Timeline and milestone projection line and milestone projection



The hydrogen strategy and business plan were adopted September 2001. Hence maturing it across management teams took over a year, and in a presentation with highlights on the initial strategy process held in 2005, the pioneers labelled the process an "endurance test". The Hydrogen Unit was established December 2001, and NHEL was integrated as part of the Hydrogen Unit. All hydrogen activities were placed in the Hydro Energy Division[204].

4.6.8 Practitioner reflections on strategy and commitment

Strategy and business planning involved talks about the next frontier so as to anticipate challenges, spot important trends, and ask what it meant to Hydro Energy business. How should resources be combined and what should be pursued, were key areas of concern in the hydrogen energy business initiation. Pioneer activities had been undertaken and established a foundational understanding of hydrogen as a future energy contender, and pioneers needed to convince management and resource providers of the

[204] Organisationally, hydrogen business activity was initially organised as a project organisation independent of line management with a steering committee that was to report to the divisional president of Hydro Energy. The main point was to provide full focus on hydrogen issues. This type of organisational structure however was soon undone when hydrogen activity was integrated in the New Energy business unit established in 2003 (section 4.2).

relevance so as to trigger commitment to a coordinated pursuit in a business division.

The adoption of the strategy and the business plan was important because building new business, involved articulating what the organisation wanted to be, and allocating resources to achieve that vision. Management had to define strategic goals and create boundaries for hydrogen energy opportunities, so as to help practitioners make choices in terms of how to focus efforts, who to talk to, and how to spend their time. One pioneer and business developer elaborated on the initiation process and the role of strategy.

«In the beginning, it was individuals in high level positions that thought this was a good idea to pursue …. But the better a strategy is embedded with management; the easier it is to sell projects internally, because either you must sell an idea or project as something entirely new, or you sell it in competition with other things that support a strategy. What was not so clear and easy was the relative risk in the different projects for they all carry a lot of risk. We cannot guarantee that this is how it is going to be…. because the market is not necessarily there… the customer is delayed and maybe cannot buy the hydrogen until the year after. So the projects we undertake are associated with risk but the process is easier if we have a clear strategy on what we are supposed to do, and that the strategy is embedded with top management… When we clean up among alternatives, when you land on focus areas, future markets and applications to be pursued, and what role should Hydro play in this in terms of supply, then there is more pressure on the designated areas … We are asked to participate everywhere, and that is positive but strategy is important because it helps us make choices in terms of how we spend our time, who should we be talking to, and where should we make presentations»

Then chief of staff in Hydro Energy reflected on why management decided to pursue hydrogen energy, and why Hydro integrated the electrolyser technology activity within the Hydro Energy division.

«From a new energy and a Norsk Hydro Electrolyser (NHEL) perspective, the orientation was to get into new areas of business. The main driver and expectation was that something was going to happen in the transport sector and from the point of view of oil and energy business, the strategic thinking was twofold. One was that the electrolyser business was the catalyst to understand developments in hydrogen energy. Without the electrolyser business, Hydro would have no more information than any other actor. With NHEL, Hydro as an energy company would be more extensively involved. We would be involved in daily business activity, understand and monitor what was going on, on a day to day basis; we would understand demand and

get inquiries into deliveries of equipment. Get insight in the frontline of development that we would not get if we were not a technology supplier. Deficits and research and development costs were accepted for these reasons, and also because of the positive profiling. The main idea was that the electrolyser business should achieve commercial viability, to make deliveries and create business that covered costs while also generating knowledge, which was a platform for the continued hydrogen venture. So that was one argument. The other key argument was that it was management's perception that we may be supplying hydrogen in the future and not natural gas. If we did not have knowledge and competence in hydrogen, we risked loosing some of the value of natural gas. We had to secure the value of the natural gas resources possibly by converting it to hydrogen. So these two arguments were central to the establishment of hydrogen energy business»

Further, elaboration on why hydrogen energy was considered relevant is reflected in the quote below:

«We were rather convinced that the climate challenge would be accentuated. If the climate change problem is as serious as we think, then something has to be done in terms of new products, and these would be either hydrogen or electricity, where energy companies play a part. Heat will be predominantly from local production. Fossil energy will have to be converted in some way. It will be either electricity or hydrogen that may become commercial energy carriers. That is the only two that a customer may use without emitting CO2 as compared to gasoline, diesel and natural gas. If we as a company were to play a part in the power market, then we needed to know about hydrogen. So that vision was another foundation. Then the question: how long will we as a company put money into an activity without knowing when and if it turns into a profitable commercial undertaking? This is where we had the electrolyser business. If we sustained the electrolyser business with an annual spending on development and knowledge building; then that was fairly reasonable for a company like Hydro. It was a cheap kind of insurance premium to ensure that we have competence and knowledge in an area that will be important in the future, or there is a great probability that it will be important in the future … The electrolyser business was seen as a valuable tool to preserve this option and to be part in a future where hydrogen is an important part of the energy supply…. The main rationale, in the long term orientation, was that the climate challenge will raise limitations on what we can use as energy. There are plenty of fossil sources – gas, oil and coal, so it is the climate question that sets the limit…. As a company we aspired to keep the hydrogen energy carrier option open, and it seemed that this was the

strategic orientation of Oil and Energy management; the main rationale being to preserve the value of natural gas by converting it to hydrogen»

4.6.9 Initiating the new hydrogen venture and making it known

Initially, there were 4 people working with business development in the Hydrogen Unit, and a lot was done in terms of addressing the question: *where are we supposed to be externally?* What events, fairs, conferences should be attended? The focus was on making presentations and speeches, to make it known that Norsk Hydro had a hydrogen venture. It was important to standout, be visible, and be on the offensive so as to be relevant for potential partners. Focus was on business development and profiling, being speakers at events, conferences and attending hydrogen fairs.

Industry fairs were central arenas to *make it known that Hydro had a hydrogen venture* as well as communicating Hydro's contribution to developing new energy in Europe. The stands, brochures and speeches were built around key messages about the promise of hydrogen energy and Hydro being a viable and committed partner in realising the promise. As mentioned briefly in section 4.5, German fairs had been attended by Norsk Hydro Electrolysers since 1996, and were used to showcase new technology and highlight the relevance of electrolyser technology. The Hannover fair was attended by the Hydrogen Unit in Hydro Energy for the first time in April 2002. A joint NHEL and Hydro Energy stand entitled "Time is right for hydrogen - Hydrogen starts with Hydro"[205] demonstrated that a hydrogen venture was in place.

Source: http://www.fair-pr.com/hm02/exhibitors/hydro.html

[205] "Time right for hydrogen" http://www.hydro.com/en/Press-room/News/Archive/2002/April/16134/

It was announced that Norsk Hydro had made a commitment to the vision of a hydrogen economy[206], and had established a Hydrogen Unit to promote hydrogen in energy markets. Information was given about Hydro Energy being responsible for commercial operations in electricity, crude oil, gas and NGL products, power production and refinery operations, in addition to the transport of oil and gas. With the Hydrogen unit and Norsk Hydro Electrolysers a part of Hydro Energy, all commercial energy activities were said to be gathered.

In advance of the Hannover Fair (April 2002), and as a product of the profiling efforts of Moe in the new Hydrogen Unit, a hydrogen brochure and an electrolyser brochure were put together. NHEL also re-launched its Internet homepage presenting high pressure electrolysers and common atmospheric electrolysers. The Hydrogen Fair in Hamburg (October 2002) was also attended, and it was Hydro's Hydrogen venture and the Utsira project, at the time still in a planning phase, that were highlighted at both fairs.

Participation in EU projects was described indicating that e.g. the CUTE project thrived and benefitted from the experience of Hydro in infrastructure, use and safety. The Iceland project, supported by the EU, was described in terms of Hydro's participation and partners. The Oslo bus demonstration was summarised as well as the H2 ferry project, and participation in multiple international hydrogen networks and collaborations (IEA, HyNet) were also summarised. Hence pioneering activities were fronted as Hydro Energy business activity.

It was the responsibility of the Hydrogen Unit to use meetings, projects and conferences to profile hydrogen efforts[207]. Profiling efforts combined speeches and presentations, written material and brochures, as well as Internet and Hydro Intranet[208] publishing. Business developers in the Hydrogen Unit aspired to create awareness and interest in their work and with extensive communication, the impression was created that this was an active unit. *"Creating a lot of fuss and commotion"* as one business developer referred to it, to make an impression of substance, like

[206] http://www.fair-pr.com/hm02/forum/electrolysers.html.

[207] To be able to communicate at an extraordinary number of events, Moe (responsible for early hydrogen communications) contributed with what was referred to as a "pick and choose" system, a kind of presentation library with generic presentations on e.g. Hydro Energy, Markets, oil, CO2 percentage per tonnes consumed energy and energy sources, project pictures, new energy engagement. On hydrogen, there was the argumentation for hydrogen as an energy carrier, and Hydro's role in this with focus areas and projects. Once activity details and a project story was built and presented in brochures, in presentations, and at fairs, this could also be written into press notices. Information packages with stories to be told combining factual information, a new energy proposition and visions of the future.

[208] Hydro Energy (later Markets) had its own Intranet, which was merged with Oil and Energy's Intranet in the fall of 2002.

Tordenskjold's soldiers[209], although actually, there were only four business developers in the Hydrogen Unit[210].

Persistently communicating in multiple media and at different events signalled involvement, and also concerned the legitimacy of hydrogen energy activity in the Hydro organisation. When activity did not create a return in the traditional sense, something else was fronted as a result of hydrogen activity.

«My motto was that we had to get the profiling right by being active on the Internet, the Intranet, brochures, seminars, conferences and fairs. Profiling and visibility is something tangible. Positive profiling is a visible result for Hydro until the activity started to generate income»

4.7 Pioneer reflections on hurdles to hydrogen business initiation

Future energy systems and supply solutions are products of private and public initiatives. Hydrogen as a future energy carrier was (is) in the making (Appendix I), and the path to hydrogen energy was uncertain. How Hydro pioneers placed their bets on certain technology paths was the product of their interpretation of trends and drivers in the energy market, and how these were built into opportunity definitions.

Views on what hydrogen as a potential energy carrier meant to the Hydro organisation varied among managers, which consequently also meant that there were different perceptions as to what business activity it was worthwhile to pursue. Creating an opportunity space for a hydrogen business venture potentially disturbed the dominant belief about what the organisation was, as it opened up for questions like what business could or should we be

[209] The expression "Tordenskjold's Soldiers" lives on in the modern Norwegian and Danish language and is used when a small group of people play many different roles, often in an attempt to deceive an adversary. Tordenskjold is a Danish-Norwegian naval Hero (Peter Wessel aka Tordenskjold / Thundershield in English). Characteristic of Tordenskjold's victories is that he attacked the enemy with an inferior force as was the case in 1719, when he attacked the heavily manned Swedish fortress Karlsten outside the town of Marstrand on the Swedish west coast. The story goes that Tordenskjold called on the commander of the Karlsten fortress, Colonel H. Danckwardt to surrender within the next five days. The sixth morning Tordenskjold took as many of his crew as possible and formed a small company. He landed a short distance from the fortress and started his little "army" marching past the commander's dwelling again and again, giving the colonel the impression that he had many more soldiers than he really had. It was, however, the same group of men who marched by every time that a "new" company passed the fortress. Finally, Tordenskjold went up directly under the window of the commander's residence and shouted out the famous words: "Why the Devil, are you hesitating? Haven't you realized that your time is up?" Colonel Danckwardt became so scared that he surrendered immediately!

[210] Ivar Hexeberg, Anne Marit Hansen, Vera Ingunn Moe, Elisabeth Fjermestad Hagen.

in, or do we want to be in? New ideas potentially overthrow traditional priorities in an organisation, which was why intrapreneurs had to struggle against the hegemony of established practice.

So which were the main hurdles and what was central in the process from pioneering initiatives to the establishment of a business venture and integration in a business division, as experienced by the pioneers?

4.7.1 Linking the new with the old

One mechanism in relevance building and commitment making was the intrapreneurial effort to link the new with the old in terms of linking the new (hydrogen energy) with existing resources and commercial focus. This involved linking the new activity with issues, priorities and value propositions of existing resources / paths. Initiating hydrogen energy required lots of explaining and anchoring with what people already knew, and existing ideas and values were important as it helped people understand what pioneers were trying to do. Reflecting on how future visions were connected to action in the present, one of business developers indicated that the build-up phase was difficult to project, and that it was not obvious how the transition to hydrogen energy would develop. In the initial hydrogen strategy, the envisioned development path was to go from decentral projects, and that a long term progression to large scale and central supply of hydrogen would follow. Large scale and central supply would evolve and be cheaper once local demand had been established with local onsite production solutions or other decentral supply solutions e.g. the trucking of hydrogen. In the initial strategy formulation, it was important to link the value proposition of hydrogen to the value proposition of existing resources. Hence the relevance of hydrogen energy activity was built by highlighting the interface between hydrogen energy and the existing order of things. The quote below indicates that the initial argumentation for hydrogen energy emphasised the linkage to natural gas experience and the energy system logic of these resources, although this focus was subject to change as time passed.

«Now we are becoming a bit more uncertain as to this position, and I am glad there is not too much focus on this, because it is really difficult to explain how the transition from decentral distributed hydrogen production to large scale centralised production, as we know it from natural gas. There is no obvious transition. So in the context of strategising, we have always been somewhat vague on this point. But it was important to include this long term point of view and projection toward a large scale centralised hydrogen infrastructure, so as to get internal support and commitment to the new venture. Hydro focused on natural gas, the processing of natural gas, and adding value to the natural gas resources; hence this became part of the long term objectives for the hydrogen venture. You have to sell it internally,

this was a sales argument. Additional argumentation was that we had technology to get started now, and argumentation for why we should not wait to get involved. But how the transition and progression would be was not obvious»

4.7.2 Communication and internal acceptance

A second mechanism in relevance building and commitment making was communication. A facilitator of internal acceptance of hydrogen energy was to have activities communicated and mentioned in company reports such as the annual reports:

«Mentioning that we are part of interesting projects in the area of hydrogen sells it internally, if it is part of the annual report. In a way it becomes official and people in the company sees that, yes this is what we are doing, and then they stop questioning, and you get into an acceptance phase. Some people will still be critical, and you are not allowed to do everything, but it has to do with the mental attitude…. It has to do with the point that if something is completely unknown then you continually have to answer questions, and you will never move ahead. If 99% is taking for granted that this is something we are a part of then you are in a phase, where it is a matter of convincing that expenditures and exposure in different courses of actions are reasonable. It is a matter of defining how far we are willing to go and how much we wish to be exposed. But first, you have to make it a part of company activity – that is the internal sale»

The HydroKraft project was mentioned in the Annual report from *1998* indicating that the project was directed toward the development of a more sustainable energy system using hydrogen as the principal source of energy. The *1999* bus project was profiled as a part of Norsk Hydro activity as illustrated with the picture of Norsk Hydro's former CEO, Egil Myklebust, pictured in the project brochure with former Oil and Energy Minister Anne Enger Lahnstein in the hydrogen bus with a sample of the bus' only emission, namely a bottle of pure H_2O – water. In year *2000*, the development of hydrogen as a future energy carrier was mentioned as an area where Hydro's composition of business areas offered opportunities for sharing knowledge and developments between operational areas, and was mentioned as being part of Hydro's research and development programmes. In the Annual report from *2001*, hydrogen as an energy carrier of the future and fuel cells in vehicles for the transport sector was mentioned under Oil and Energy as part of the work in new alternatives. It was indicated that Norsk Hydro, as the world's largest producer of electrolysers and through the participation in pilot projects in Iceland and Norway, were on the way into a market believed to have interesting prospects. In the Annual report from *2002*, it was indicated that Hydro Oil and Energy's worked to develop clean and responsible energy supply based on gas and hydrogen as a future energy carrier. That Hydro was cooperating with other leading companies in testing future energy supply at pilot facilities in Iceland and Germany by building on 75 years of experience producing hydrogen. It was indicated that Hydro was increasing the commitment to hydrogen as an energy carrier while continuing to concentrate on renewable energy sources such as hydro-electric wind and wave power. In the *2002* Annual report Form 20-F filed with the US Securities and Exchange Commission[211], the pursuit of hydrogen and renewable energy opportunities are also mentioned. "There is an increasing interest in renewable energy projects and the utilization of hydrogen in the energy market in developed economies throughout the world. The major political drive - and basis for a number of public support schemes – has its roots in concerns about the security of energy supply and environmental considerations. Hydro has extensive experience within the traditional industrial hydrogen markets as well as with renewable hydroelectric energy production. Hydro is combining this experience with the new developments to establish the Company as a player in renewable energy projects and new energy markets for hydrogen. Hydro is involved in several hydrogen projects targeting the transportation market and renewable hydrogen energy systems. The hydrogen generation solution, produced by Hydro's wholly owned subsidiary, Norsk Hydro Electrolysers a world leading company within alkaline electrolysers, is one element of Hydro's strategy".

The excerpts from company reports illustrate the importance of actionable first steps. Action, events and insights, communicated by pioneers, shaped the mental maps of the organisation, the understanding of activities, and the business of the business.

«To stay afloat, early markets are very important, and you have to make your efforts visible in particular to your own stakeholders… You have to create involvement. To Hydro in general, it is important with a positive mention. If everything else fails, we will still have positive publicity from what we do. But there has to be substance to what we do as there are enough critics in the Hydro system that thinks we can get positive mention and publicity in other ways and the way we used to. So you continually have to sustain involvement upwards, downwards, as well as horizontally among those with important competences. It is about how to integrate products, develop technology, and build plants; if one disappears there is not much

211 http://www.hydro.com/upload/Documents/Reports/Annual%20reports/hydro_2002_20f.pdf

left, so we cannot loose important competences if we are to accomplish something. Sustaining involvement and commitment is very important»

Early projects and market activities were important to make efforts visible to your own stakeholders. Making efforts visible by communicating action and project activity also triggered attention and interest from other organisations.

«When you enter into new areas and show willingness to pursue this area (hydrogen inserted by author*) then you become an interesting partner with whom to discuss ideas. Suddenly we get inquiries in other areas where we may not have had the original business idea. Through such conversations and dialogue we get ideas from others, and this all build into each other»*

4.7.3 Mobilising top management involvement

A third mechanism in relevance building and commitment making was to mobilise top management involvement. This was important to relevance building inside the organisation and to external stakeholders. A main role of top management and the CEO was to set a general direction for the organisation and focus on particular endeavours. Top management attention signalled an assessment of the importance of issues and influenced priorities that in turn shaped action. The early involvement of the CEO (mentioned in section 4.4), where the attention to new energy and environmental challenges, heightened the internal focus on hydrogen efforts and new energy projects. The external communication of involvement in hydrogen energy was also heightened with the media profile and attention when the CEO fronted the projects. One pioneer also commented that in most of CEO Reiten's speeches, presentations or interviews there was something about new energy like wind or hydrogen projects. What the CEO included in speeches built legitimacy and made the hydrogen venture 'official'. It signalled what the organisation was doing, and what it communicated about itself to the world. Another pioneer also commented that top management was important to spark commitment and motivation among business developers working in the hydrogen area:

«I met our CEO while at a seminar where he had a main introduction, and I was to speak on hydrogen. At the seminar he meets representatives from across the organisation as well as the press, and he spoke in length about our involvement in new energy carriers and put it in perspective. Wind and hydrogen, and the wind/hydrogen combination were mentioned as areas where we meant business and not just profiling. I also talked to him before we entered the seminar, and he expressed that there was to be full speed ahead for hydrogen. It was very good to hear this from the "horse's mouth"

…. We must continue to point to our development and make our efforts visible in early markets, especially to our own stakeholders»

4.7.4 Challenging dominant modes of thinking

Finally, a fourth mechanism in relevance building and commitment making was to challenge dominant modes of thinking. Initiating hydrogen energy required that pioneers dis-embedded from existing structures defining relevance, which could also be referred to as breaking a tunnel vision. Pioneers had to mobilise despite resistance to their efforts. Interviews with hydrogen pioneers provided illustrations of dominant modes of thinking that questioned the involvement in hydrogen energy. As one business developer put it:

«It is often a combination of time, place and individuals that have a special interest in an area and contribute to pushing it along. That is if it is not considered mainstream, where there is logic and calculations… If it is something new, you always need that combination because new things are not received with a warm embrace… No new things are considered disturbing»

Producing, using and handling hydrogen was by no means new in the Hydro organisation, but shifting orientation and seeing new potential applications in energy business, was a different story.

«At one point in time there was a Hydro internal hydrogen forum with meetings across diverse business units (fertilizer, metal, energy, electrolysers) discussing applications, safety, prices, and with Hydro's own use of hydrogen being the primary focus. The forum ceased around 1994 due to low attendance, and was indicative of a low point in the interest in hydrogen. Yet the forum looked at this purely from an industrial perspective….This was before the world had realized and before we really understood that hydrogen could become something else than an industrial input factor and product, and had I come through the Hydro system, I would most likely have seen it the same way»

Pioneer activity needed to challenge the voices of convention. In practice, dominant views may have material and physical implications, in the sense that some potential hydrogen energy alternatives were ignored. The Hydro organisation enclosed multiple potentials or historical competences that could be brought to new life or/and be transformed by being connected to hydrogen as an energy carrier. The historical competence in electrolysis was mobilised. Yet in the agricultural division (now Yara), the extensive experience with hydrogen production based on natural gas could have been another entry ticket or passageway through which to pursue hydrogen production and hydrogen in energy markets. But the pursuit of such a path would need interest and support from this particular division.

«Previously with Yara, the Agri business and industry gas, a possible path could have been trucking compressed hydrogen gas[212] but there was little or no interest…On several occasions I tried to talk to the management but it was my impression that it stranded in a "not invented here" stance»

Hence one thing was to boost interest and pioneers indicated that they had to repeat and repeat until the hydrogen areas started to get noticed. Another thing was to shift orientation and challenge the interpretations of what the organisation was doing, and in which businesses it should participate.

«We are a supplier of large scale energy…. so you meet these things which are rooted in the current role that we have, which we shall continue to have, and why on earth should we be doing something entirely different…. When selling the initial strategy, the hard part to defend was the question: are we supposed to be a technology supplier? Because Hydro delivers large scale energy or we are in trading or in aluminium, but we are not a technology supplier and selling electrolysis equipment was not the real Hydro business…. That was a dilemma right from the start in the first round of the strategy process, that is the aversion in Hydro against being a component supplier because that was the last thing we should be»

Over time, however, the perception of hydrogen energy has been subject to change:

«…. There is a higher willingness to look into renewable energy which is a result of efforts over time but also external factors. The climate discussion is higher on the agenda, support and incentives structures for renewable energy are being developed. You see and hear more talk about hydrogen, and the response we have had on some projects. All these things add up and combined trigger the perception that these may be areas of future business»… «I think it is probably fair to say that a common perception now is that hydrogen is viewed as a hedging activity. Hedging against uncertainty in the energy market; hydrogen may become, the world may change, the energy market may change, and we pay careful attention to transformations, and long term, hydrogen may turn into profitable business…. Another perception is that of profiling and signalling that we are involved in innovative activity. What we do has a clearly positive environment profile. At one of the annual meetings gathering the Hydro management team, there were representatives from the financial sector, and

[212] Another possible path coupled with Hydro's hydrogen experience in the agricultural / industry gas segment.

somebody from within the Hydro organisation posed the question: What does the financial market think about Hydro's venture into hydrogen? The response was that this was perceived as positive, as hedging for the future and showing that Hydro is an innovative company that thinks ahead»

5 Relevance building and commitment making – contributions based on hydrogen initiation

5.1 Summing up empirical findings

> Innovation is not like most other business functions and activities. There are no reliable templates, rules, processes, or even measures of success. In a sense, each act of innovation is a unique feat, a leap of the individual – or the collective – imagination that can be neither predicted nor replicated. Innovation, in short, is anything but business as usual….
> (Ellen Peebles, HBR on the innovative enterprise, 2003)

The first part of this thesis has portrayed the initiation processes behind the launch of the hydrogen energy venture in Hydro. Business and path development in hydrogen energy had a long pre-history before getting on track and before resulting in a strategy and business plan. The hydrogen energy path got on track because pioneers or pathbreakers from diverse settings in the organisation worked to sort out information; reinterpret Norsk Hydro's resources and their potentiality in different contexts; and built a case for hydrogen that was used in an internal sales job to convince different management levels about the importance of initiating the pursuit of hydrogen energy.

The first part of this thesis has been concerned with the becoming of hydrogen energy in Norsk Hydro. How hydrogen has taken on relevance and a reality path in Hydro; and what happens in the very beginning of path creation when embarking on innovation processes and a possible venture or path? How does the process unfold from ideas to purpose, to projects and to the launch of the hydrogen energy venture? Chapter 4 has provided the empirical basis to address these questions that were outlined as aspect one or output one of this thesis in chapter 2. The questions are concerned with relevance building and commitment making in organisations that lead to new development path or venture creation.

Chapter 4 has illustrated a mobilisation of action and participation in activities and vision-making long before the formal decision to establish a strategy and a business venture. Pioneering activity was described as initiated from diverse settings in the Hydro organisation, three non-coordinated settings from where bottom up activity, people and ideas converged not as a result of careful planning, but as part of initiatives and action related to the emerging vision and potential of hydrogen as an energy carrier. Many parallel streams of activity, ideas and possible orientations were explored. Development paths and projects were explored and participated in, both in their defining and development over time. Project initiatives and actionable first steps were central and concerned with an exploration of different ways of integrating hydrogen into energy-systems.

The descriptions of research, the technology provider and pioneering hydrogen as part of business development, illustrated that the pioneers got involved in hydrogen energy with different considerations and motivations.

Pioneering hydrogen energy as part of research was concerned with looking at connections between different forms of energy, trying to picture future energy development, and contemplating how it would affect Hydro's business divisions, opportunities, and threats that challenge the value of existing resources. Research was about envisioning, making approximations, and creating the best possible depiction and conception of future development. Participation in demonstration projects were pointed to as an inexpensive way to develop an informational foundation and a backdrop of understanding, on which intentions and courses of action resource wise could be based, so as to position the company in hydrogen energy. There was participation in the EU arena, in developing an industry position on a vision and roadmap to build European hydrogen infrastructure, and in proposing large demonstration activities, which formed the decision basis for industry and politics. The actions and efforts in this arena also established an opening for participation and for assessing technologies, entrepreneurial activity and business ideas in the embryonic hydrogen energy market.

Hydrogen exploration efforts were particularly stepped up with climate negotiations and the Kyoto Agreement since 1997. A prime motivation for the internal hydrogen research project was the concern for the value of the portfolio of oil and gas resources in a world with climate change mitigation and obligations to decarbonize fuels. The environmental challenges associated with particular emissions, and the expectation of obligatory actions to curb emissions, prompted activities in hydrogen as part of exploratory efforts to decarbonize fossil fuels in the anticipation that the expected cost of CO2 would defend investments. Pioneering hydrogen activity and making hydrogen available as an alternative energy carrier, was part of strategic research work to secure the value of the core energy business, oil and gas resources by decarbonizing fossil fuels. *Research pioneers pointed to hydrogen energy as potentially relevant to the core energy business, and failing to get involved in hydrogen energy would potentially threaten the value of existing energy sources.* Although it was been difficult to delimit the transition to natural gas-based large scale hydrogen energy with decarbonized fossil fuels, *this orientation with reference to core energy business has continually been upheld as a flagship in strategies and in the relevance building for hydrogen energy activity.*

The experience with both water electrolysis and natural gas-based hydrogen production (from Hydro's fertilizer production in Agri business) had built a reputation that Norsk Hydro was an actor that efficiently and safely produced, used and handled hydrogen. The natural-gas based competence was a potential starting point to work with Norsk Hydro's natural gas reserves to position the company in relation to hydrogen energy.

However early experimentation and exploration activity did not start with mega factories, large scale hydrogen production stations. Instead Hydro had technology (electrolyser) for on-site production solutions, important in the beginning, and resources were prioritised in this direction. In the initiation period, however, the important thing was not to foretell the eventual future solution but to create a position so that the company could play a part in any possible future hydrogen energy production model (decentral, central, a combination).

It was also consideration for the strategic positioning of electrolyser business activities (NHEL) that led to decisions to join several international research projects. It was by virtue of the extensive and historical industrial experience with hydrogen, that pioneers could put the company out there on the hydrogen map, and offer the company's expertise, competence and technology. Electrolyser technology enabled the participation in demonstration projects, and was used as the door opener and the concrete offering with which to position the organisation in the emerging demonstration markets. Electrolysis competence with Norsk Hydro Electrolysers turned out to be important to Hydro's research entry into the hydrogen era in energy markets and to gain access, monitor progress and courses of action.

Finally, concrete action and participation in research projects was a way of 'investing a little to learn a lot', to invest small amounts to build, test, and shape ideas from which a possible new venture could be developed. The research-related transportation projects were relevant to get a real world validation of components and systems, real world safety records, real world feasibility and performance of hydrogen use, which were all inputs in the process of building the value proposition for hydrogen. Doings and real action built different orientations and alternatives with the outcome involving propositions on a potential future energy system. Actions and propositions themselves became resources and building blocks in continued activity. Action and participation in research and demonstration projects with the design and construction of hydrogen solutions involving electrolyser technology were part of what made this future hydrogen solution possible. It became part of the conception and creation of the future as experience and results in research and demonstration projects became building blocks for further development.

Pioneering hydrogen energy as a technology provider in the Hydro organisation was initiated by NHEL management in response to crisis. The managing director had been given a year to turn around business otherwise its fate was uncertain. The internal demand for Hydro's own electrolysis technology and equipment had withered away and been replaced by industrial hydrogen gas production based on natural gas, and NHEL was increasingly dependent on external industrial customers using hydrogen in industrial applications. *Hence the particular corporate resources associated with water electrolysis were experiencing a declining value inside the company while the existing industrial market was also subject to fluctuations. That the value of the competences and resources eroded with the decline in demand was a key driver of exploration- and intrapreneurial activity.* Emerging out of this material situation, new paths were explored to turn the crisis into an opportunity, while also working to sustain the traditional industrial market outlets as the lifeblood of the company.

A search for new opportunities and prospective markets was initiated, which rested on pioneer sensitivity noticing that hydrogen was potentially of interest to others than the traditional industrial users. *Hydrogen had advocates in multiple circles arguing for its energy carrier potential, and relevance building involved linking hydrogen energy with what may be labelled as issue and attention drivers* that is challenges of the present such as finite fossil fuels, security of supply, environmental degradation. Hydrogen energy and hydrogen technologies re-emerged as a low carbon energy solution conceived as means to handle these challenges and as enablers of energy independence. *Hence building relevance in relation to unresolved attention drivers was a main aspect in the mobilisation of resources in early of intrapreneurial initiatives and in commitment-making.*

Ideas and visions matured and materialised by having a large circle of contacts internationally through conferences, journals, research, politics, and interest groups, that is by participating in hybrid forums where hydrogen, as an energy carrier, was in a process of being defined. Interacting with others and staying connected allowed the organisation to access ideas, conceive of technological development and potential applications, and to explore collaborative options. Linking with issues or attention drivers was part of the relevance building within Norsk Hydro Electrolysers (NHEL) in terms of arguing the relevance of new paths for NHEL activities. Entering into partnerships, participating in demonstration projects, and market preparation activities were also ways to sway international- and partner focus toward production of hydrogen via water electrolysis.

Existing technology and historical competences in NHEL were concrete building blocks to reconfigure something new around. However the orientation into new ideas and actions quickly took on a material path as the existing technology was not suitable for the type of production profile and sites that were conceived and emerging as opportunities for hydrogen energy. New performance attributes were sought in hydrogen energy applications at new sites, for which technology development had to be launched. *It was the pre-existing resources that provided an entry ticket, but once the electrolyser technology was put out there among other hydrogen energy actors, it triggered a re-interpretation of resources and skills through its re-coupling with new applications and new objectives. Opportunities arose from seeing opportunities for the coupling of resources and technologies in new combinations in new settings. With hydrogen energy carrier activities, there was a necessary re-coupling of resources and skills also with a consequent coupling to new actors and networks through which further relevance was build for the activity.*

It was an interesting mix of individual advocacy and historical competence, which was used to access arenas and hence actors that were part of defining, developing and realizing hydrogen in energy markets. This mix became the entry ticket to the composite of technological, political and business development. There was absolutely nothing automatic about this, it was very much a story about pioneers or pathbreakers[213] that argued for future activity. That new paths in hydrogen activity was initiated by the technology provider was neither accidental with external threats or 'shocks' being the sole explanation, nor can the initiation of the hydrogen energy paths be said to be determined by a planned and natural extension of electrolyser activity. The initiation of new activity was the result of pioneer or pathbreaker efforts trying to build relevance for the existing resources experiencing declining value by taking actionable steps such as participating in international arenas and demonstration projects. However, to create a break-through for the initiated activity, the perceived new opportunities, and to be able to carry out the technology development effort, it required a linking process to get resources beyond those in their immediate control. *Demonstrating internal relevance to top management was a necessary ingredient in this respect, and the exchange and interaction with representatives from the corporate division and the energy division were important to tap into the resources of the core business organisation, so as to make hydrogen significant beyond its relevance in the electrolyser business.* It was important to trigger a process of understanding why the electrolyser technology provider was still important in relation to core

[213] 1. One that opens a path or trail. 2. One that is original or innovative; a pioneer. The American Heritage® Dictionary of the English Language. Fourth Edition copyright ©2000 by Houghton Mifflin Company. Updated in 2003. Published by Houghton Mifflin Company. All rights reserved.

energy activity, and to build relevance for electrolysis in the pursuit of hydrogen in energy markets.

Pioneering hydrogen energy as part of business development in Hydro Energy was part of exploration and efforts to assess the potential threats to existing energy business. Hydrogen was looked into among alternative fuels to ascertain trends and contestants to the products/ fuels of the core energy resources. The motivation behind exploratory activity was to learn about hydrogen for transportation and as an energy carrier. Early hydrogen and mobility oriented projects were a way to track development and get feedback as to the introduction of hydrogen in energy markets; when the hydrogen market was going to come; what other actors and companies were doing; to get best practice information; and insight into main competition.

Participating in dialogue and examining efforts with industry/authority/research partnerships provided insight into value chain analyses, the planning and organisation of future energy demonstration projects, hydrogen energy roadmaps, and objectives among hydrogen stakeholders through collective vision building activity. In concrete projects, action and resources were considered toward the development of technologies, energy system solutions as well as applications. By connecting with international activity and other hydrogen actors, practitioners attempted to stay attuned to activities and ideas of advocates and other organisations, and to establish an orientation and a sense of direction in hydrogen energy activity. Practitioners tried to position the organisation based on what was interpreted as possible and likely. Align what was observed and heard with what to do, believe and initiate inside the organisation. In a world with hazy boundaries the pioneers were building a world view, so to speak, by taking concrete, actionable first steps.

However, practitioners were just as much part of defining and building the opportunity space by shaping the strategic orientation, material and development action necessary to make hydrogen energy visions a reality. Participating in multiple and hybrid forums allowed pioneers to move their ideas around by communicating about NHEL/Hydro initiatives and views with respect to technology and applications, and thereby influencing and setting action into motion to create a future with hydrogen energy. International cooperation and project participation were arenas or opportunity spaces where possible action and resource constellations were explored and defined. Participating in the definition and planning phase also put the Hydro name out there among hydrogen constituents, as did other communicative acts such as journal articles, reports, and presentations.

At the time, pioneering activity and international involvement were without clear foundation in a business division, and hydrogen energy did not have a clear standing as relevant for business activity. The outcome of

collective vision building, getting involved and connecting with others in concrete activity, was unclear at the time, as a business strategy and business plan were both non-existing in Norsk Hydro. Business potential was studied and 'guestimated' to find a way to communicate the significance of hydrogen as a possible future energy carriers. Based on the initial spurs and early pioneer activities, Hydro Energy management eventually requested a plan. Expectation from management had emerged to come up with a plan.
The practical involvement built relevance by fostering an understanding and projection on the possible role of hydrogen as an energy carrier; building a timeline for infrastructure development; building an informational basis for evaluating and substantiating the possible involvement of Hydro, and the potentiality of Hydro resources in different hydrogen energy paths. The meaning of international initiatives and visions emerged as pioneers worked out what they meant to them and to their specific situation and organisation. The meaning of hydrogen initiatives and visions was moulded by the way people took them up in activity in their local company setting in a particular place at a particular time. The pioneers or path breakers had reinterpreted Norsk Hydro resources and their potentiality in different contexts.

The actual strategy proposal and business plan showed that business development was far from the linear sequence of "identify demand and market supply". Rather a multitude of activities was suggested such as analyses of risks and uncertainties; identify demonstration projects and partnerships with other market makers such as industry, and research, with the objective to build competence, access technology and customers, and explore technical feasibility; as well as partnerships with authorities for planning and support. All enabling activities were proposed to diversify risk and share costs, and construct a basis for a hydrogen energy path so as to develop business opportunities, and for Hydro to become a preferred supplier of hydrogen.

However, having built an understanding on possible futures that substantiated hydrogen as a contender in future energy markets, the pioneers or path breakers still needed to get commitment from management layers to a hydrogen energy venture. The 'WHY hydrogen' argumentation was entangled in concrete activity and the actions of others. It particularly advanced a dynamics where connecting with others, undertaking collective development projects, and other organisations' hydrogen activities were communicated inside the Hydro organisation, which helped legitimize a venture, created a sense of urgency, and supported the argumentation before Hydro management.

As it concerns mobilisation mechanisms in the commitment-making process to get management approval to the new venture, the study points to several aspects. *Firstly*, it was important to challenge dominant modes of thinking and voices of convention about what the organisation did and were (a supplier of large scale energy, being a technology supplier, selling equipment, owner of energy plants). Attention is a scarce resource. It was important to continuously pitch information and ideas about hydrogen energy to people in management positions so as to sustain interest and win hearts and minds by shaping their views on future energy, and their views on the potentiality of Hydro resources in relation to such world views. *Secondly*, it was important to link the new with the old by linking the new activity with priorities and value propositions of existing resources and core business. The pioneer/ path breaker argumentation projected a long term opportunity and use of hydrogen in energy markets eventually would require large scale CO2 free hydrogen supplies for which Hydro had natural gas resources, power, and deposition opportunities to build a position. However since the short term sourcing of hydrogen was expected to be more local, it was central to build on other strengths. Electrolysis technology and competence could be used to build a commercial position and establish a presence in an emerging market by participating in demo projects as a player in on-site hydrogen production. So the new was anchored against the backdrop of existing resources and commercial focus. *Thirdly*, communication of pioneer activity in company reports was important as it triggered attention from other organisations, but it was also central to commitment-making as it shaped the mental map of the organisation by making efforts visible to internal stakeholders, signalling the new path and activity as something the organisation was part of, which was part of building acceptance for the new venture. The point was also to stir up enough interest for a formal strategy process to be initiated. And *fourthly*, it was important to get collaborators in high level organisational positions where it was possible to elevate hydrogen, as a possible future energy carrier, before central management. Further, top management involvement was central in commitment-making as it set a direction and signalled the relevance of projects and business activity.

5.2 Contributions to conceptual resources and disciplinary dialogue

5.2.1 On equivoque, mindfulness and sensemaking

The research questions on how hydrogen energy was initiated and incorporated into the organisation as something relevant for business activities relate to the discussion of sensemaking. Because new technologies are equivocal, they require ongoing structuring and sensemaking if they are to be managed. When committing to innovation projects and a new venture creation that hold uncertain outcomes, practitioners are involved in sensemaking and building an understanding based on which action is mobilised. It is based on this understanding that activities and initiatives are given explanation, which is used to convince, 'sell' and make sense of the innovative activities to the organisation at large.

In the discussion of perspectives and conceptual resources in chapter 3, it was argued that sensemaking is a collective phenomenon among interactive organisational members inside the organisation. Based on my empirical study, I argue that organisational sensemaking emerge from an assemblage of inputs from within and from others. There is a relational dimension in these processes, and sensemaking and the processes of enactment are distributed phenomena emerging while connecting with others. When connecting with others in concrete activities, something becomes when one's understanding, ideas, people, and objects (material resources) come together with the understanding, ideas, people, objects (material resources) of others. This is particularly relevant when trying to understand development activities in the making, where scientific, cognitive, technical, social, institutional dimensions not only come together but evolve together. Sensemaking and processes of enactment should be explored as emerging from dynamic interpretive processes and connections in practice and between actions, actors and objects.

Pioneering activity and connecting to international initiatives and projects were ways of acting one's way into an understanding, get input, and be a part of the shaping and the definition of when, if and how hydrogen energy was going to come. But pioneering activities were about much more than fitting the organisation to its circumstances. Yes, activities involved an element of finding consonance with the circumstances, but it was not about responding in a reactive mode. Rather there was a much more proactive process, where pioneers in the organisation creatively tried to influence actors and organisations outside their domain. The organisation activates others and other actors and resources activate the organisation. The organisational circumstances emerge from a more proactive stand to shape ideas, activity and development in a desired direction, and where pioneers, and hence the organisation they represent, also try to convince others to build momentum behind certain directions in hydrogen energy, and where the organisation in junction with others actually are part of defining and setting up the organisational circumstance.

Taking part in concrete actions, doings, project activities, international negotiations and arenas were much more than making a delivery and being done. Connecting with the actions of others, being in research, policy arenas, development and demonstration projects, were sites and platforms for multiple activities, discussions or doings, and ways of acting one's way into understanding. Action also turned ideas into realities such as defining policy and enabling programmes, building technological experience, conceiving future energy solutions, and building solutions for a hydrogen infrastructure. Connecting with others in concrete actions is part of what generates an understanding of future paths but also creates future paths, and such involvement is also used inside the company in relevance building and in commitment-making. Hence in the enactment of strategy under uncertainty, there is an interesting coupling process of attention, communication and action, where the organising and interpretive efforts of others are connected with the organising and interpretive efforts of the organisation. My study illustrates how actors mobilise attention, relevance, commitment and resources around certain alternatives, and that the relevance of these alternatives in hydrogen energy emerges while connecting with others in projects and in practice.

Further, pioneers or pathbreakers see and develop ideas and opportunities that their resources can handle. Organisations operating in new technological fields have to cope with high levels of uncertainty. They try to create meaningful and sensible strategies in fields where technological trajectories are uncertain, regulatory frameworks are evolving and markets are undeveloped. In such circumstances, the company seek to keep uncertainties under control by shaping the strategic vision around the immediate resources and opportunities they have at their disposal, and attempting to shape actions and the future around the strategic vision. This involves trying to persuade others to help build momentum behind the favoured strategy and outcome, which suits the capacities and resources available to the company. The organisation thereby also seeks to build the 'business case' and preserve its continued relevance by offering solutions to issues or attention-drivers at hand in national and international domains.

5.2.2 On path creation and mindful deviation

In path creation thinking a central argument is that diverse actor-groups involved in development in emerging technological fields, including producers, users and regulators, create their own set of practices and relevance structures that co-evolve with technological artefacts. The perspective acknowledges that there are many constraints on human agency associated with entrepreneurship and the disembedding from established practice and webs of significance is central. Wherefore building alternative webs of significance and relevance seem to be the flip side of the coin and important among actor-groups but also within an organisation. However, the path creation perspective does not address how relevance emerges or the mobilisation mechanisms in the commitment-making process from perceiving opportunity, creating attention, to committing resources as the basis for path creation. Garud & Karnøe (2001) do not specify and work with *what relevance building is made of and how it comes about in* *organisations, which on the other hand seems central to grapple as it addresses what happens at the very beginning of a possible path to trigger commitment to path creation.*

My study has illustrated that business and new venture ideas emerged at "the bottom" of the organisation among business developers / pioneers through their activities and associations. Connecting to the outside of the company was a central aspect in building an understanding, visions of possible future energy states, and hence connecting to the outside of the company was central in relevance building. A business developer eloquently described the challenge of "not knowing" the end station or final destination, when trying to advance business strategy and project ideas, where there are vague contours as to the future, possible applications and market segments.

"We do not know if the market is coming, we may not even completely know what the market is about. Planning in a fog is not easy. You know that there will be something when the fog lifts but you don't know what it is and how it will affect us»

The mobilisation of ideas and resources around certain hydrogen energy alternatives, and the relevance of these alternatives emerged while connecting with others in projects and in practice. Ideas and alternatives then had to be sorted through and packaged into strategy plans that could win support, funding and commitment. Relevance building and commitment making to hydrogen energy paths, that did not have assurance on returns on investment, growth potential, and demand, were arduous tasks. Figuratively put it was like searching for something in the dark and to provide compelling argumentation for action in the present to make it possibly big in the future. The demonstration of large potential was necessary to gain internal relevance and this was achieved through a cross coupling of resources that is by showing the relevance of hydrogen energy to other company resources. Hence central to commitment-making, and to getting resources beyond those in the immediate control of the pioneers, was to make the new venture relevant to core resources and competencies; this was a central ingredient in demonstrating internal relevance to management.

Collective action and connecting with others were central to relevance building and commitment-making, and my study has illustrated how pathbreakers linked pioneer activity in connection to others with path creation and venture development in the organisation. *Mindful deviation was only the starting point. Then it was about nurturing and sustaining relevance and commitment.* Why is it important to study these dimensions? Because relevance building and commitment-making are key aspects in the initiation of path creation activity and thus innovation processes. My empirical study has illustrated that business development and path creation in hydrogen energy had a long pre-history before getting on track. The hydrogen energy path got on track because pioneers or pathbreakers from diverse settings in the organisation initiated actions and projects, communicated development efforts and international visions that combined built relevance for hydrogen energy.

My study shows that mindful deviation and mindful actors in organisations start working on new paths with their immediate organisational circumstance as the basis for activity. While recognizing the embeddedness in structures and activities from which practioners attempt to mindfully depart, my study also indicate that pathbreakers shape their strategic visions around available resources, and that ideas and opportunities are developed that their resources can handle or may be transformed into being capable of handling. It was the existing resources that provided an entry ticket to development initiatives, but once the existing resources were put out there among other hydrogen energy actors, it triggered a re-interpretation of resources and skills through their re-coupling to new applications, new objectives and agendas. Relevance was built through re-coupling. Opportunities arose from seeing openings for the coupling of resources and technologies in new combinations in new settings. Hence resources had dormant potential that could be mobilised, meaning that they could be re-invented with new actor linkages, material constellations and new applications.

Commitment-making inside the organisation was pursued by challenging dominant modes of thinking, communicating extensively about pathbreaker activities hence creating familiarity and acceptance of the activity as part of company activity, by mobilising top management involvement, and by linking the new (new paths / activity) with the old (existing resources, value propositions and priorities of the organisation), which made management more inclined to commit to new venture activity.

Path creation activity within organisations are described as fuelled by entrepreneurs that are knowledgeable agents with a capacity to reflect and act in ways other than those prescribed by existing social rules and taken for granted technological artefacts (Garud & Karnøe 2001:2-7, 23), but the emphasis is on collective action, as mentioned in the review of process theories of technology emergence (Van de Ven and Hargrave 2004:277-292). There tend to be lopsided attention to technology entrepreneurship as the larger process that builds upon the efforts of many; at the expense of attention to initiation and path creation activities within the organisation. Focusing on the collective process of creative synthesis somehow leaves a focal organisation an unopened box.

This is tricky as collective path creation activities, to emerge and continue, rely on commitment from organisations. We cannot make sense of path creation without reference to the intentions of practitioners in organisations, their visions and plans or orientation to goals located in the future. Pioneers / pathbreakers in organisations work from existing resources with some future destination in view, try to construct relevance for their orientation and then seek to bring it about. On the other hand, when trying to handle path creation and innovation activity - e.g. in an uncertain setting such as hydrogen - plans and intentions are not set in stone as practitioners are concerned with the definition of the subject matter, and then taking steps to deal with it e.g. by undertaking activities and projects with others, which in turn brings about further redefinition of the subject matter, plans, and intentions.

Pioneers / pathbreakers organise, without having the support from a recipe or a 'one best way' to do so, nor any clear and stable alternatives to choose between. This is why the initiation of path creation activities within the organisation is interconnected with collective path creation activities because connections are conduits to collective framing processes and to joint activities such as experimentation with new resource configurations. Connections likewise shape path creation inside the firm by involving a spiral of taking stock, reinterpreting resources, modifying the strategic vision, seeking to build relevance for the vision, conceiving development needs, working for commitment to development, and then seeking to bring it about, which in turn sets in motion a new spiral of taking stock, interpreting resources, visions, development and so on in a growing spiral. *Path creation conceptualisation should therefore be extended to consider how connections and the collective activity in innovation processes/ path creation are interconnected with interpretive and path creation activities within organisations.*

5.2.3 On The Innovation Journey

In chapter 3 discussing the innovation journey and focusing on the initiation period, 'Innovation Journey' authors talk about a gestation period where people are engaged in a variety of activities that set the stage for innovation. Innovation processes are not initiated on the spur of the moment, and the gestation period is frequently a lengthy part of the process, which was the case in my empirical study with the long pre-history before hydrogen energy got on track. Innovation journey authors indicate that innovations are not initiated by a single individual or by a single entrepreneur; and "shocks" from multiple sources, such as deteriorating performance, changing conditions or awareness of technical possibilities, may happen in parallel and may trigger the recognition of the need for change, which then cause entrepreneurs to start innovation efforts and identify the feasibility of a business idea or project as a vehicle to solve a problem and exploit a commercial opportunity. My empirical study shows that single pioneers or pathbreakers indeed were extremely important for the innovative venture to be launched. The hydrogen energy path got on track because pioneers or pathbreakers from diverse settings in the organisation worked to sort out information, reinterpreted Norsk Hydro resources and their potentiality in different circumstances, and mobilised an internal sales effort to convince different management levels about the sense of initiating the pursuit of hydrogen energy and to undertake hydrogen energy-related projects. 'Shock' or crisis set off the explorative search in one of the three settings (the technology provider) from which hydrogen activity was initiated. In the other settings (research and energy division) exploratory activity was set off as part of trend spotting and awareness of technical possibilities and not so much immediate necessity.

In the mapping of innovation processes, Innovation Journey (IJ) authors indicate that the prospect for innovative action, path creation and nurturing parallel paths depend on 'shocks' that may trigger the recognition of the need for change. This conception however depends on what qualifies as a shock, and paths are difficult to deviate from without a shock.

Recognising that people may or may not perceive a given event as a shock that stimulates action was by the IJ authors explained with different individuals adaptation and threshold levels for dissatisfaction and opportunity recognition, and it was indicated that the shock and stimulus may not be of a sufficient magnitude to exceed the threshold and to cause the people to act to correct their situation.

Based on my empirical study of pioneering activity, I think there is more to say in addition to the explanations that sees it as a matter of stimulus magnitude, equivocality, and threshold levels for opportunity recognition. The reason is that organisations are not monoliths with a homogeneous unified purpose but products of their creative participants that initiate new courses of action. Opportunities do not hang loose waiting to be recognised rather they must be created, committed to, and the recombining of resources and development is tied with ideas. People in organisations do not have attention to the same issues neither the same resources, and hence may not share perceptions on 'shocks', opportunities, and ideas. In a pluralistic organisational world, managers coexist with different and competing interests and perspectives.

This observation seems to be a central dimension in the gestation period. It takes practical intelligence to get initiatives rolling and innovation journeys do not sell themselves. It takes time and effort to move from awareness of trends or threats, technical possibilities, early ideas amongst some pioneers, and to commitment-making to something tangible like setting up a business unit and initiating technological development projects. There are numerous possible courses of action in hydrogen energy, and there is no single ‘best’ way or right answer to how to proceed. Wherefore ideas need to get attention, and innovation journeys and path creation activities need to be made relevant. A central aspect in the empirical study of the establishment of the hydrogen venture was the involvement of pioneers in concrete activity and then taking this experience inside the company where practitioners’ defined organisational reality - ‘reality creation’ – in efforts to describe urgency, technology opportunities and new courses of action. A value proposition for the new venture / hydrogen energy activity was also advanced by linking it with public issues or attention drivers.

Wherefore my study adds to the innovation journey perspective particularly by illustrating a less reactive and a more action-oriented process than the interpretive processes (adaptation and threshold levels for dissatisfaction and opportunity recognition, stimulus magnitude) mentioned by the authors of the Innovation Journey. Pioneers or pathbreaker activity involved doings and real action in development projects and in connection with others. They built different orientations and alternatives with the outcome involving bids on potential futures, and the bids themselves became resources and building blocks in continued activity. *Concrete projects and doings created an understanding, and pioneers and pathbreakers were actively portraying and communicating about a possible hydrogen energy future, opportunities for company resources in this future as well as communicating suggestions on priorities and related action.* This illustrates a more action-oriented process within and outside the organisation, where action is intertwined with interpretive sensemaking processes, which is intertwined with communication and suggestions on development activities and new priorities for the organisation.

6 The Utsira demonstration project

6.1 Synopsis Utsira

Source: www.statoilhydro.com

The island of Utsira is located 18 km west of the city of Haugesund, 1 ½ hour's boat trip off the western coast of the Norwegian mainland. It has the smallest population of all municipalities in Norway (about 240 inhabitants) and a total area of only 6,15 square kilometres. The island is connected to the mainland for electricity through a ~17.5 km sub-sea cable (from 1983) with an operational voltage of 21 kV, while the power on the island is distributed through a lower voltage grid (10 kv). The transformer station connecting the low and high voltage grids has a capacity of 750 kW. Due to the transmission restriction caused by the existing connection, only a limited development of wind power is possible on the island. The whole island's peak power consumption in winter time is approximately 900kW and the annual consumption is approximately 2.5GWh. The municipality of Utsira has an objective of being independent of power supply from the mainland and to be self-supplied with renewable energy. Utsira has a history of having diesel electric generation on the island but with the ambition to be self-supplied with renewable energy, plentiful wind resources have been conceived as a natural means to achieve this goal. Yet in order for an island community to be self-supplied with renewable energy, and at the same time be independent of a cable to the main land, energy storage is a key issue. Storage of energy as hydrogen is a possible solution to comply with the need for long-term (days) storage also with a potential for compactness and low maintenance costs.

July 1st, 2004, Hydro inaugurated a wind power and hydrogen plant on Utsira, and it has been in operation since winter 2004/2005. The main aim of the project has been to provide a full scale demonstration of how renewable energy resources may provide a constant and effective power supply in remote areas. The hydrogen and wind power plant and demonstration project was to operate in a real life autonomous mode and the system was to serve a load consisting of ten domestic households, which was selected for technical as well as financing reasons. Utsira has the world's first full-scale[214] combined wind power and hydrogen plant with the aim to demonstrate, test and develop new technology based on wind power, hydrogen production technology as well as hydrogen-based electricity generation technology.

It is a full-scale test with real customers getting their entire energy supply either from wind power or wind-generated hydrogen. The project is aimed at better understanding how an intermittent energy source like wind can be more effectively utilised using hydrogen as an energy storage medium. The ample wind resource makes Utsira a natural choice for wind power production. However, as is also the case with other renewable energy sources, power production varies. At Utsira, wind power alone would not be sufficient. The island can be ravaged by violent storms, but at other times there may be no wind at all. Wind turbines cannot run in either of these circumstances. A storage solution can encourage local production as well as help facilitate that consumers can have their demand covered independently of the wind intensity.

Hence at Utsira, hydrogen is used to conserve wind energy, and there are three basic principles in the combined wind power and hydrogen plant: 1) when the wind turbines at Utsira are running at optimum level, they will produce more energy than the community needs. The surplus energy / excess wind power is used to produce hydrogen for storage through water electrolysis and hydrogen thereby provides chemical energy storage. Additional surplus energy will be sold in the market and one of the two wind turbines will produce solely for the market. 2) The hydrogen produced is compressed and stored in a gas storage vessel and will be available when needed. 3) When the wind turbines are not in operation – when there is too little or too much wind – a hydrogen engine and a fuel cell converts the hydrogen back to electricity, when electricity is needed. This ensures a constant, secure source of power without having to rely on the national grid.

---

[214] As discussed in Appendix I there had been private home experimentation with a wind-hydrogen combination. In 1894 Danish scientist Poul LaCour worked with the idea to use the DC-electricity from his wind turbine to electrolyse water into hydrogen and oxygen, to store the two gases in big gas containers and use them for room lighting at Askov Folk Highschool which he did from 1895 to 1902. A central disadvantage of LaCour's activity was that he had to replace school windows several times due to hydrogen explosions when too much oxygen entered the hydrogen volume. www.poullacour.dk
http://www.windpower.org/da/pictures/lacour.htm

Ten households on the island will regardless of wind speed receive wind power all along and using hydrogen to store the energy produced by the wind turbines will ensure a sustainable energy system. It has also been envisaged that stored hydrogen in the future can be used as fuel for island vehicles and boats.

During the demonstration period, the main focus is on: making the installed components in the autonomous system function together; deliver power with the expected quality and reliability to the customers; cost reductions, technical/ operational simplifications and optimisations; and commercialisation and market-related activities.

The demonstration project was well on its way and ongoing as the project idea was advanced in the latter part of the 1990s, and I gained access and permission to conduct my study in October 2004. So some aspects of the project were 'history', the initiation and construction phase was complete, and the project had started its demonstration activity when I commenced my study. The project was still up and running when I for practical reasons (my PhD period) drew an artificial line for the conclusion of my study, which I set at the time the organisation merged with another Norwegian energy company, October 2007. So my study has combined the study of 'history' with a real-time research approach, which as Magnusson (2003) points out, distinguishes the study from most technology studies, which have been conducted retrospectively. The advantage of this approach is that it has provided an opportunity to portray the twists and turns on the project as experienced by the involved practitioners asking into the role of the demonstration, learning from experience, the unfolding of events and activities that is the ongoing process where practitioners navigate midstream activities.

The chapter provides a holistic account of the realization of the project as it has been described, told and presented to me in interviews with Hydro people that are part of Hydro's hydrogen venture team and have contributed, been associated with, and worked on the Utsira demonstration project. Flaws in the account like important people and important information left out are naturally my responsibility. The picture below is an attempt to sketch the contributions made from people in Hydro. Since I personally prefer to see the people that I read about, I thought readers would find it valuable to see the people that are mentioned as the figurative hands that have shaped the Utsira project from Hydro inside.

Figure 6 Making the Utsira demonstration happen in Hydro

6.2 Initiating, designing and deciding Utsira

"For Hydro it is important to integrate technical and research expertise in operational demonstration projects… through projects we wish to show that hydrogen may be part of our lives in the future….It is important for us to show what is feasible today, even though cost levels and policy frameworks are not making the technology available in large scales. The challenge is to show that we are patient enough to develop energy concepts further and over time so that they become interesting to a larger market segment."
(Rostrup 2003 *Looking ahead to the future*).

Company documents outlining Utsira facts on the inauguration date indicates the start of the pre-project period to be January 2002. Further, presentations show the final decision date to be April 2003, construction from June 2003, commissioning of wind turbines, hydrogen system to the site spring 2004 and opening summer 2004, and fuel cell implementation end of year 2004. However, looking into the conception and unfolding of the project takes one much further back time wise.

Christopher Kloed[215] was instrumental to the becoming of Utsira and has been given credit for bringing the wind-hydrogen project idea to the Hydro organisation. Inside Hydro, the initial Utsira idea was carried by Kloed, and as we shall see, once a decision was made to realize the project, new people became instrumental to the project's realization. Kloed, however, also pointed out that the initial idea or conception of a combined hydrogen and renewable energy system on a Norwegian island was presented to him, and Norsk Hydro Electrolysers in the Hydro organisation, by an external consultant, who in 1998 approached Kloed and invited NHEL to be part of an island project with a combination of wind power and hydrogen. Together with Kloed, the CEO from the project development company, Energy Development AS[216], was on the board of the Norwegian Hydrogen Forum in the late 1990s. Energy Development AS investigated hydrogen energy systems for islands and the concept of local renewable energy systems based on hydrogen and renewable energy sources as an alternative to investment in new transmission lines or sea cables. Energy Development AS was part of three Norwegian island studies (reports issued: Orten June 1999, Utsira 2000, and Røst October 2001).

[215] Managing director of Norsk Hydro Electrolysers NHEL, 1993 through August 2004

[216] Energy Development did analytical work and was also central in advancing the idea behind the Oslo Hydrogen Bus Project, a project that was since realised with NHEL representing Hydro and with participation from Elisabeth Fjermestad Hagen from Hydro's Energy Division as part of her work and investigation into alternative fuels (chapter 4).

The Orten study was an early inspiration to the initiation of the Utsira project and Hydro's hydrogen energy activities. It is through the acquaintance and collaboration on the Norwegian Hydrogen Forum (NHF), that NHEL's managing director Kloed in 1998 was approached by the managing director from Energy Development AS with a proposed feasibility study involving an imagined wind-hydrogen system on the island Orten (outside Molde with about 15 inhabitants). The study was partially supported by the Foundation for Environmental Responsibility (Stiftelsen Miljøansvar), but was in need of additional funding, which is why Kloed at NHEL was approached. The Orten wind hydrogen system was never realised or built, but to Kloed and NHEL, the preliminary study (June 1999) was a concretization of a wind / hydrogen system design, which had also been discussed in international journals since the early part of the 1990s (see chapter 4). Although never built, Kloed indicated that the Orten study provided additional impetus, since it supported the idea that it would be possible to develop such a system. It provided information that made this type of project appear as a realistic solution and not just 'wishful thinking'; a solution where hydrogen could be used as energy storage for wind power, solar, and wave energy. This was at a time where Kloed, as part of fronting hydrogen energy for the electrolyser business, was on the look-out for new and potential markets (chapter 4).

In the summer of 1998, Kloed was on a leisure trip to the island of Utsira; Norway's smallest municipality (at the time about 250 inhabitants)[217] and an island with rocky shores, windswept scenery, hiking trails, and an archaeological site. Kloed and a companion walked to the highest point of the island and met a fellow working by the island's lighthouse. The fellow turned out to be islander and Chief Councillor, Robin Kirkhus. They ended up in a conversation about renewable energy where Kloed talked about his interest in the hydrogen and wind combination, and Kirkhus indicated that this type of sustainable solution was exactly what would be desirable for the island. Here is how the story of the initial contact and meeting was referenced on the Hydro's

Source: http://www.hydro.com

[217] Utsira population 1999:246, 2000:256, 2001:232, 2002:233, 2003:224, 2004:215, 2005:213 http://www.ssb.no/folkendrhistlf/tabeller/tab/1151.html

home page:

«But the exciting story of Utsira begins with a series of chance occurrences. Like many Norwegians, head of Norsk Hydro Electrolysers Christopher "Toffen" Kloed and his companion are fond of hiking in the Norwegian forests. On one occasion, however, the challenges were proving too great: thick, damp fog came rolling in, completely surrounding their mountain lodge near Kongsberg. It was clear that their planned hike to Vestvidda would have to wait; as he grasped for his map book that had fallen to the floor, they contemplated alternatives. By chance, the book had fallen open at the pages for Utsira – a windswept island on Norway's craggy west coast. Since neither Kloed nor his companion had ever visited the island, they decided to head west. On Utsira they followed the hiking trails around the heart-shaped island, ending up at the lighthouse overlooking the cluster of wooden houses below. Their arrival aroused the curiosity of the man scything the grass around the lighthouse, and they exchanged greetings. The man with the scythe was none other than chief councillor Robin Kirkhus, at the time living in the lighthouse itself. The visitors' background triggered his interest; sensing an opportunity, he invited them inside for a drink. Kirkhus and Kloed enthused about renewable energy, wind power – and hydrogen. Utsira was already an island community with a vision - interested in green technology and actively searching for projects involving biodynamic food, ecological farming, solar power, and windmills. But hydrogen hadn't been on the agenda until Kloed mentioned it to Kirkhus. He said Hydro was looking for a prime site for an energy self-sufficiency project involving wind power and hydrogen. "We should get together!" exclaimed Kirkhus, and Kloed agreed. The beginnings of the Utsira story were born, and although the road to project start was long and complex, that initial meeting was decisive. Christopher Kloed is philosophical: "It's a story that shows that it's not just planning, but chance events and the ability to exploit them well, that lead to success»[218]

"Let's try to work something out" was the end of that meeting, but a location suitable for this type of project seemed to have been found. Kloed forwarded information about hydrogen to the Chief Councillor; and subsequent to the initial meeting on Utsira, the municipality sent a letter to Hydro expressing their interest in this type of project. The letter was addressed to the R&D director, who in turn expressed his support for the idea and for exploratory work on the project concept.

[218] http://www.hydro.com/en/press_room/features/utsira_lighthouse.html

The embryonic idea was to work with a wind power company, and then NHEL could deliver the hydrogen plant, which combined with a fuel cell system could provide storage of intermittent renewable energy and at the same time provide fuel for most applications in the energy sector – electricity, transport, and heating. However, knowing that the Hydro organisation needed to be behind this to make it fly, and since this was in 1998 and long before the establishment of a hydrogen energy venture, Kloed had shared the project idea with pioneers inside Hydro (the R&D director Sund[219] and Hagen in business development exploring alternative fuels) to elicit their reactions to the concept.

To NHEL exploration into this type of project was of interest in terms of becoming a market for electrolysers down the line. However, the early research-related project initiatives into hydrogen energy, and subsequently the entry of Bjørn Sund and Dag Christensen (Hydro's corporate director of research and chief of staff in the Energy Division) on the NHEL board (year 2000), provided arenas for the discussion of hydrogen energy as well as new market niches for electrolyser technology. These discussions provided enough assurance that they would react positively to the Utsira type project idea, and NHEL's managing director (Kloed) sensed this reassurance before flagging the idea on the island and before meeting with people in the municipality. Pioneering activity in hydrogen energy had been advanced from diverse settings in the Hydro organisation (NHEL, Corporate research, and the Marketing and Refinery division), and upon the initial contact with the municipality, the corporate director of research (Sund) supported exploration of the wind / hydrogen project concept.

As part of the initial exploration, Kloed started to work with the island's technical services manager on a project proposal and correspondence went back and forth. It was agreed that there should be a public meeting with the islanders to get a sense of the interest and attitude towards the prospect. From Hydro's point of view, a supportive local atmosphere was deemed necessary to move the project idea along. At the public meeting, Hydro representatives spoke on wind power, the project idea, and broadly about hydrogen. In an interview from 2001, then mayor, Reidar Klovning, indicated that he was an enthusiastic supporter of the project ever since discussions started with the municipality in 1999/2000, and that the hydrogen project would be a demonstration of green energy[220]. The Chief Councillor, Robin Kirkhus, touched on the same aspect in an interview when discussing how the project idea needed the support of the

---

[219] The former director of corporate research (chapter 4).

[220] http://www.statoilhydro.com/no/NewsAndMedia/News/2001/Pages/BlikketVendtMotUtsira.aspx

municipality and island, and also mentioned the professionalism of Hydro in their initial approach to the island:

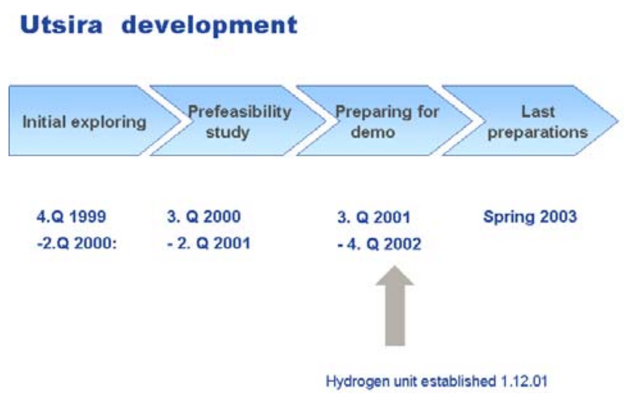
«It's been inspiring working with such professional people ….instead of inviting community representatives to lavish lunches as other companies have done, Hydro sent a delegation to the island to see if they were able to tackle such a project. Kloed and his colleagues have worked extremely hard to achieve this …. Kirkhus also gives much of the credit for Utsira's support of the project to former mayor, Reidar Klovning, who achieved a "mental turning point" on the island by promoting the idea and winning the islanders' enthusiasm for the project at public meetings. After their initial curiosity was satisfied, support for the project has been unanimous»[221]

Subsequent Hydro presentations[222] also summoned the choice of the Utsira location using the following parameters: "Very good wind conditions, small but variable load, power supply from main land by sub sea cable ….and a very supporting community". Due to the positive feed back and goodwill from the island in the initial public meeting, it made it easier for pioneers to go back to the Hydro organisation and communicate that this could be a suitable site with a supporting community and then further advocate that a feasibility study should be conducted.

6.2.1 Initial exploring and feasibility studies

The planning of Utsira took place from 1999 through the middle of 2003. In a project evaluation meeting in 2005, project exploration and preparation was summarised as follows:

Figure 7 Utsira project preparation



221 http://www.hydro.com/en/press_room/features/utsira_lighthouse.html

222 Tobias Hüttner (2004): Utsira and similar wind-hydrogen systems from a modelling perspective, Hydro Oil and Energy Research Centre in Porsgrunn, 15-11-2004.

The initial exploring consisted of conceptual studies and initial partner discussions from the end of 1999 to the beginning of 2001. Communication and partner discussion with the Utsira Municipality (Autumn 1999); discussions with Statkraft (January 2000); Haugaland kraft (May 2000), the regional utility company and net owner, signed an agreement with the project on handling electricity supply for the customers / households and the use of the ordinary net; as well as evaluating possible fuel cell partners/suppliers and various energy storage solutions. At this point in time it looked like the partner consortium would consist of Aker Elektro AS (Aker Maritime group) to be responsible for the fuel cell as Aker planned to commercialise fuel cell technology with their first test installation conceived to be Utsira[223], cooperation with the regional utility company (Haugaland Kraft AS), and Norsk Hydro as the coordinator of the demonstration project on Utsira. Agreements were reached with the Utsira Municipality and Haugaland Kraft during the second half of 2000 and early 2001

As it concerns the conceptual exploration, the Orten island study and report (June 1999) conducted by Energy Development for NHEL had provided technological status, an overview of required equipment and components, hydrogen production estimates based on NHEL electrolyser technology, as well as cost estimates. Now a conceptual study was initiated for Utsira using the same consultant company and the same methodology but adjusting the study to the larger Utsira Island. The study was financed via the budgets of Hagen who at the turn of the year 1999/2000 were transferred from the Refining and Marketing Division to the Strategy group in Hydro Energy. The conceptual study (published December 2000) gathered preliminary information on the diverse components and services required for the installation.

The study explored technical and economic dimensions of this type of system, and it also consisted of measurement of energy on the island in terms of wind resources and the electricity consumption. Knowing the wind profile and energy demand/ consumption allowed for estimation of when hydrogen must produce electricity, and from this an idea of size and scaling of the individual components, frequency, and availability could be estimated. Finally, the price of the electricity was estimated and made comparable to alternatives like a sea cable and / or a diesel unit. The study by Energy Development estimated a total cost of NOK 18,6 million and an energy price

[223]In May 2002, Aker Kværner informed that they were going to install a pilot power plant with hydrogen fuelled fuel cells during 2003. Partners in the commercialisation plan on fuel cell technology were Aker Kværner, Norske Shell and Statkraft. Aker Kværner planned to develop, test, produce and integrate complete fuel cell plants (Teknisk Ukeblad Magasin 28.5.2002: 99).

of 1,33 per kWh. Calculations further showed that a system connected to the local net would be the most economic alternative where excess wind power in the system could be supplied to the electrolyser for the production of hydrogen or sold and supplied to the net on Utsira, and the existing sea cable[224] could be used as a back up for the supply of energy. Enercon as a wind turbine supplier was mentioned with technology suitable for a stand-alone application, localities for the wind turbine installation were discussed, and the north-eastern parts of the island proved to be the most promising area for locating wind turbines and the autonomous system.

Road conditions were evaluated finding that they were unsuited for the transportation of wind turbine / equipment. On Utsira most places road width were measured to 2, 5 – 3 meters, and wind turbine equipment were outlined to require a minimum road width of 4 meters (Enercon quote December 2000 in Energy Development 2000). For this reason a sea side access and a new docking ramp construction was contemplated with improvement of the remaining road to the turbine site. The initial feasibility study further mentioned that for the planning of a future installation, more details were required on wind measurements, the Utsira locality, and a 24 hour energy consumption profile.

Hence another pre-project feasibility study was conducted for NHEL by research institutes, Institute for Energy Technology (IFE) and Kjeller Vind Teknikk (also at IFE). This was a six months study conducted from October 2000 and finalised March 2001, and the pre-project study was supported by the Research Council of Norway[225] and the Norwegian Water Resources and Energy Directorate. Building on and supplementing the previous study, the purpose was to present a simulation study addressing some of the design issues of the wind / hydrogen system and see how costs, operation strategy (output of the system) and design are linked. Two cases were presented where the wind energy conversion system was dimensioned to exploit the extremely good wind conditions on the island and export the surplus energy to the local grid, and another where the wind hydrogen system was operated in a stand-alone mode. More details on the wind resources were supplied using data from a meteorological reference station located at Utsira. It proved that the available wind resources were plentiful.

The historical wind data along with domestic load measurements from the island were used in simulations carried out for a system serving the whole island, as well as for a smaller system serving only a selected, domestic load. Wind speed data were mapped based on 1980-2000 data, and

[224] The sea cable was from 1983 and the condition, at the time of the study (1999/2000), was classified as good and with an expected lifetime of an additional 10-15 years.

[225]Elisabeth Fjermestad Hagen was listed as the project manager with Norsk Hydro AS. http://www.forskninsraadet.no prosjekt # 144550 Vind-hydrogenanlegg – forprosjekt.

software were used to strip the wind data of shadow effects, increase the wind speed to those found at the hub height elevation (46m) and introduce terrain roughness and topography effects. Average wind speed was estimated to 10,3 m/s at the preferred site, and a representative year (2000) was used as input in computer simulations. A daily profile of the user load (heat / electricity for the application / building under consideration as well as the consumption of a municipal car run on hydrogen) was constructed to get to the details of energy demand. With the techno-economic analysis, it was shown that the size of the hydrogen storage unit is very dependent on the wind system size and the operation mode of the system[226].

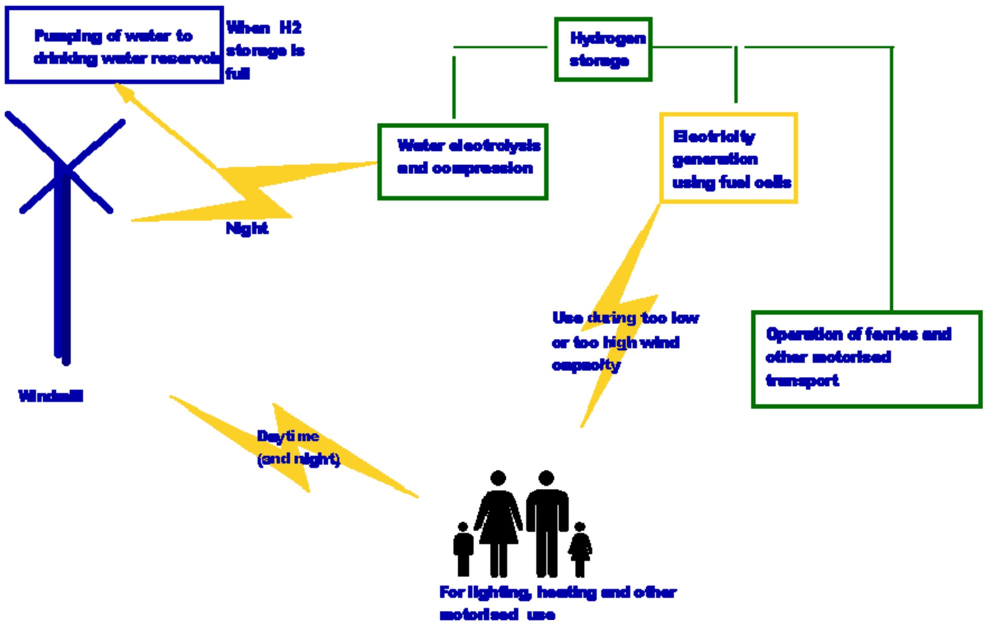
In addition to providing the techno-economic analysis, the conceptual study by IFE also built relevance for this kind of system by referring to market potential in Norway focusing on islands, remote installations and recreational cabins[227] as well as mentioning literature indicating a market potential in Europe amounting to 500- 700 million USD for micro, small and medium stand alone power systems (SAPS) in the midterm (2005) and some 25 billion USD in the long term. The Greek islands where diesel engine generator systems are a main power source were mentioned as the largest market segment (Glöckner et al 2002). The conceptual studies also advocated the system as a means to improve local economies, increase energy independence, and reduce greenhouse gases and other harmful emissions from stationary and mobile sources. Wind hydrogen systems using renewable energy sources (wind) are zero emission system during energy production. Albeit expensive to build this kind of installation for the first time, the study helped fuel the conviction that it would be possible to develop such a system. NHEL's managing director (Kloed) also drew up the project concept in March 2000, and the same artistical drawing was later integrated in Utsira project presentations (Moe/Eide 2004) to illustrate "a dream of the hydrogen society".

---

[226] In the stand alone case it would be necessary to reduce the wind turbine size and increase the electrolyser and storage capacity in order to handle both surplus and deficit supply of primary energy resources. A 230 kW was modelled for the stand-alone case and a 600 kW in the grid connected. In the grid connected, the wind system costs accounted for a majority of the investment. In the stand alone, hydrogen storage would dominate the investment. The study also found that a hydrogen/wind stand-alone system had an investment cost that were four times higher than a comparable wind-diesel system (Glöckner et al 2002).

[227] Norway with 660 habited islands with a total number of 140000 inhabitants. On the smaller islands far from the mainland there are long sub-sea transmission lines where upgrade and maintenance of the transmission line may prove costly, and a renewable energy system with electricity stored as hydrogen may be an attractive option. A number of remote installations such as lighthouses and beacons which uses diesel engine generator systems or batteries, and the number of recreational cabins that use PV/battery systems.

Figure 8 Early illustration of the wind-hydrogen project concept



6.2.2 Selling the Utsira project internally

One of early pioneers pointed out that in the early days, many people did not see the point in being involved in an Utsira type project and it was a lengthy process to sell the idea internally.

«One thing was that they didn't think the company should be doing this type of project; the other was that they didn't see the point with this type of project at all»

The Utsira project needed to pass what two hydrogen pioneers characterised as lukewarm layers of management in order to get approval. This was similar to the experience from pioneering efforts trying to advance strategy work on hydrogen energy where one of the pioneers felt that the reception at the management level of Hydro Energy was lukewarm (chapter 4). Both CEOs, Myklebust and Reiten, were mentioned as being supportive of environmentally oriented innovative work and research. But then there was the challenge of getting through management layers in-between, preoccupied with their respective areas of business and budgets. An Utsira project developer saw the layers of management as a two-edged sword.

« You are forced to be structured and to think carefully through what it is that you wish to do because you are questioned and challenged time and

again. To make presentation in an external forum is like child's play compared to making presentations in an internal forum where you are put on the spot. But that is also the beauty, the end result becomes better. You are forced to be sharp and to the point. But of course a lot of times you may throw out the baby with the bath water, and there are a lot of ideas that are killed that should not have been killed, exactly because projects were not formulated well enough and that support had not been mobilised in advance. So the heavy internal processes are a two-edged sword»

Assisting the path through the Hydro Energy division[228], was the fact that Sund, since the reorganisation of research in 2001 (chapter 4), was now part of the management team in Hydro Energy. One of the Utsira pioneers recalled a presentation of the Utsira project before the Hydro Energy management team where the respective managers were asked for remarks and reactions but little comments or concerns were raised. Only the former director of corporate research vocally expressed his support and that Hydro just had to pursue and do this. One of the Utsira project pioneers characterised Sund as a vigorous person, someone with strong points of views and someone whose opinions were noticed and carried weight in the Hydro organisation[229].

As part of early project selling activities, during the Utsira project preparation and before a 'go ahead' signal was granted from management, the Utsira project idea was also communicated extensively outside the company and in different arenas. One illustration of early and external communication is that the project was mentioned at Greenpeace's environmental conference in London (the fall of 2001) to get feed back on the project concept:

«I made a presentation of this at Greenpeace's annual conference in London, but then it was just as an idea, that this is something one ought to be doing in the coming hydrogen economy, right… we are often asked to come and talk about ideas in the area of hydrogen, and this was a concrete project that we were working on. We just said we are working on this idea, as a project not realised yet. But it is frequently interpreted as if we are up and running»

[228] Hydro Energy was a Division in Norsk Hydro AS and responsible for Hydro's commercial operations relating to electricity, crude oil, gas and NGL products. Hydro Energy was also responsible for Hydro's power production and refinery operations, in addition to the transport of oil and gas, and Hydro's initiatives regarding new forms of energy. Hydro Energy was renamed: the Markets Sector in Norsk Hydro's business area Oil & Energy.

[229] Sund had been with Hydro since 1977 and he had worked extensively and all-round in the oil and gas industry – exploration, reservoir studies, concept and technology development, licensing, infrastructure, and the whole value chain from upstream to downstream.

Communicating externally gave the impression that this was part of company activity. The Utsira project idea was communicated and then interpreted as something that was being done by Hydro long before Utsira was even built (2003-2004). To illustrate, the passage below is from a paper from the World Watch Institute in Washington (Dunn 2001) writes:

«Over time, hydrogen will also provide an ideal storage medium for renewable energy. Norsk Hydro is testing out a wind-hydrogen plant in the municipality of Utsira that will produce hydrogen through an electrolyzer and then provide electricity via a fuel cell when the wind is not blowing. Eventually the hydrogen produced could replace fossil fuels in broader applications, including ferries, which are major contributors to Norwegian air pollution»

The Norwegian environmental NGO, Bellona also described the project on its website in November 2000 as part of information on Norwegian hydrogen projects[230], and the project concept was described in detail under the heading: *Hydrogen in Norway* in the Norwegian publication on *New Renewable Energy Sources* (KanEnergi 2001). Another international mention of the project before Utsira had been built was the reference to the project, as part of emerging distributed generation experiments, in a power point presentation by Amory Lovins[231] from the Rocky Mountain Institute (2003).

For Hydro approval of the project, what turned out to be important, was support of the project from the highest levels of management. In an

---

[230] "Norwegian hydrogen projects: Utsira – Hydrogen and Wind" 8-11-2000 http://www.bellona.no (accessed 6-12-2007): "The island of Utsira is located outside Haugesund. It has got no production of electricity of its own, but is connected to the mainland electricity net through a cable. However, the island is a good location when it comes to wind generated electricity, and now it might be interesting to exploit this source of energy. Even though Utsira is a windy spot, stable supply has been a problem when it comes to energy based on wind. Through the production of hydrogen by electrolysers, the energy can be stored at windy days and used on more calm days by generating electricity using fuel cells. The first of October this year Norsk hydro started a preliminary study to examine the different aspects of such a project. This study will give answers to the questions of whether it is reasonable to build a wind/hydrogen power station at Utsira and what dimensions such a station should have."

[231] Lovins has worked professionally as an environmentalist and an advocate for a "soft energy path" for the United States and other nations. He has promoted energy-use and energy-production concepts based on energy conservation, efficiency, the use of renewable sources of energy, and on generation of energy at or near the site where the energy is actually used. His books include *Winning the Oil Endgame*, *Factor Four*, and *Natural Capitalism*. He founded the Rocky Mountain Institute in 1982. Lovins has provided expert testimony in eight countries and more than 20 US states, briefed 19 heads of state, and published 29 books. http://en.wikipedia.org/wiki/Amory_Lovins

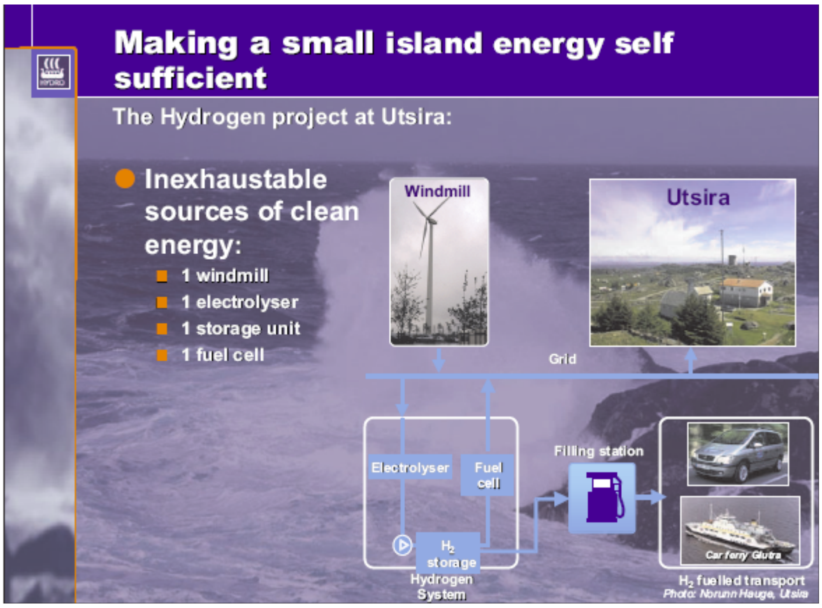
evaluation of the Utsira project, this type of lesson learned comes across in the following words from the Hydrogen group: “anchor at highest level, high risk for middle management, ignore resistance to change”, which was part of a ‘looking back’ presentation and project evaluation held in March 2005. An important event for the project was a speech from former CEO and at the time, chairman of the board, Egil Myklebust. Right after attending the World Summit on Sustainable Development in Johannesburg, 2002, the chairman of the board was a keynote speaker at the World Petroleum Congress in Rio de Janeiro (WPC-17) in Sept. 2002. Before closing his speech, there was an announcement of the project on the small island of Utsira albeit this was prior to approval and construction of the Utsira plant[232].

«Before closing, I would like to touch upon an example from a real life laboratory in Norway. Energy is vital for a sustainable future – globally. A sound basis for sustainability thinking is to start with local resources and apply the concept of industrial ecology, closing the loops and mimicking nature. Let our project in the remote community of Utsira – a small island off the west coast of Norway – serve as an example. Here, we are investing in research on and development of renewable energies and the use of hydrogen as an energy carrier. We plan to install windmills to produce electricity both for the grid and for producing hydrogen through electrolysis. Hydrogen feed fuel cells for the electricity grid as well as in cars, buses and the local ferry»

In the subsequent WPC proceedings handbook[233] (*The Utsira project aims to make a small island community energy self-sufficient*), a visual illustration of the project idea was also integrated.

[232]“Balancing the Development of the Petroleum Business and Social Responsibility” http://www.hydro.com/library/attachments/en/press_room/WPCspeech.doc

[233] http://www.world-petroleum.org/publications/handbookold.htm



Source: http://www.world-petroleum.org/isc2004/File%20026/170_171_172_173_174.pdf

Many of the interviewed refer to a sentiment that there was no turning back when the project had been mentioned so explicitly by the former CEO and, at the time, chairman of the board of the company. This explicit mention was hence in a way part of the decision on the project. One project team member comments on this triggering event in the following way:

«It is true that Egil Myklebust was important…. but there was a distance between us and the top, the management group to the top that were somewhat lukewarm and not that supportive to be completely honest….. I think it is safe to say that Egil Myklebust was a good man for Utsira…..when Egil Myklebust had said it then it became high agenda and we had to get it realised»

Through communication, the company influenced the perception of what outsiders thought the organisation was doing, its role and actions and through this Hydro got a new role e.g. in the eyes of Greenpeace and the World Petroleum Congress. The speech by the chairman of the board also exemplified some type of internal acceptance of the innovative project, signalling this hydrogen energy area as a part of the organisation's activities. The speech was hence an event that coupled past, present and future, and where to come to this point a lot of work 'within' had been accomplished by pioneers working in the Hydrogen Unit. Reactions and feedback to the project idea from other organisations could in turn be used in path creation activities within the Hydro organisation to gain approval, and as part of the argumentation for what other organisations considered to be worthwhile. To illustrate, communication and reactions to the project (before decision and construction) was mentioned in the documentation submitted to Hydro Corporate Management at the time of the final decision to carry out the project (Decision gate 4 April 2003). It was indicated that the Utsira project had already received a lot of media attention being the first full-scale wind-hydrogen project; and this was in turn used to argue that the project would allow Hydro Energy to position itself as a market-leader and a total hydrogen supplier for the future.

Another illustration of how external stakeholder reactions impacted path creation activities within the organisation, is the fact that about NOK 10 million[234] were raised in external funding from the Research Council of Norway, the Norwegian Pollution Control Authority (SFT), and the clean energy agency, Enova[235]. The external co-financing acted as a driver in getting the project accepted internally.

« If people inside the company are questioning a project, then you don't get a budget but if you manage to raise money from external sources, then you carry it out»

The external support helped build a "license to operate" and that this was something that should be done. External funding was commonly sought as part of exploratory activity looking into the financing of projects prior to getting the final acceptance and approval of projects inside the organisation. As one developer referred to it:

«Activities are frequently carried out in parallel…. there is no law against applying for money, if you end up not needing them you can always just say no thank you»

In the fall of 2002, the New Energy unit was established with Jørgen Rostrup as the manager. Rostrup was updated on ongoing hydrogen initiatives and was supportive of the project. As the manager of New Energy, Rostrup was central in taking the project to an internal decision and required that the 'Decision Gate' tool used on company's project should be carried out on Utsira to secure the proper basis for the decision. Decision gates are milestones at which time a formal decision is made by a gatekeeper that is responsible and accountable for the decision. The project was taken from

[234]The project's investment cost was 40 million and was supported from several public institutions. Enova (5 mill.), SFT (600.000) and the Research Council of Norway (4.3 mill.)

[235] Enova is a government body set up to promote environmentally friendly energy consumption and production in Norway. It was established in 2001 and is owned by the Ministry of Oil and Energy.

decision gates 1 – 4 between January and April 2003. As the project was far along in it practical planning, decision gate 1 concerning the documentation of a project and business idea, the commercial and technical innovation level, and the start-up of feasibility studies had already been passed. Decision gate 2 and 3 (demonstrating technical and organisational feasibility, selected concept and design basis, stakeholder dialogue, partners, and a project schedule) were cleared in January and March 2003 with the approval to pursue a principal decision. Decision gate 4 was the final basis for the decision and expenditure approval. Acceptance to start was given by the Corporate Management Board in April 2003.

6.3 Realizing Utsira

[Visions are good……realities are better……
A vision becomes a reality]

The planning of Utsira took place from 1999 through 2003 and construction was initiated in the fall of 2003 and until the opening July 1st, 2004. Many hands shaped the Utsira project in Hydro. In the process of representing the physical and technical realization of Utsira, one easily reduces and simplifies the number of people involved in the project. People have worked in parallel and been part of the project in distinct ways and with different focus[236]. But for the sake of addressing distinct aspects of the project there is a risk of reducing the intricacies of the real process. This section concerns the physical realization of the project.

Kloed with NHEL was instrumental in the initiation of Utsira and bringing the idea into the Hydro organisation while realizing Utsira brought new people to the project. The planning and project realization was handled by Eide, Bratland, and Nakken working together to carry out the project's practical realization process[237]. Eide's background in power was an advantage as it related to the "product" that Utsira was to deliver namely electricity to end-user households with the right quality in terms of

[236] To illustrate, Elisabeth Fjermestad Hagen in the business development group under Ivar Hexeberg worked with financing, commercialisation and continuation aspects in the capacity of being responsible for the stationary energy area in terms of renewable hydrogen systems, Vera Ingunn Moe with communication and public relations, and Pål Otto Eide, Sjur Bratland and Torgeir Nakken were central in bringing the Utsira project from idea to actual realization and operation.

[237] Bratland had worked in magnesium, oil and gas related business before joining the hydrogen group in New Energy in 2002. Eide came from the Power Production unit and was asked to be project manager on Utsira and joined the project January 2002. Power Production handled Hydro ownership in power projects and plants and was usually not involved in carrying out the technical construction of projects but handled project aspects such as regulatory framework conditions, contact with authorities, permits, and framing partner contracts. Nakken worked in hydrogen research at the Research Centre in Porsgrunn.

frequency and voltage, stability and reliability. Elisabet Fjermestad Hagen in the Hydrogen Unit was the owner of the project and hence became Eide's client. As the project manager, Eide's role was to create a consensus on what was to be build, how big should the plant be and with what components, and finding the right people and organisations that could carry out the project properly and responsibly.

6.3.1 From vision to actuality – preparing for demonstration

When project manager Eide came on board in January 2002, Utsira was mainly an idea and the job was to make the project happen and have it materialise. The idea had to be concretized to figure out what the Utsira project really was practically and technically.

Because the Utsira project had been communicated and presented in many arenas, it was often thought of as something that had already been done and built by Hydro. Project manager Eide commented on the early and extensive communication on the project:

«The project had been presented as something that we had done. The skin had been sold and now it was my job to find the bear and shoot it… the attention this kind of project would get was neither expected nor well understood and extensive relations with authorities and the media had to be handled …. What was important with the project was that Hydro management had been around the world talking about Utsira. Now the job was to do it, and the priority the project got in Hydro in a way gave us 'a license to operate' on wider terms. Sometimes this meant to challenge things, to step on some toes to get things done, but it was clear that the project had become important»

The Utsira idea had to be transformed into something that people could relate to and subsequently build. An existing tool used in Hydro's construction projects was *the design basis*[238]. This document was the important pillar in a project as it specified the goals of the project; the necessary site preparations and where the plant should be located; it provided a functional description of the system design in terms of components and capacities which was then the basis for purchases; it outlined how components were supposed to be put and function together; and outlined the operation philosophy in terms of how the plant was to be operated both as an autonomous system, in emergency situations, in a grid-

[238] Researcher Nakken and Bjørn Gregert Halvorsen contributed in the design basis preparation, and after the project's inauguration, Nakken handled the operational research and development period of the project.

connected mode under what conditions, and operation under periods of maintenance.

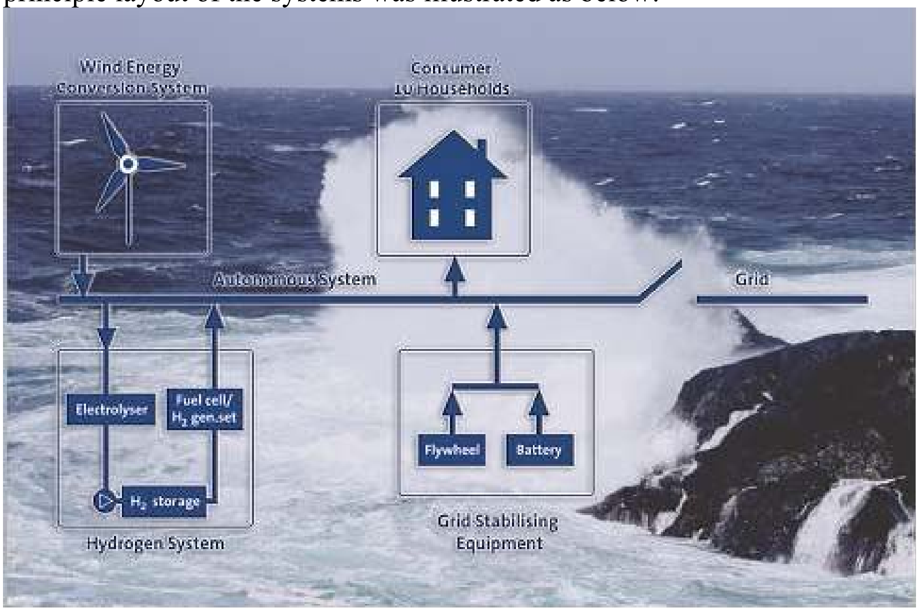
The project was to supply electricity to domestic customers. Further, the demo should provide operational data and experience for further development and commercialisation of stand-alone systems based on renewable energy and hydrogen storage, and the project should disseminate the results. The plan was to obtain operational experience through 2-3 years of operating the demonstration project, and the wind turbines would remain in operation for their full lifetime (normal concession 25 years). Some primary requirements framed the design basis. *Firstly*, since the project's goal was to demonstrate autonomous supply to households, the Utsira system had to be capable of serving the designated load (both peak load and energy consumption) comparable to that supplied by the cable connection to the main land. The system also had to be designed to be able to supply electricity reliably with the right qualities. The plant and system should be built so as to deliver a product with comparable quality to the product that the consumers got previously with cabled electricity from the mainland. *Secondly* and linked to the first requirement, since this was / is a research, development and demonstration project, the plant had to be designed with a back up source available so that the households would have alternative supply in periods of maintenance, adjustments, repairs that by the nature of this being a research and development project, were unpredictable.

The energy dimensioning of the system was done through simulations based on load data and the wind speed series. From these simulations one was able to investigate the operational characteristics of the different components of the energy system in energy-flow type runs, and to estimate the number of operation hours and start/stops, which was important for the control, operation and maintenance required. The simulations were used for sizing purposes by showing the capacities and estimated operation hours for the different components.

A system serving a load consisting of ten domestic customers was selected for practical/technical (grid connection) as well as financing reasons. As investment costs were considered to be proportional to the peak power capability and redundancy of the system, limiting the load[239] to be served was important considering funding constraints. Since a main design criterion was that the system should be able to operate autonomously, the peak power capacity of the system was fitted for the selected load with an

[239] The total peak load of the ten households was approximately 40 kW (energy consumption approximately 200 MWh/year) and to verify the load profile, measuring devices were installed in November 2002 at the substation serving the selected group. From three available months of load monitoring and by using a generic profile for typical residential electricity loads in Norway, a load profile for one year was constructed.

additional margin implying that the wind turbine, the electrolyser, the storage unit and the fuel cell / hydrogen combustion engine had to be sized to avoid dumping or exhaustion of energy. A redundancy limit of one day of operation was also inserted. The wind data series also showed that the maximum period without sufficient wind was two days; hence the energy storage had to be capable of serving the load during this period both in terms of peak power and stored energy. From simulations, the main conclusion was that the sizes and operational demands for the hydrogen technology components were realistic and that present technology could ensure a satisfactory and redundant supply of energy to the households[240]. The principle layout of the systems was illustrated as below:



Source: Illustration of the Utsira autonomous wind-hydrogen energy system Hagen et al (2005b)

With preparation and concretisation, the projected costs went up from the estimates presented in the early conceptual study (about NOK 20 million) to a total around NOK 40 million[241]. Costs went up with the concretisation of

[240] The simulations also highlighted the need for accurate wind data over a longer period to support the optimisation of the autonomous system as recorded data for the selected load to be served by the system is vital to be able to properly design the system both in terms of energy storage optimisation as well as peak power serving capability (Nyhammer et al 2003)

[241] Securing the financing, was not a part of the responsibility of the project management team, rather the financial aspects resided with the hydrogen group (Hexeberg and Hagen) as the owner of the project. External financing possibilities were explored while preparing for the demo from the end of 2001 through end of 2002.

components, project management and realisation costs, infrastructure development, estimation of costs in the demonstration phase. The main component characteristics were summarised as seen below:

Key Components	Key data	Manufacturer
Wind turbine	600 kW	Enercon
Battery	35 kWh	Enercon
Flywheel	5 kWh, 200kW$_{max}$	Enercon
Synchronous Machine	100 kVA	Enercon
Electrolyser	10 Nm^3/h, 48 kW	Hydro Electrolyser
Compressor	11 Nm^3/h, 5.5 kW	Andreas Hofer
Hydrogen storage unit	12 m^3 @ 200 bar = 2400 Nm^3	Martin Larsson
Hydrogen genset	55 kW	Continental
Fuel cell	10 kW	IRD

Source: Nakken et al. (2006b)

It was decided to add components and hence to expand the demonstration.

«Utsira became something much more because at the time when deciding that this was going to be a demonstration and a test case then additional components were added»

As one illustration of the component integration in the realization of Utsira, both Eide and Bratland elaborate on the decision to expand the Utsira system to include a hydrogen combustion engine in addition to the fuel cell, making the system a hybrid composite of electricity producing technologies. Although the original idea was to only have a fuel cell and a wind turbine as the electricity generating part of the system, knowledge[242] on how far fuel cell technology had come, indicated that this was immature technology:

«Experience with fuel cell projects was that they are always delayed, I have never heard of a fuel cell project delivered on time and they are part of research and development projects. So I thought that we needed to have more robust technology, which may be anti-innovative but sometimes you have to let go of ideals to have an idea realized. Utsira is one such example where we included a rebuilt diesel combustion engine that runs on hydrogen and can be bought on commercial terms. That is proven technology and costs only a fraction in comparison with the fuel cell…. But we added the hydrogen engine and the whole point was that if we were at the opening and inauguration of the project then we would have a unit, which could produce electricity even if it was not the fuel cell… It was a budgetary question as to how large the fuel cell could be; ideally it could have been larger but it was also about the symbolic effect that the fuel cell is the future. The hydrogen

[242]Fuel cell technology status was monitored by the venture capital fund, Norsk Hydro Technology Ventures NTV also part of New Energy)

engine was less sexy as compared to the fuel cell that everybody is talking about, but we had to consider robustness, execution, costs and maturity in technology»

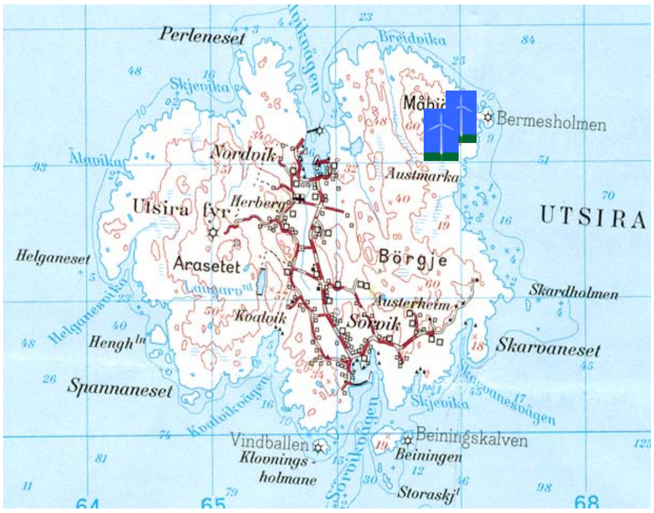
Including a proven technology, the hydrogen combustion engine was considered as a bridging technology between what was available and proven, and to fuel cells as the promising and future-oriented energy solution. However, in Hydro's Utsira project team, the decision to include the hydrogen engine/generator was not without debate, mainly because the initial project idea had set out expectations of a zero-emission plant concept. If including the hydrogen engine it would mean accepting a level of NOx emissions, to which critics might react. But the project executors' prevailed and were allowed to include the hydrogen engine after pointing to the numerous visits with fuel cell producers that could not guarantee operation and durability over longer periods without sending the price through the roof. This is how the discussion is recaptured, by one of the project devlopers, in terms of taking steps to learn before reaching the ultimate technical solutions.

«We will get to that solution, but we can't say that if we are not there right a way then we will not do it at all… I say that we have to take some steps at a time, and the rebuilt diesel engine is one such bridging technology which is important …. Ok we did not solve it all with the fuel cell, let's do some more work, we are not completely there on the storage aspect, let's do some more work. We have to use what we have got. In transportation for example, we may demonstrate that cars can run on hydrogen and emit some NOx but it is nothing compared to what busses emit. But we had sold Utsira as the ultimate future solution with no emissions, so it was a hard decision to swallow. But I think that is the important learning, that we are allowed to buy a fuel cell, allowed to negotiate the contract, and that you really see if this works or not. You set out demands on the delivery, guarantee, safety, the whole package, and then you see what it can do. We went to a diesel engine supplier and they said, yes we can fix this by making alterations… I don't see that as a defeat, I think it is actually what we were going to test on Utsira, test how far technology development had come and what we need to work more on»

Practitioners work with some future destination in view and then seek to bring it about, but future energy solutions are not born perfect, and the Utsira demonstration project was a site for rehearsing a future solution and for exploring a new configuration of technologies. The eventual system design related to the goals and key requirements to the project (energy balance in an autonomous system; peak power capability in relation to maximum expected customer load; power quality requirements; redundancy and emergency mode requirements; and technology robustness and execution (Eide et al. 2004). The design of the hydrogen system was directed towards verifying state-of-the-art within fuel cell technology, but to add robustness to the project due to the project schedule as well as technology maturity, the hydrogen generator based on combustion technology was included. That is also why the demonstration was considered important in the first place, to test how far technologies had come in terms of performance and to determine what needed more work.

6.3.1.1 Preparing the demonstration on site

Searching for a good location and site for erecting wind turbines at a small island may be troublesome due to the lack of space and the short distance to houses and other local landmarks or cultural sites. The challenge was to find a location where the wind conditions were good and at the same time the audible noise level and visual impact could be accepted and where the environmental impact may be minimized (Nyhammer et al. 2003). In choosing the location, Hydro considered wind measurements and impacts in the landscape. The environmental impact assessment evaluated the following: visual impact, audible noise, impact on flora and fauna, and archaeological landmarks and cultural heritage sites were evaluated.



The prevailing wind come from South and North and due to the sparse population in the north eastern part of the island and the hilly topography, the visual impact on the local community was considered to be the least intrusive in this area.

Source: Moe & Eide (2004)

Low mountain ridges would screen the wind turbines from the two main communities, and from most of the scattered settlements, yet the wind turbines would inevitably become new land marks as seen from the sea and from parts of the island itself. Another consideration was to avoid visual competition with the old lighthouse, the islands local landmark. Seven alternative turbine sites were considered and the potential impacts at all the seven sites were ranked by taking photographs from several key locations including the Utsira lighthouse, the Nordvågen hamlet, a wartime memorial site (WW II) and the location of two holiday homes near the sites. The WindPro[243] software package was used to envision the impact on each site. Five sites were rejected due to visual dominance over the wartime memorial and /or holiday homes, audible noise, demand for levelling out the site and dominant position close to the local road (ibid).

The impacts of the wind turbines were visualised as illustrated below as the wind turbines would cause visual changes to the landscape by being new landmarks in the scenery.

Source: Eide and Moe (2004)

Two sites remained and were considered to have the smallest overall visual impact though two holiday homes located close to the two wind turbine sites were considered to be heavily influenced by the visual impact and another effect was that a new road and turbine site would have to be built in an unspoiled area. Still the impact would have been greater from any of the rejected sites. Audible noise levels were also investigated from the seven sites creating sound maps on the noise levels at the nearest houses[244]. The

---

[243] WindPRO is software suitable for the design and planning of both single wind turbine generators and wind farms

[244]Maximum permitted noise level at the nearest house is specified to be 40 decibel (dBA) given regulations form the Norwegian Pollution Control Authority (SFT). In the construction permit from the Norwegian Water Resources and Energy Directorate, noise levels were not

two sites were chosen on the basis of expected average wind speed and distance to housing areas. The average wind speed at an elevation of 46 m (hub height) was estimated at about 9, 3 m/s at the preferred sites (Nyhammer et al. 2003). Of the two locations considered for the hydrogen system; one was close to the customers and one close to the wind turbine. As the customers could easily be served through a high voltage cable, the location close to the wind turbine was selected (Eide et al 2004). The decision to have the wind-hydrogen system in one location was made to minimize the impact on the environment and also because it was preferable to have the whole installation in one location for visitors interested in seeing and learning about the functioning of the system.

As part of the environmental impact evaluation, the project was also evaluated from an ornithological perspective considering bird species, the island as a resting place, hatching areas, and migration patterns and the probability of collisions with wind turbines and towers. The impact on flora on Utsira was also evaluated. Vegetation shows signs of hundreds of years of human influence such as grazing and burning, and there are no threatened plant species. The most valuable vegetation type on Utsira is the coastal heath lands, which is considered a threatened vegetation-type all over Europe. However, the hydrogen system was planned to occupy an area of 4 decares[245] in total, and was hence not considered to be an excessive disturbance of the uninterrupted coastal heath land. Further, as the hydrogen system and the grid stabilising equipment were to be installed in containerised systems for weather protection and installation purposes, the hydrogen system was considered to have little impact on flora and fauna (Nyhammer et al. 2003).

---

considered a problem for the plant construction on Utsira because the distance to built-up areas in Nordvikvågen and Sørevågen and the planned wind turbines was about 1 km and 1,6 km respectively. Further, two recreational cabins were about 600 m from wind turbine 1 and about 400 m from wind turbine 2. Noise levels with the establishment of the two 600 kW wind mills on location 1 and 2 was estimated to 38 dBA with the closest cabin and 37,7 dBA by the other.

[245] 1 decare = 1000 m². A decare is a unit generally used for the measurement of land area. One decare is the same as 1000 square metres.

Source: Norsk Hydro photo

Finally, as part of preparing for the demonstration, archaeological and cultural sites had to be considered. The planned development was designed not to affect any known archaeological sites but during winter 2003, a Stone Age settlement site, among the oldest in West Norway and with stones laid in a pattern not previously seen in Norway, was found close to the southernmost wind turbine site. The authorities granted exemption for this site, given that necessary excavations would be carried out and registrations completed before construction activities (Nyhammer et al 2003). The Archaeological Museum in Stavanger carried out excavations on the site in the spring of 2003, and Hydro changed the position of the plant to preserve the find for the future.

6.3.1.2 Partnering with the community

An energy plant cannot be built without some intrusion to the local environment[246] and cooperation was needed from authorities and from landowners. Visits and conversations with each affected landowner were a central part of the prepatory activity and amicable and voluntary signing of

---

[246] By each turbine, a levelled area (14x27m) was needed for the erection and if needing a crane at a later date for the replacement of part. A docking ramp was needed close to the site (at Tjørekloven), about 400 m long and 4 m wide road was needed from the docking ramp to the plant site. Road improvements from the northern end of the public road to the planned road from the docking ramp were also needed. Installation of water supply to the hydrogen plant, 1,5 km cables transmitting power from the autonomous system to the customer substation to which the 10 households were to connect was built by the existing transformer.

landowner agreements was achieved. Another important aspect was to use local knowledge especially because of challenging weather conditions with the wind, waves and building infrastructure to get to the location. A small anecdote illustrates this point. When preparing for the installation of the wind turbines and the installation equipment, a docking ramp had to be built. One of the Hydro project participants indicated that they talked to the locals about where to build the docking ramp. They thought they got it right until an old fellow on the island commented on the construction and expressed that they should have moved the ramp more to the left and that the waves would take it down over the winter. Sure enough, the ramp disintegrated during the winter.

«These are the things that only the locals know and to me, working on commercial development, it teaches you humility, taking time to talk to the locals and not believe that the engineers can calculate it right. They had probably calculated this perfectly, but he had lived there all his life, was probably about 80 years old and he just laughed at us. I asked him if he had talked to the fellow that we worked with on the placement of the ramp, and his comment was that this person was just a young bloke (when he was probably close to 50). These are the things that only the locals know about. Sure enough the docking ramp was destroyed during the first winter. We used it for what we were supposed to, but would have liked to have it for later use. So now if we need to land something we need to rebuild or to use the original quay. This has nothing to do with the technical aspect in the project but it has to do with local knowledge, being humble towards the locals that know the area. And we did that, went around the island and talked to people, talking about this and that, and we are competent in this area but we missed the mark on the docking ramp… Now I work in wind power development and you really need to get out and see what is going on in the community, are there local conflicts, take time to talk to people and not just get one side of the story, you cannot just get one version… it is very much about building trust and being present»

Partnering involved relations with the community, informational outreach and handling different issues in relation to the local population on the island. From Hydro's point of view, a supportive local atmosphere was deemed necessary to move the project along. Utsira was already an island with a vision being interested in green technology, and actively searching for projects involving biodynamic food, ecological farming, solar power, and windmills, but hydrogen had not been on the agenda until mentioned by Hydro representatives[247]. In May 2003 the Manager of Hydro's New Energy

[247]Lighting the way for the hydrogen society http://www.enviweb.cz/?env=obecne_archiv_ejcfj&print=true

Unit, Jørgen Rostrup, commented on the importance of the pioneering pilot project and the positive reception from the local community.[248]

«This is a very exciting full-scale project. Utsira will be a real-life presentation of the use of sustainable energy systems based on renewable energy….As this is a pilot plant we cannot expect it to be commercially viable, but it still has great value. The Utsira project will give us unique experience of building and operating a future-oriented plant. We are grateful for the enthusiasm and support we have met both from the inhabitants of Utsira and from the local and national authorities, and we are looking forward to working together with the people on realizing these plans»

Obviously, an energy plant cannot be built without some intrusion to the local environment and cooperation was needed from authorities and from landowners. In December 2002, there was an orientation meeting for local and regional authorities as well as a public orientation meeting at Utsira. At the same occasion, the Norwegian Water Resources and Energy Directorate (NVE responsible for the licensing procedure by the authorities) inspected the location with representatives from Hydro Energy and Haugaland Kraft. Commentary and remarks sent to NVE indicated that the municipality had participated proactively in choosing the wind turbine location and was positive to the initiative. In the NVE concession application it was indicated that the Utsira municipality considered the wind-hydrogen plant as an important driver and element in business development and 'nature-based' tourism. For this purpose it was also mentioned that the wind-hydrogen plant was intended to supply green energy to a conference centre/hotel/coastal cabins called Utsira Havstuer to be built at Skarvanesvågen[249]. The following excerpt is from the licensing application[250]:

«The Utsira municipality wishes to promote primary industry in agriculture and fishery, as well as tourism founded on nature and cultural experiences. For the 'green tourism' venture, the wind-hydrogen project plays a special role in making the island self-sufficient with green energy. The municipality expects that the project may contribute to the marketing of Utsira with a green profile»

County authorities also supported the initiatives albeit Utsira had been kept out of the wind power plans of the county's coastal area due to the many cultural sites on the island. After ensuring that the project was not in conflict

[248] Hydrogen society on the island of Utsira
http://www.hydro.com/en/Press-room/News/Archive/2003/May/16340/
[249] http://turist.utsira.kommune.no/historie/dfdfdff?set_language=en&cl=en
[250] Haugaland Kraft & Hydro Energi (2002)

with such cultural heritage sites, the wind-hydrogen plant was supported for the purpose of showing energy self-sufficiency (Rogaland Fylkeskommune 2003).

Another public and informational meeting was held on the island (September 16th. 2003). The meeting was scheduled around the completion of the initial construction phase, namely getting the wind mills installed before fall storms and winter. On Hydro's homepage it was reported that more than 80 people showed up. The atmosphere was reported as positive with the community expressing pride in hosting a future-oriented demonstration of a unique kind. A detailed folder was prepared for the meeting also making the partner constellation visible (Haugaland Kraft, Enercon, and Hydro). The folder explained the concept, the technicalities, and the timetable of the project. The folder also outlined what Hydro was hoping to do for Utsira:

«We hope the plant will enhance the interest in Utsira… that project activity will enhance tourism and visits to the island…. after completion of the project the wind turbines will remain on the island and produce renewable power»[251]

To the community and municipality, it seems that a central intention was to link the project to additional benefits and more than 'just' energy supply. On the Utsira information and municipality homepage (www.utsira.no), the wind-hydrogen plant was added to the list of Utsira points of interest, the Utsira Sights menu under the title: *The world's first wind and hydrogen plant*. One of the Hydro project team members reflected on this aspect:

«There is something about the location, the island meeting the open sea… if the demonstration project had been located at the Research Centre in Porsgrunn; it is unlikely that it would have about a 1000 visitors a year. There is something about experiencing the island and instead of being a strain on the island; it has become an asset where it has boosted the number of visitors to the island. So the project may be seen as an asset or a starter's kit to be used by the island to boost tourism and activity on the island»

The home page of the Utsira municipality also announced:

«To Hydro, the pilot project with wind and hydrogen = power, has given a lot of attention, not least internationally. To Utsira, the plant has been an important attraction in marketing the destination Utsira, and it is import that Utsira exploits such spin-off effects»[252]

[251] Vind-hydrogen-project Public Meeting, Utsira 16. september 2003
[252] http://turist.utsira.kommune.no/severdigheter/hydro/historie/view?searchterm=hydrogen

To actively pursue these intentions, an initiative labelled *Generator Utsira* was also established with participation from the Utsira Municipality, a research foundation Polytec (managing the initiative), Norsk Hydro and Utsira Havstuer to look into opportunities and new initiatives as spin offs from the wind-hydrogen plant. Hydro could at the time inform about 1073 registered guests that visited the plant just in 2006 and 20 nations had visited the island to see the wind-hydrogen plant. Hence the plant brought a lot of positive attention to the island and the challenge was to build on, and in a broader perspective to show how the profiling and attention to the introduction of new energy technology could be turned it into population and employment. The initiative was supported by the County of Rogaland with RUP funding[253] and also by the municipality initiative "Bulyst Utsira" (translated to something like 'Living at Utsira' an initiative to create a viable island community). Brainstorming on the initiative brought out ideas such as 'zero-emission society', test station for renewable energy, Utsira as a show room / educational site for environmentally friendly energy solutions[254]. Activities within tourism, related to the ocean, agriculture, research and knowledge transfer and /or looking into opportunities to establish an EU project where Utsira could be an arena for information and experience with environmentally friendly energy solutions. The Utsira efforts were since integrated with efforts (also involving the research foundation Polytec) to push a regional perspective and plans to establish the region – Haugalandet – as a central actor in clean energy within a network based Centre for Sustainable Energy[255].

The general purpose however, of collectively brainstorming ideas between local authorities, representatives from local trade and commerce, Hydro and the research group, was to identify synergies and new activities "outside the fence" to build upon and benefit from the wind- hydrogen plant. To the Utsira community, the project has therefore become more than 'just' energy supply. Although the Utsira plant is not a commercial project, the wind-hydrogen plant became a valuable asset to the community as reflected in the news article quote below:

---

[253] RUP funding are funding and a tool to support regional development processes. http://www.rup.no/om_rup_norge.aspx

[254] Information from Utsira Municipality (2007): 11/5/2007 http://lokal.utsira.kommune.no/siralappen/2007/microsoft-word-siralappen-nr-10.pdf, http://lokal.utsira.kommune.no/siralappen/2007/microsoft-word-siralappen-nr-11.pdf.

[255] http://www.haugalandradet.no/dokumenter/38-07b_AU_refsak_Fornybar_220807.pdf, http://www.haugalandradet.no/dokumenter/190608/Sak%2014-08%20Fornybar%20energisatsing%20for%20regionen.doc

Centre for Sustainable Energy (CenSe) was established by University of Agder, University of Stavanger, International Research Institute of Stavanger IRIS and Teknova.

«The Utsira mayor Jarle Nilsen is nonetheless ecstatic about the system and its effects on his small island community…."This is a fantastic project that has been good for Utsira," he says, pointing out that initial concerns about noise levels and birds getting caught in the turbines had been laid to rest. "We haven't found a single dead bird," he says. Most importantly, the system was helping nudge Utsira towards its goal of zero emissions within the next decade and had become a major tourist attraction. "The tourists go over to the lighthouse first, but then they go to look at our windmills. They want to see the world's first full scale wind and hydrogen project in action," he says proudly» (Energy Daily 2008)

6.3.2 Technology development: planning, commissioning and building

The main activities in preparing for the demo from the second part of 2001 and through the end of 2002 involved practical issues on the location, landowners, infrastructure; applying for concession and license to operate the energy plant (15/11/2002 and granted April 2003); exploring external financing; and the discussion with potential partners, main suppliers and the signing of main contracts. The project contract strategy was to procure and contract the key equipment components through separate EPC contracts[256], handling interfaces between contracts within the project.

MILESTONES

- Start of the pre-project: January 2002
- Concession for the plant: April 2003
- Main contracts signed: April 2003
- Site construction start-up: June 2003
- Wind turbines commissioned: September 2003
- Implementation of hydrogen generation plant: Winter 2004
- Stand-alone system ready for demonstration phase: Spring 2004
- Implementation of fuel cell: Summer 2004
- Inauguration: July 1st, 2004
- Partner: Hydro, Enercon
- Financing partners: Enova, SFT, NFR

Source: Utsira wind power and hydrogen plant, Inauguration July 1st, 2004

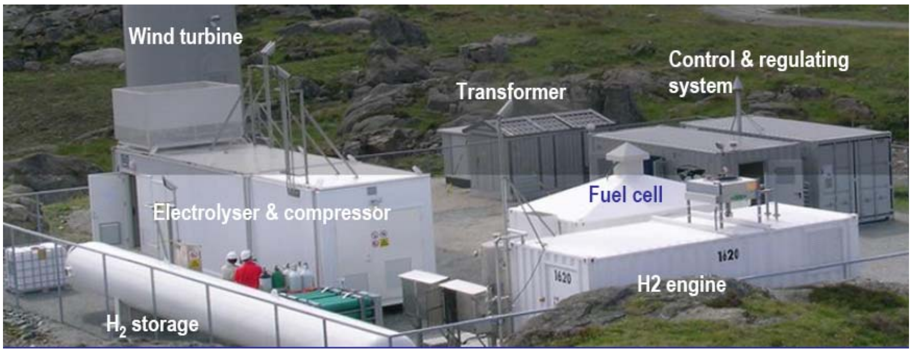
Project execution was initiated in April 2003 when all necessary government, local, and Hydro approvals had been secured, as well as the necessary funding. The necessary infrastructure in the form of roads, water and electricity supply and the

[256] An EPC contract (engineering, procurement and construction) is characterized by functional requirements, with clearly defined responsibilities for the systems part of a production system. In an EPC contract, the EPC contractor agrees to deliver the part of a commissioned plant to the owner for an agreed amount. In an EPC contract the owner will define the following: scope and the specifications of the plant; guarantees, quality; project duration, and cost which is negotiated.

foundations for the wind turbines were set up in the summer of 2003. In connection with the installation, a new docking ramp was built, which was needed to get the turbine and mobile crane to the installation site. A 4 meter wide and 400 metres long road from the docking ramp to the turbine sites had to be prepared, some was new road and some existing that needed improvement, and both the plant site and road was private property. Hence the project needed goodwill and land owners had to be consulted and negotiated with in terms of rent, crossing property, and establishing the site. The project had a compressed schedule of about one year before the inauguration on July 1st, 2004.

6.3.2.1 Technology partnering

Realizing the project relied on work with external partners, and hence Utsira has been a practice site for working collectively and being connected to others for the purpose of advancing an innovative endeavour. The project is a site where the ability to recombine resources and develop in coordinated effort with others came to the forefront. The Utsira demonstration project was a site where consideration and decisions were made about who the organisation should partner with to give the hydrogen venture area more reach, and considerations were made as to what the role of each partner in the collaboration should be. Since the technological combination was created with other organisations and other technologies, the demonstration project played a role by being an arena for practicing and handling collaboration. Since the innovative technology combination emerged through the recombination of resources in a new constellation, then the demonstration project became a test site for handling the competences of the organisation; while at the same time mobilising and managing external actors and their competences. Otherwise unconnected players were linked to form the new technical constellation while the organisation also added its own competences to the whole. The whole was based on the vision as well as the ability to actually bring players with disparate assets and competences together and the Utsira wind-hydrogen combination became the product of this set of competences and assets, which were mobilised and coordinated in the new value constellation as illustrated by the Utsira system configuration below.



Source: Hydro photo (Hexeberg 2005)

6.3.2.2 Landing partners

An important aspect of partnering on hydrogen demonstration projects is that uniting with other organisations and important players in the energy sector, is a way of signalling interest and relevance of a project concept. In this regard, one could say "the more the merrier", however this needs balancing with the number of interfaces and discussions that emerge with more partners. What is referred to as a kind of Hydro philosophy is that the number of partners should be kept to a minimum because the experience is that with every partner you add, it adds to a project's time and execution because it becomes more complicated to agree and reach consensus on the project. Another aspect is that the partner needs to bring something to the plate, not just be interested in a spot in the limelight. Rather the potential partner has to have some kind of technical competence that will enhance the likelihood of project success. A final mention of a trait or a Hydro way of running projects is that when Hydro is responsible for a project, Hydro wishes to be in a position from which control may be exercised. In Norway, the company is very exposed and the organisation is accountable and must be able to stand by the actions on a project. This is important for partner selections on projects, that they understand Hydro's role, in addition to identifying the critical competences sought in the partner.

> "Partners with the right equipment and competence are of course important, but having a partner that is fully determined and dedicated to pull this through is equally important" (Nakken et al 2006a&b)

The main activities in preparing for the demo, from the second part of 2001 and through the end of 2002, involved discussing with potential partners and suppliers. At the time the design basis was finalised in May 2003, the two main partners in the project were German wind turbine manufacturer and project manager, Norsk Hydro Energy that jointly was to finance and construct the research and demonstration system. Other partners were important collaborators like Haugeland Kraft (the net owner for the ten households in the project) that signed an agreement with the project on the handling of electricity supply for the customers and the use of infrastructure / the ordinary net[257]. The project was also well received and in agreement with the Utsira Municipality.

6.3.2.2.1 The wind system and partnering with Enercon

With project manager Eide's technical competence and experience from wind power projects, he knew that a supplier was needed with experience in grid stabilisation of small electricity grids and turbines suitable for operation as a component in an electricity system. Technically it would not be feasible to use any kind of wind turbine in a stand-alone system. Choosing to partner with Enercon was not entirely coincidence. From a bidding round on a Hydro wind park prospect on the Harbak Mountain on the mainland, there had been amicable discussions with Enercon. Enercon was visited in the spring of 2002 in Aurich, Germany, and the vision and idea was sold. Enercon was interested, cooperation was discussed and the visionary owner of Enercon was particularly mentioned to be in a position and have the discretion to make quick decisions when a project is of particular interest. A comment in an interview is that: "Enercon says that they do not have the lengthy decision making processes that we do".

Enercon had the experience to understand that this was a research and development project that fit their activity area which in addition to selling wind turbines also included wind-diesel and stand-alone system. With early conversations about the Utsira project and based on technical premises, it seemed that Enercon had a suitable product and had ongoing product development; hence an important aspect in the partnering with Enercon was that they had worked with renewable energy and storage solutions. The plan was to use Enercon competence on control of stand-alone systems as well as in-house competence on electrolysers and hydrogen in general (Eide et al. 2004).

Enercon would deliver two E-40 wind turbines with a maximum output of 600 kW[258]. One of the turbines would feed energy directly into the

[257] A 1,5 km cable is transmitting power from the autonomous system to the customer substation. All the 10 households are connected in the customer substation at 230V, the standard voltage level in Norway. The customer substation also comprises a 22 kW bus bar circuit breaker for easily switching the customer from autonomous system mode to grid-connected mode in case of failure, and during maintenance and modifications. Hence an emergency mode for the customers could then easily be provided and requirements on autonomous system redundancy (and costs) could be minimised (Eide el al 2004).

[258] At optimum performance, this is more than enough energy to supply the entire Utsira community; the estimated annual production was about 5 GWh. The wind turbines operate at

grid, the other to the autonomous system and surplus power to the grid (see Eide et al 2004 for more details). The wind turbines were purchased on EPC contract and Enercon was to design and deliver the overall control system, which communicate with all components in the system. As part of the partner supply to the project, Enercon was also to be responsible for the grid stabilising equipment that consist of a flywheel that controls the frequency and has an energy storage capacity of 5 KWh, which helps to maintain a stable power supply from the plant to the grid[259]. This was combined with additional grid stabilizing equipment, a synchronous machine for voltage control (stabilising the local grid), and a battery (50 kWh for emergency back-up power) providing redundancy for the production units within the autonomous system (Eide et al. 2004). These are system measures taken in order to compensate for fluctuating winds. By means of a sophisticated control system this guarantees a constant output depending on the amount of consumption. This way, when the winds are favourable, the wind turbine and the flywheel can supply power to the connected users, and any excess wind energy was to be used to produce hydrogen to be stored for later use.

The commissioning date of the wind turbines were put forward in relation to the rest of the system. This reduced the weather risks associated with challenging conditions and stormier weather at the site with a possible erection of wind turbines in the winter season. Hence the installation of the wind turbines was put forward to the fall of 2003. The account of the

---

wind speeds in the range of 2.5-25 metres/second. From 25 m/s, the output power declines to 34 m/s, when the windmills shut down automatically. The turbine tower rises 46 metres above the ground, and the blades on the rotor have a diameter of 40 metres.

[259] Enercon's stand-alone system combines several different components to form an efficient system with the main supplier of power being the wind turbine and a storage system which is deployed when necessary The current has to be constant so that the stand-alone grid user is able to utilise the produced power. When the winds are favourable, the wind turbine and the flywheel can supply power to the connected users and control a stable frequency of 50 hertz. The wind fluctuations in a short-term period (seconds) are regulated by a flywheel system developed by Enercon. In the Enercon magazine Windblatt (Issue 5/2004), efforts in the area were summarised: "Currently, for some isolated regions or islands, the only possibility to provide the inhabitants with energy is diesel power stations. However, this method not only involves costly long-distance fuel transportation, but also pollutes the environment. Enercon has taken a detailed look at this question and has developed an autonomous energy supply system where the main power supply is generated by a wind turbine and while constant and stable electricity supply is guaranteed despite fluctuating winds. The story of the so-called "Enercon Standalone System" is still quite recent. It started in 1998 when the first test station was set up at the base of an E-30 wind turbine in Aurich. In the following years, several different storage media, which are one of the important components in the system, were developed and/or tested by Enercon. After the stand-alone system was further optimised to pass from a test station, which attained the target of high quality power supply, to the actual application phase, no obstacles could bar the way for a pilot project on the Norwegian island of Utsira (see Windblatt 05/03). The system, which was installed in 2004 is the first of its kind functioning in real conditions worldwide.

construction process from Enercon's Magazine Windblatt (2003) gave an impression of the challenging site conditions.

Transportation and Construction

"Normally, the 70 m long "Elektron" is used to transport heavy cargo around Norway and Great Britain. This time ENERCON and Norsk Hydro chartered the ship to transport two wind energy turbines. Norway's main transportation obstacles are the numerous mountains, craggy fjords and winding roads which is why heavy loads are usually transported on ships. Brisk commuter boat traffic enables cars to cross the fjords which have the advantage of being deep and sheltered by the surrounding mountains…. Utsira, Norway's western most island in the North Sea, however, is unsheltered and holds the risks of high wind and waves. A five day time period, which included the construction and the transport of the trucks and cranes to and from the island, was planned to realise the project. On the first morning, the captain had to abort the first docking attempt because the docking ramp was turned towards the wind. An hour later they were able to make a second successful attempt, because the wind had switched direction. It all had to go quickly because the ship couldn't dock for very long, but they were able to unload the crane. Another landing was made later that day and the construction team was able to get all the components for one of the turbines offloaded. The trip between the harbour in Haugesund and the island of Utsira is only 1 1/2 hours, so the next day they were able to deliver the rest of the second turbine. The ship came back again in the evening even though the waves had increased. The next two days were unusually calm for the month of September which meant that the teams were able to erect the two turbines and finish 18 hours ahead of schedule. So the crane was loaded back onto the "Elektron" to escape an oncoming storm coming from the southern tip of Norway and safely reached the mainland."

Source: Windblatt (2003)

Partnering with Enercon on the Utsira project provided food for reflection on partner selection in research and development projects. Project manager Eide and Bratland, being the central figures in the construction period, both point to the importance of being in agreement about the idea and purpose of the project. This reflection arose because other potential partner discussions came to a halt because of differences in opinions e.g. on core purpose, demonstration activity, contributions, and commercialisation issues. With

Enercon there was an accord in the thinking about the project, an agreed approach and common expectations, as illustrated by the quotes below:

«With Enercon and us, there was an agreement about the idea and what we were to accomplish on Utsira. Not necessarily all the technical things that were to be tested but that this was a research project that we were to realise, we were to make it work and that was it… We visited Enercon several times and they seemed rather lenient about the budget, their response was that they just wanted to make it work. They have a charismatic founder and owner, Aloys Wobben[260], who after hearing briefly about the project made a commitment to the idea and project realisation. That was a good partner to have, we agreed on how it was to be built, function and that this was a 'high status' project. It was important that this should work as this could become a profiled project useful to both of our organisations»

The accord in the thinking about the project is also illustrated below:

«By the director of research Martina Kuhlmann, we were introduced to the owner of Enercon, Wobben, and he works with innovation and research and development… Wobben has two visions- bringing clean water and clean energy to the world. And that fit perfectly, there seemed to be a reflex that this suited Enercon activity, we quickly got that impression… We were also in dialogue with Danish Vestas, a large wind turbine manufacturer but they did not really have the product and they did not seem to see the scope of the idea. Now in retrospect they see what they missed out on…. I think they saw this as a small project and also their strategy is to sell wind turbines, not to bring clean energy to the world. Enercon had a small demonstration plant in Germany that they showed us, they had supplied a standalone plant to Australia, and they have supplied a desalination plant to produce freshwater somewhere by the Mediterranean Sea. So they had suitable product development…Hence it was easy to define what each partner should be preoccupied with. Enercon to produce electricity and make sure the electricity had the right quality. And then Hydro was to store the electricity as hydrogen and that electricity could be produced from the stored hydrogen. So within the scope of the idea, it was rather easy to divide the project roles in a way suitable to both companies… We have focused on what each partner should contribute with functionally and that each partner was obligated to ensure that their contribution to the system was working in a manner favourable to the total project»

[260] http://www.enercon.de/en/_home.htm

6.3.2.2.2 The electrolyser and hydrogen storage vessel

The electrolyser and the hydrogen generator were commissioned winter 2004. The electrolyser and the storage vessel were purchased on EPC contract from Norsk Hydro Electrolysers AS. The electrolyser is the device that produces hydrogen and oxygen by splitting water molecules by means of electricity (see appendix II). The electrolyser has the capacity of supplying 10 Nm3 of gaseous hydrogen per hour[261], and the hydrogen produced by the electrolyser is compressed and stored in a container that can hold up to 2400 Nm3 (normal cubic meters) of hydrogen gas at a 200bar gas pressure. As it concerns storage, this is sufficient for two full days of energy supply to the households in the autonomous system, which was based on the longest period of no wind in the historical data.

Source: Electrolyser in front and storage vessel behind (Eide et al. 2004)

6.3.2.2.3 The hydrogen engine/generator and the fuel cell

At times where the wind turbines are not delivering electricity, electricity production is to continue based on the hydrogen storage capacity and power produced by a 10 kW fuel cell[262] and a 55 kW hydrogen combustion generator. The hydrogen engine and the fuel cell are the components that the

[261]The hydrogen plant requires electric energy for the production of hydrogen (estimated annual consumption was 0,870 GWh). The power requirements for the electrolyser at maximum load is approximately 54 kW including the compressor needed to bring the hydrogen gas pressure in the storage vessel up to 200bar. A challenging interface is that the hydrogen storage must provide a stable supply of hydrogen at a pressure (static and dynamic) suitable for the hydrogen generator and the fuel cell.

[262] The fuel cell produces power through a chemical reaction: energy is released from the hydrogen when it reacts with the oxygen in the air (see Appendix II).

partners Hydro and Enercon have no experience with. Both were included in the demonstration project and hydrogen is thereby used in two independent systems of re-electrification in the Utsira project. Both were included to reduce the risk of unstable electricity supply or inability to meet customer demand at all times. Further the agreement signed with the net owner Haugaland Kraft, the local energy company, was also intended to deal with any such problem on an ad hoc basis.

The hydrogen generator was purchased on an EPC contract and supplied by Continental Energy System, Belgium. The engine is based on a converted combustion engine, and has, using hydrogen as a fuel, a rated power of 55 kW. The capacity was to be sufficient to supply the customers without relying on the fuel cell. The hydrogen generator was designed for black start[263] and parallel operation with the fuel cell (Eide et al. 2004).

Procuring a fuel cell under an EPC contract proved to be challenging given the performance requirements in an autonomous system and the climatic conditions on the site. As part of preparing for the demonstration a partnership had been planned with Aker Electro (part of Aker Kværner) that was planning to commercialise fuel cell technology and their first test installation was conceived to be Utsira[264]. The company however experienced financial difficulty and withdrew from the project plans. A number of other fuel cell producers were contacted to get tenders for the supply of the fuel cell (Ballard, Siemens, Cetez, Intelligent Energy). However when Hydro started to make demands on durability and a guarantee as to the performance, that it needed to be containerised at the Utsira location, and integrated so that it was more or less to plug it in, then discussions halted and in some cases the price tenders skyrocketed, which made it hard to find a supplier.

IRD Fuel cells[265] in Denmark, is an independent high technology company working with research, development and production of fuel cell

---

[263] By definition a generator with black start capability must be able to restart without a network connection. Black Start capability is the ability of a generating unit to go from a shutdown condition to an operating condition, and start delivering power without assistance from a power system.

[264] In May 2002, Aker Kværner informed that they were going to install a pilot power plant with hydrogen fuelled fuel cells during 2003. Partners in the commercialisation plan on fuel cell technology were Aker Kværner, Norske Shell and Statkraft. Aker Kværner planned to develop, test, produce and integrate complete fuel cell plants (Teknisk Ukeblad Magasin 28.5.2002: 99).

[265] IRD Fuel Cells A/S (Innovation Research & Development) was founded in 1995 and has it core competence in energy transformation, conversion"; (solar panels, converters DC / DC, Inverters, DC/AC, 'flat' lithium polymer batteries). The latter (the batteries) has established the economic foundation for what they do today in terms of the focus on the 'heart' of the fuel cell, the fuel cell units and to build plants including the system around the fuel cell.

materials, fuel cells and fuel cell systems with its competence in energy transformation and conversion. IRD was contacted by Hydro in the fall of 2003 making a "customer" request on fuel cell technology for the Utsira project. IRD worked out an offer and there were discussions back and forth on the fuel cell system components and configuration. IRD was chosen for the development and construction of a 10 kW PEM fuel cell, and for its demonstration. The fuel cell was to be integrated and implemented in the wind-hydrogen system in a container and fitted with necessary heating as well as black-start capability (Fjermestad Hagen et al. 2005b).

Project participants from Hydro elaborated on finding the fuel cell supplier:

«None of the suppliers of fuel cells could deliver… because we did not only wish to buy the cell stack, we did not want the fuel cell to play with in a laboratory, we wanted it on a real site, integrated and containerised to handle the climatic challenges, this was outdoors. All that made it complicated. IRD was the only company that we perceived as professional. Hydro has extensive experience with suppliers of all kinds, and this was the only one that we considered to be credible and realistically could deliver a fuel cell at an agreed price and at an agreed time»

«It was not until we visited IRD FuelCell in Denmark that we made a match. They understood that this was highly profiled and they understood that they had to price below costs. They managed to get additional funding to cover the gap, and they understood that we wanted a product that was integrated. In other words, they understood what the customer wanted and at what price. They were the only ones»

«Visiting one supplier our specifications and demands were expressed, that it should be integrated, and operate and function for two years. The suppliers in turn responded that then the price would have to double if it was to work beyond three months… Most suppliers said that they could supply a fuel cell on the dock and then we would have to integrate it ourselves. But it was the integrated fuel cell, durability, performance and operation that we were concerned with. They could deliver a cell stack and then we had to make it work. IRD was the only company that was interested in a development path where they would make it work, hence IRD became a development partner»

A contract was signed in February 2004 in which profiling the project was part of the contract; Hydro people were to come to IRD for in-house training; there was to be information sharing and full access to technology information, performance and evaluation; and the plant was to run for 2 years[266]. The installation of the IRD Utsira 10 KW fuel cell was completed at the Utsira site in June 2004.

Source: Fjermestad Hagen et al. (2005b)

Below is the site with the grid stabilising system to the left and hydrogen system to the right/back, and the fuel cell in the middle.

Most of the plant components were in place during the fall of 2003 and now started the work of making it function before the opening in July 2004. The criterion against which to evaluate the project was the demonstration - that it should work, that the components should work together and supply electricity. The project had an R&D focus and commercial issues were not

[266] Interview Søren Jacobsen, IRD, 27/10/04.

prioritised. In a press statement from April 2004[267], project manager Eide pinpointed this aspect of the demonstration:

«We want to prove that this is possible, not economically viable, but technically possible»

The central challenge was to make it work, make the components function together and to supply electricity with the right qualities. A key demand to this kind of system is also to make it intelligent and robust so that it may be installed in remote area, as intended without hands on handling on a day to day basis. That was the objective down the line but with the demonstration it was first and foremost to make it function. At the time of installation, the components functioned separately and the demonstration phase would involve the control system to make the components interact and to handle the behaviour and performance of the component technologies in the new configuration.

From the construction and commissioning of Utsira, key lessons learned were summarised in a conference paper (Eide et al. 2004) with emphasis on interfaces, design considerations, and project planning.

> The key lessons learned from constructing and commissioning the project can be summarised as follows:
>
> - Interfaces in the hydrogen loop are critical. Careful considerations with respect to static and dynamic performance are needed. Detailed simulations in the design phase are difficult as they depend on having equipment data as well as detailed process knowledge.
> - Interfaces in the electrical loop must consider quality demands on the consumer side.
> - Individual equipment is generally not designed to operate in a very weak system with associated reduced power quality. Design requirements must be clearly established in the design basis.
> - Any redundancy is cost driving. Consider reduced quality of supply to the customers as a cost reduction option.
> - Interfaces in the control loop must be standardised. Different suppliers normally have proprietary system and selecting a standard communication protocol in early design phase, preferably based on industry standards is vital.
> - Operation philosophy is key in the design. Location, quality of supply, as well as maintenance philosophy must be included in the design.

[267] http://www.associatedpress.com 4/28/2004, Doug Mellgren Associated Press Writer

6.3.2.3 *Challenges in building an R&D plant*

The construction and commissioning of the project turned out to be more complicated and time consuming than anticipated at the outset of the project. Utsira is located where it is, and logistically, you are not there in a couple of hours, and for practical purposes it may be considered as an off-shore project. Climatic conditions on the site are close to an offshore environment i.e. wind, waves, temperatures below zero, and salt must be considered. Wave heights had to be considered as transport of the largest components during the winter period can be difficult and as some of the components are long lead items, it was important to plan with the weather conditions in mind. Electronic equipment and housings had to be prepared for a saline environment, and especially the fuel cell and the electrolyser must not be exposed to temperatures below 0^0C (Nakken et al. 2006).

Another aspect that had not been anticipated was that albeit this was a small project in a Hydro context, then all Hydro standards or what was referred to as corporate social responsibility including safety issues and relations with the local community had to be complied with. One such requirement was that when the suppliers or partners were on site, then a Hydro representative also has to be on site to be responsible for safety. Since this was a research and development project with nothing comparable executed in the world before, this was one aspect that complicated the execution.

Undertaking a development project, there was also the challenge of handling the internal Hydro organisation in terms of 'internal' partners or cross sectional teams in addition to external partnering. As far as the internal organisational dimension, Norsk Hydro's large scale projects are executed by "Projects" as the executing organisation. "Projects" was a professional engineering group and construction division in Hydro (previously called Hydro Technology Partners (HTP). Compared to typical Hydro projects (offshore oil and gas projects), the Utsira project was minute in scale, and albeit the actual building of the Utsira plant was not an insurmountable challenge to the HTP group, the standard way of doing things were challenged by the Utsira project.

Two members in the Utsira venture team touched on challenges raised by the R&D project, and that the Hydro organisation had little experience with building an R&D plant. The challenge had nothing to do with whether or not the organisation was capable of building the plant. Rather it had to do with the customary way of doing things and the fact that the organisation was accustomed to projects with extensive contracting where demands can be made in terms of guarantees, responsibilities, delivery, performance, and operation at the time of handover when the plant is up and running. Typically, Projects (HTP) built projects and handed them over to the internal Hydro client once the project was built and going into operation. For the practical realisation and the building of Utsira, *one challenge* was that modification of common practice was inevitable, as this concerned a research and development plant.

«Building the demonstration brought out the issue of responsibility when it was going into operation. The builders hand over the responsibility when they see that now the components are working and they hand over responsibility for the operation to someone else. But in this case, to make it operate and work was part of the demo and there was a problem with accepting that there was no formal take-over, there were no clear boundaries. It took almost a year before the components functioned together in the operation of the plant, and the whole point of the demo was to make this function and operate. When we realised that this was a time consuming process we had to let them go as they had no knowledge and could not contribute with the actual integration, and other people were needed for this. Normally take-over would have been when the plant was functioning as a plant but then the project would have been over if you could just turn the key. This was an aspect that we had to discuss and agree upon along the way and we had to draw a line and change the criteria for take over. The components were to function separately»

Project manager Eide similarly mentioned this challenge when discussing the way projects are usually carried out in the Hydro organisation.

«Usually when we develop a project we use the division called Projects, before it was called Hydro Technology Partners, a large organisation with a couple of hundred people, and normally they are handed the terms and conditions for a project and instructed to go and build it. What I realised was that this was a research and development project, not as big a project as Projects are used to handle. Key aspects were the partner integration, handling land owners, the municipality, all interested parties were critical and in addition, time was of the essence, we were given a short amount of time to realize the project. My reflex was that we cannot do this the way we usually do projects; we had to do things differently. So we made a different kind of organisation that was more integrated where I continued as the project manager – I took on the role that Projects (HTP) usually has – and then we called HTP the technological project manager instead of the total project manager. Because I had to handle the processes and interfaces with the authorities, partners, land owners, all in parallel with the technical development; we could not handle this sequentially as is often the case, we had to do things simultaneously. There was opposition to this but it worked out well….Further, we had to define when the construction project was over and when research and development started. We had to define the time of handover and when my role as project manager was finished. It could not be

when everything was functioning because this was a research and development project. So it actually was when all components were delivered on site and tested individually. If the engine worked alone then the engine was ok, if the wind turbine worked alone that was ok. So when all the components worked individually, then project construction was technically complete»

Another challenge concerned the use of EPC contracts on a research and development project. Engineering, Procurement and Construction contracts concern the Engineering part where the supplier is given the total responsibility in constructing and designing what is to be supplied. Procurement means that the supplier of a component is responsible for handling their own potential suppliers, and Construction means the suppliers are responsible for their component or building block within a defined scope and area. Using EPC contracts on a research and development project required adjustment. The plant components, except for the fuel cell, use commercially available technology, which could be purchased on commercial terms, still the challenge was to define the R&D aspect in the project and take that out of the EPC contract. Working within the EPC framework is elaborated in the following excerpt:

«In the Utsira project there were several EPC contracts but the research was to put it together and make it into a functioning system. That was the R&D. But the point of using EPC was to make our demands clear to the individual supplier. And then Hydro, together with Enercon, had to take the risk in terms of the interfaces between the technologies …. So the electrolyser was supplied on an EPC contract being a customer to our own organisation. Same goes for the hydrogen engine and the wind turbines were bought on commercial terms with an EPC contract on our partner Enercon. In parallel there was another supply from the partner from a different part of the organisation, namely the research part of the project. The wind turbine is the core business of Enercon, but the containers with the control system and the equipment giving the electricity the right quality, that was a partner supply, that was not EPC .… The EPC comes from the Projects organisation (Hydro Technology Partners HTP) and we made a mini EPC version for the smaller projects, which we used at Utsira»

Making contractual demands through EPC contracts on a research and development project needed modification.

«What we do is that we try to delimit the research and development aspect of the project and take out the R&D part. An R&D contract is legally a contract where we cannot specify the outcome while the EPC is a contract where it is clearly defined what is to be delivered….It creates a framework

and a situation where specifications are made and in which suppliers understand there own risk and then we have to take the risk that they can't take on»

One organisational lesson learned, when purchasing components to the Utsira plant (in particular the fuel cell), was the unsuitability of setting out stringent contractual demands in a research and development project, where you do not know how things will work.

«When you build an R&D plant, you are never really in the clear, and you can not specify the occurrences of events beforehand. The plant doesn't work perfectly, and it is unlikely that it will for the entire two year operational period, that is what the specified period of operation is intended to provide operational experience on the running of such a plant. This also means that in commissioning, you cannot draw up the boundaries and set clear demands to the product and plant. You have to have a different mindset towards suppliers etc. And that means that the system that we had was not really suitable … Now it was not easy to get a fuel cell but we managed to get one from a supplier, who understood this in a way. Without them we probably would not have gotten a fuel cell because by setting such strict operational criteria to the equipment that we were to purchase, and since it was a prototype under development that we were buying, it then follows that the pricing of the supplier becomes awfully expensive…. That is not the way to do it because you have to share risk; and the most important thing in a demonstration project is to work with partners with whom you can share the technological risk as well»

Finally, the Utsira team also had to consider what part of the organisation that was to be responsible for the plant in the demonstration period. Hydro has the ability to override and control the hydrogen components (the electrolyser, the hydrogen engine and the fuel cell). Enercon has the superior responsibility for the operation of the plant, which is controlled from Enercon's facility in Germany, and involves making the system components function and interact[268] and to ensure the right voltage and frequency in the grid. The Hydrogen Group in New Energy is not an operational unit; rather it works with innovative ideas and business development. Hence the project was manoeuvred into Hydro's operations central at Rjukan that oversees Hydro's power production plants. They were given the responsibility of

[268] The operation of the system is automatic with the wind turbines supplying the customers and with excess feeding the electrolyser to produce hydrogen and conversely, when the wind drops the hydrogen generator starts to produce electricity and balance the lack of wind power. If there is more power production than there is power demand and hydrogen storage capacity then the excess wind power is exported to the mainland.

monitoring the operation of the plant. This part of the organisation was also given the maintenance responsibility using people from Hydro power plants at Nesflaten, in the western part of Norway. From this part of the country access was more convenient with a two hour drive to Haugesund from where the ferry goes out to Utsira. The internal organising around Utsira in the operation period was that Torgeir Nakken with the Hydro Research Centre (Porsgrunn) was to manage the technical aspects in the research and development period as well as the interaction with the partner. Elisabet Fjermestad Hagen in the Hydrogen group was responsible for the commercial aspects and for contemplating the future of Utsira that is working on the business case and how to take the project further in terms of business development.

6.4 Learning from operating

"… you can also take the position that if this comes (hydrogen energy) then we buy our way into this in some way… what you say and do depend on the role that you plan on taking in the future… But somebody has to get to bottom of this and really understand the technology, run the systems, and you only get that by learning from scratch – down to basics – you need these people and this knowledge. You may be able to buy this but it depends on what you believe to be true and the strategy you decide to pursue" (Mostad 2004)

At a 'lessons-learned' seminar in March 2005, the importance of the demonstration project and a practical testing site was conveyed, as illustrated in the following remark:

«When our engineers involved in the Utsira system operation presented all the experienced problems and how they have solved them, then the question came, well if you had had better time to think through all this in advance, could you then have made routines that handled all this? But they responded that there is no way you can think through it all and make routines because things have to be experienced and solved at the time the problem arises, that is what demonstrations are all about»

The value of the site, practical experimentation, and learning by doing was also communicated in the following remarks:

«We have learned a lot and there are a lot of things we could have done differently, which we have solved and which has been improved. And all the things we have learned just go to show that a demonstration has been and still is absolutely necessary if we are to deliver a system that works and where you can just push the button"……."By having a practical laboratory, we make adjustments all the time from which you may learn… when you see the Enercon people, they understand their job and skilfully work on the

system, they manage to fine-tune the plant and make it work, and they are there all the time testing and looking into something… This poor Indian guy, he thought he was going to be there for 2 weeks and ended up staying for three months… that is the kind of people you need in a project… We learned about the type of electrolyser that we ought to have, it was proved in practice, the need for technology development. And the same goes for Enercon with them testing their control system; they are out there learning something. And that is the fantastic thing about Utsira and having done this, we encounter problems and the question is how to overcome them, we stumble and learn something every day and that is what moves us forward»

6.4.1 Handling the innovative challenge

The innovative aspect of the Utsira plant was the new configuration of the individual technologies. The conceptual study by New Energy Development (2000) pointed out that in a stand-alone system construction, all components, except for the fuel cell, use commercially available technology and where the wind turbine stands in parallel to the hydrogen system. *The innovative aspect of the project was the integration* and recombination into a new technical configuration, in putting the elements together and making it function, and with continued development, to make it cost-effective and competitive with conventional power supply to remote areas.

«The innovative aspect of this project is the way all the different components are put together into a functioning system. The major challenges are the high number of interfaces in the system, controlling a grid with a large wind turbine serving a relatively small load, and operation of the fuel cell and hydrogen engine in parallel» (Nakken et al. 2006a)

Rarely can the complexity of putting things together in a new way be anticipated. This aspect came across from one of the project developers.

«The idea behind was simply to 'take proven technology and put it together'. Maybe that sounds a little dull and simple, but it absolutely is not. Taking well-known components and putting them together to function in a way that you have never done before, that is technically more difficult than people believe but does not get much attention. And that is actually too bad when you consider what we have actually done out there, which maybe has not received enough credit, that is the small technical aspects that has to be solved but are rarely emphasized. That is what I see as development of technology; yes you can make huge leaps, but there are so many nitty gritty things that have to work along the way, and some organisations have to take on that responsibility. It is great that researchers take great leaps but there must be linkages and something in-between….. By having a practical laboratory where you constantly make adjustments then you may learn.

Another pioneer behind the project referred to this aspect of the demonstration in similar terms:

«The wind mill was by and large commercially available, so was the electrolyser and storage of hydrogen. There were two components that were challenging which were the fuel cell and the combustion engine, which is also in someway available as long as you are willing to pay enough. But what has not been done properly is connecting and linking it all together. How does this behave together, what complications arise when we connect the components. When the wind drops how quickly can we get the other equipment tuned in and up and running? With electronics you have hiccups and then it all turns black. To get the control system and the design of the component that is to harmonise all this; that was the real challenge…. Hydro should have an interest in this; one thing was that we wanted deliveries for the Norsk Hydro Electrolyser technology, but Hydro ought to take an interest in this kind of competence, being able to master and handle interfaces. You can enter the market and say that we can put together this type of system anywhere in the world…. Enercon, the German wind turbine supplier is an important partner in understanding and handling this type of system, and either we can say that Hydro should be able to do everything ourselves or we can tag along a partner in this type of cooperation. Until now Enercon has been heavily involved and a very important partner»

With the recombinations of technologies came new capabilities built by cooperating with others. Hence experience with and the development of the system developed dependencies across the partner constellation involved in the project. With a composite product, who owns the knowledge and the competence? In the case of Utsira, it resulted in close collaboration between Hydro and Enercon, negotiations and entering into a partnership agreement with Enercon in order to continue development of the integrated stand-alone system as well as cooperation in the market launch of the Utsira type of system.

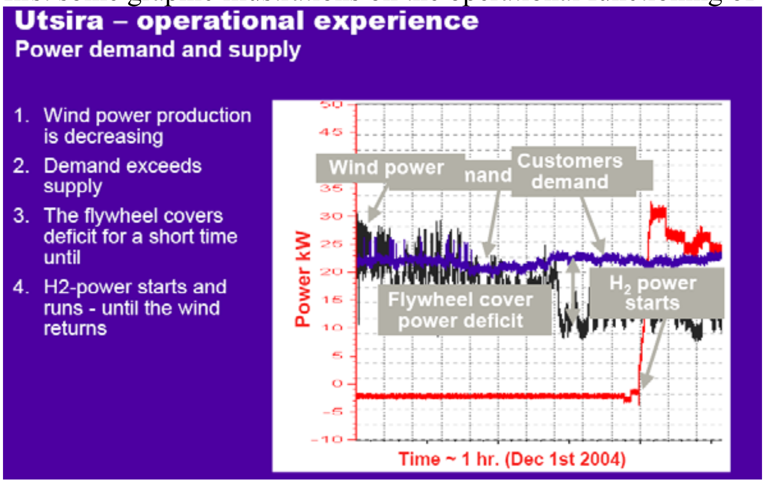
6.4.1.1 Operational experience

During 2003 and 2004, the wind hydrogen plant was built. All the individual components had been delivered, installed, and tested at Utsira by June 2004. During the remaining time of 2004, the components were interconnected and the autonomous energy system was established. The system was ready for full scale testing in February 2005, after which a steep learning curve followed:

«Since this is the first and so far only project of this type and scale, we did not fully know what to expect. We have during these first months of operation met many problems that we could not foresee. Even though there

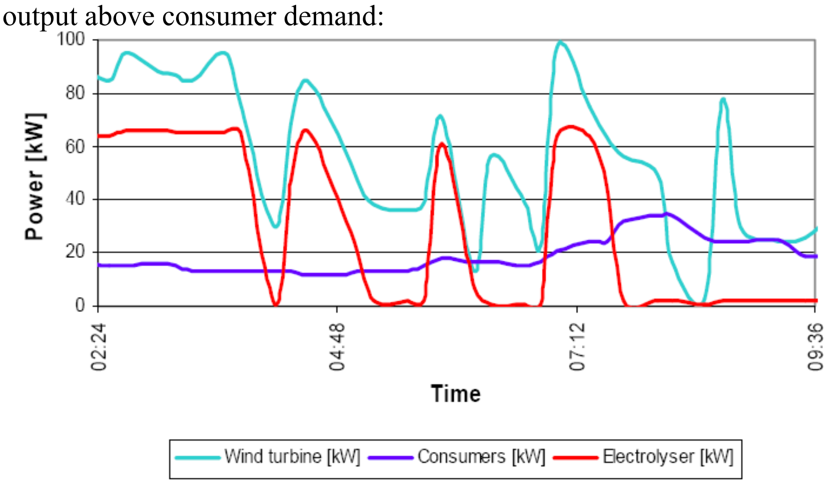
are still things to be improved we have solved most problems and this has given us valuable experience and knowledge on how to build and operate the next wind-hydrogen plant» (Nakken et al.2006a).

Next, there are brief summaries on individual component experience[269], but first some graphic illustrations on the operational functioning of the system.



Source: Nakken (2005)

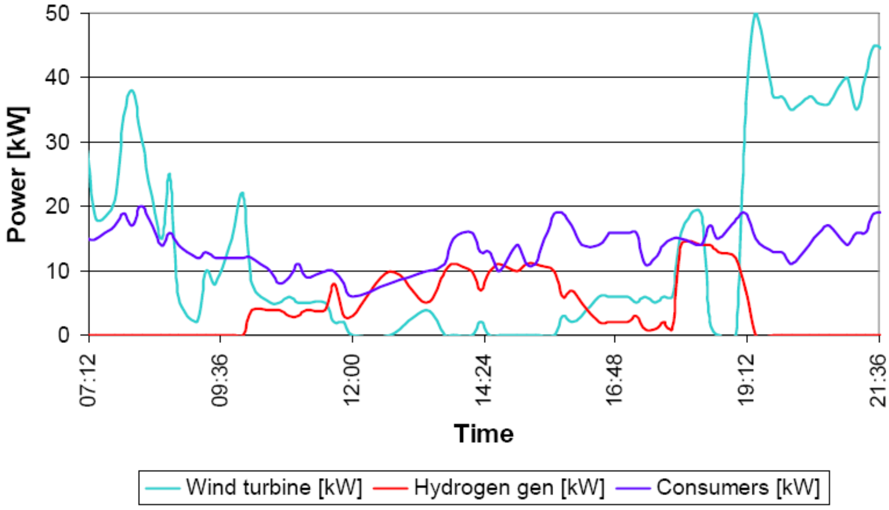
Operation in a high wind mode with hydrogen production at wind energy output above consumer demand:



Source: (ibid)

[269] Summaries are based on an interview with Nakken and Hagen, March 2007. Otherwise all repairs, work, modifications and associated costs were documented by the people at Hydro's power plants at Nesflaten given the maintenance responsibility as well as in operations and modification schemas with the Research Centre in Porsgrunn, which provide an overview of the challenges encountered in the demonstration.

And an illustration of a low wind mode with electricity produced by the hydrogen engine/generator



Source: (Ibid)

6.4.1.1.1 Experience with the control system and grid stabilising equipment

The control system was ready to start the full scale testing by February 2005. Enercon's competence and interest in developing solutions to provide constant and stable electricity supply in stand alone system, while handling fluctuating winds, is why Enercon was considered capable, and as discussed in the section on landing technology partners, Enercon had a product and ongoing development in this area. Hydro researcher, Nakken, referred to the technical aspects handled by Enercon, not as problems but as minor challenges with the grid stabilising equipment (the flywheel, the synchronous engine) that had to be handled along the way and adjusted to the specific requirements of the location and plant combination. The biggest challenge was the control system to make the components function together. This was not 'hardware' but part of the development of the software control system so that components work together, and work together efficiently. Enercon developed an Energy Management System that depending on the production and demand, automatically either switches off or on, or adjusts. In this way the force of the wind may be exploited and grid quality in the stand-alone system guaranteed in all possible operating conditions. The Energy Management System also worked as a remote monitoring system, which transmitted all the stand-alone system information to the centre at Enercon in Aurich (Windblatt 2004). In the interview with Nakken and Fjermestad Hagen (March 2007), it was indicated that Enercon had reported that the control system was functioning and that satisfactory development had been achieved.

6.4.1.1.2 Experience with the electrolyser

In chapter 4, the focus was on the initiation path of technology development with Norsk Hydro Electrolysers and why such development was considered necessary. Flexibility was a major concern, as the existing product line serving the industrial market was build for continuous operation and did not handle production variations well. With the use of hydrogen in energy market application, such as on Utsira in autonomous renewable energy systems, production requirements are by nature variable and tied to the wind power, user demand, and storage capacity that determine the need for hydrogen production. Hydro experience and competence in alkaline electrolysers was something concrete and existing technology to build something new around, which made it possible to explore demonstration projects in hydrogen energy.

Integrating electrolyser technology in the Utsira system provided operating experience with this type of system where a key feature is the interplay and phasing in and out of production technologies. To Hydro and Norsk Hydro electrolysers (NHEL), the manufacturer of the hydrogen production equipment, the performance of the electrolyser, the hydrogen generator and fuel cell were particularly important to optimise. The relevance of these components was to enhance the use of the available wind energy when there was energy in the system above the demand[270] and to provide electricity when power from the wind turbine was insufficient. Hence a requirement was flexible operation with frequent start and stops, and after operating the plant for 8 months, an operational finding was that the number of annual start and stops would be around 2-300 for both the electrolyser and the hydrogen engine, and the yearly operational hours would be around 1500 and 500 for the electrolyser and hydrogen engine, respectively (Nakken et al 2006b). With the hydrogen producing equipment, flexibility was hence a major challenge, to be able to scale production up or down and switch from a low to high percentage utilization in a short period of time so as to exploit the energy in the system. The goal has been to develop an electrolyser well suited for operation in combination with

[270] There has to be enough energy /effect in the system to start the electrolyser and a requirement to start the electrolyser was that the wind speed should be above 10 m/s for at least 10 minutes and that there should be available hydrogen storage capacity. In turn if the wind drops below a certain wind speed, the electrolyser is stopped. As it concerns the wind speed, the wind conditions available on the island have by Enercon been confirmed to be the second best location in the world, next to the Azores Islands, and with very high availability and production.

renewable energy sources. There have been many adjustments, and it has been a challenge to learn how to more rationally and efficiently operate the hydrogen part of the plant (Nakken et al. 2006a).

Hence an important experience from using the electrolyser in this type of system was that it illustrated the need for technology development in practise; and thereby confirmed the relevance of the technology development paths that Hydro and NHEL were pursuing (see chapter 4 and appendixes II-IV). A key finding in the initial demonstration period was that the operational flexibility of the electrolyser was such that it could not utilise all surplus wind power for hydrogen production (StatoilHydro/Nakken 2007). To make the Utsira type system efficient in terms of exploiting the surplus wind power production, an electrolyser was needed with a short response time to make use of the available effect.

6.4.1.1.3 Experience with the hydrogen engine

The hydrogen engine/generator combusting hydrogen to produce electricity in periods with no wind power, as an alternative or in combination with the fuel cell, was sized with a capacity to cover the households' energy demand. Since the hydrogen engine originally was not built for hydrogen, this meant that it was not running optimally, which in turn meant that the efficiency of the hydrogen engine was low and consuming a lot of hydrogen in the combustion. This in turn meant that the hydrogen storage emptied faster than expected, which increased the risk of running out of hydrogen in periods without wind power. So a challenge has been to produce enough hydrogen which then accentuated the problem of operational inflexibility of the electrolyser as discussed above.

«One problem is making enough hydrogen…The operational flexibility of the electrolyser is such that we cannot utilise all surplus wind power. At the same time, the efficiency of the hydrogen engine is low so we consume a lot of hydrogen. This, together with the fact that the consumers are now using more energy than in the beginning, means we could run out of hydrogen when longer windless periods occur. If this happens, we'll connect the customers back onto the ordinary grid» (StatoilHydro/Nakken 2007).

6.4.1.1.4 Experience with the fuel cell

The fuel cell has been challenging to integrate in the system but as the hydrogen engine was included in the system, the fuel cell was not decisive to the operation of the system.

«The fuel cell has caused the most problems. "For various reasons we have not been able to fully integrate the fuel cell as part of the system. However,

the fuel cell is not critical to operating the plant. The main reason for including a fuel cell was to gain experience with what we thought to be the future solution» (Nakken/StatoilHydro 2007)

By Hydro representatives, it was indicated that the fuel cell had about a 100 hours of operation during the demonstration period (interview March 2007). It was indicated that it had been challenging to make the fuel cell perform in this kind of system with variability in the production requirements. The fuel cell was also very sensitive to variations in voltage and frequency on the grid on Utsira, and a problem was said to have been the incompatibility with the Utsira grid.

Experience with the fuel cell was summarised by IRD in 2006. The report indicated that the energy output delivered to the Utsira grid had been 140 kWh. During the 2 years projected period, it had become evident that the match between the initial specification for the fuel cell generator and the actual operating conditions on site had not been ideal. Repairs were confirmed and it was indicated that work was being done to ensure future operation for another two year period. The targets were to make the fuel cell generator run autonomously for extended periods and be able to be remotely restarted and not require manual intervention on site (Jacobsen 2006). Below is how IRD summarised the demonstration.

A grid connected and Hydrogen fuelled 10kW PEM fuel cell based electrical power generator (UtsiraFCG10kWe) has been designed, constructed, and implemented on the Norwegian island of Utsira by the 11/06/2004. The generator operation has performed according to design requirements on the commissioning event, and for the periods during which design operating interface conditions were present. These include fuel quality (purity of H_2 supplied from the electrolyzer), quality of the Utsira grid in terms of voltage level and range, characteristics of voltage transients, and frequency level and range. On a single occasion (ultimo 2004) grid voltage exposure was up to 280Vac vs. the common neutral potential. i.e. beyond design specifications of the UtsiraFCG10kW generator, causing damage its inverters.
During the 2 years project period it became evident that the match between the initial specification for the Fuel Cell generator and the actual operating conditions on site were not ideal. Consequently, updates and repair of a number of components/subsystems on the Utsira site have been implemented by Hydro to establish a safe and better match of the operating conditions for the fuel cell generator.
During the last year of the project period the fuel cell generator has been subject to update of the cell voltage monitoring system in terms of changed voltage sense terminals on all Fuel Cell stack cells, and replacement of a few cells of the stacks.
At the present time (where this PSO-4 Project is terminated) Hydro and IRD are planning for the immediate update actions required to ensure future operation of the UtsiraFCG10kWe PEM based fuel cell electrical power generator for another (two years) period.
The target is to enable the UtsiraFCG10kWe generator to run autonomously for extended periods (e.g. weeks and more), and with the option to be remotely restarted after a routine system shut down. At present, restart of the generator requires manual intervention on site Utsira due to the original safety requirements.
For the above described reasons, the total accumulated energy output delivered to the Utsira grid during the project period has been rather modest, approx. 140kWh.

The project in this report was funded by PSO-04 and implemented with the purpose of continued developing, constructing and testing of the 10kWe PEM fuel cell based electrical power generator being part in the overall Utsira project setup by Hydro.

For IRD the experience achieved from the participation in the Utsira project is of great value in the implementation of similar projects, such as the demonstration project Hydrogen Society demonstration project in Nakskov (DK) (EFP-06, J.nr.: 33032-0144, Project Period: 03/04/2006 – 31/12/2007). The project partners in this project are Nakskov Kommune and IRD.

Source: Jacobsen (2006) http://www.risoe.dk/rispubl/NEI/nei-dk-4955.pdf

An Utsira project member reflected on lessons learned with the fuel cell, the challenge with durability and cost, and emphasized the value of the demonstration:

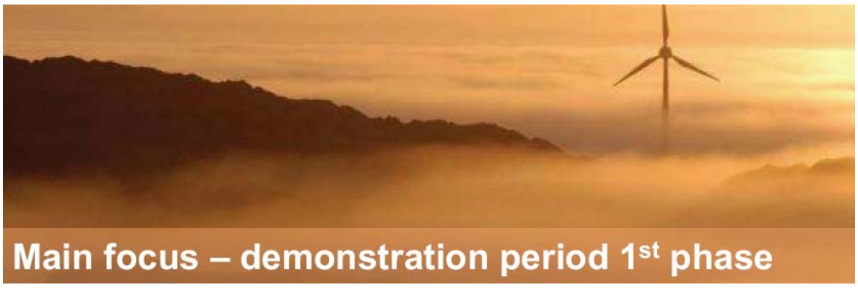
«The problem is durability and costs…I think we have demonstrated that fuel cells are difficult. Well it is not difficult to make the fuel cell work if you are willing to spend enough money. They have used fuel cells for many years. But we needed one to function all the time and at a reasonable price; it had to be able to tolerate this and that and could not just be replaced. So it was the real-life test of technology that we were after, and fuel cells have been said to represent this. Well it was proven that it was not proven technology in terms of the scope and scale that we were talking about in terms of durability and costs, so that is why we included the hydrogen generator….. I think it says something about how far fuel cell development has come in relation to the mass market. It does not say anything about fuel cells in space shuttles where it doesn't matter what it costs…. But I think that is the important learning, that we are allowed to buy a fuel cell, allowed to

negotiate the contract, and that you really see if this works or not; you set out demands on the delivery, guarantee, safety, the whole package, and then you see what it can do.… I think it is actually what we were going to test on Utsira; test how far technology development has come and what we need to work more on… and here we see that as far as the fuel cell and the re-electrification unit, there is a need to take more steps»

In an article on the StatoilHydro homepage a conclusion on the fuel cell experience was that high cost and low durability still makes this technology prohibitive also indicating that the hydrogen-fuelled generator was a good near-term alternative (StatoilHydro 2007).

6.4.1.2 Conclusions on initial demonstration period

In concluding the initial demonstration period some conclusions were drawn. The project had shown that it was possible to supply a remote area with wind power alone using hydrogen as storage medium. Compared to the goals of the demonstration, the project had proven that it was possible to make the installed components in the autonomous system function together, and that it was possible to deliver power with expected quality and reliability to customers.



- Ensuring that the installed components in the autonomous system function well together
- Deliver power with expected quality and reliability to customers

⇨ This we have successfully accomplished

Source: Nakken (2008)

The main achievements with full scale testing since February 2005 were presented in March 2006 at the European Wind Energy Conference (Nakken et al 2006a):

- Stand-alone mode (autonomous grid) for 6 months
- Availability 90 % (deviations from 100% is due to errors in the system and the customers are connected to the mainland grid)
- Power quality very good
- Customers satisfied – no complaints
- Good media coverage, several publications, several presentations in conferences and at fairs
- Contribution to local activity
- Many visitors
- No accidents

Hence experiences and results from the first year were reported as a mix of technical and non-technical achievements. The main experiences from the planning, building, and operation of the plant also emphasised the importance of having a well-defined design basis and operational philosophy focusing on: climatic conditions, signal quality, communication (control system), and key component interfaces.

Climatic conditions (offshore climate with wind, waves, temperatures below zero and salt) impact the realisation of the project (when components are brought to the island) and must considered for the electronic equipment and housing prepared for a saline environment. A main challenge was the high number of interfaces in the system, controlling the grid with a large wind turbine serving a relatively small load, and operating the fuel cell and the hydrogen engine. Variations in signal quality (voltage and frequency) were inevitable in the start up phase (Nakken et al. 2006a)[271]. Overall, it was indicated that the equipment should be kept as simple and robust as possible so as to be able to cope with such variation. Redundancy should be considered to buffer uncertainty in future wind power production and customer demand, and one could consider over-dimensioning the plant or alternatively a trade off could be made between plant availability and cost.

Another technical experience and learning aspect was to make the system suitable for remote operation[272]. This was not possible at the onset of the project because choices had to be made on available technology which was not necessarily built for this purpose, meaning some of the equipment

[271]The paper indicates that reactive power, resonance, over-harmonics can occur and must be considered. Especially the supply of the electrolyser can be a source of such problems and all equipment should be designed to handle this (Nakken et al 2006b:8)

[272] The plant is meant to be remotely operated with self-testing and where automatic remote resetting of components after shutdowns should be possible.

needed a manual restart – someone to go out there to push a button – which was not very efficient. Remote operation was implemented during the initial demonstration period. Finally, focus should be on safety[273] and when selecting the location, the following should be considered: Good wind conditions, a small but representative load, back-up system in place, not too remote, access to service personnel and a supporting community.

Another conference paper from 2006 (Nakken et al. 2006b) expressed another learning aspect, namely that this was not plug and play but a R&D project stressing that this was a prototype meaning that the outcome was uncertain, not knowing if it would be successful, at least commercially. Selecting the right partners should be considered carefully where there is a dedication to make it work. Another realisation from operating the Utsira plant was that this kind of system will continue to be a very site specific product when ready to be marketed. An Utsira type plant has to be tailored to the site specific history. Adjustments need to be made in relation to a new site, where it is to be located, the production potential in the wind, the size of the components, and energy consumption. In principle the plant will be the same, yet even though a lot will become standardised there will be tailoring and competence needed to meet customers' demand when it is put into operation. Keeping customers satisfied and positive was/is considered important for the public acceptance of hydrogen.

A researcher with Hydro Research Centre sums up the general achievement in the following way:

«The demonstration of the Utsira system is considered a success technically as we managed to build this and make it function. There is a lot of talk about this type of solution, but no one in the world has done it before. Hydro has done it, and demonstrated that it works. Utsira was not designed to be a commercial product; the idea was to demonstrate that it works; that you can put together the components and make them work together and supply electricity…We are also involved in the commercialisation process. New types of Utsira projects, we have gathered a lot of information on how this type of system behaves, how we may optimise, how the components work together, many component that need to work together while also supplying electricity to a consumer at a given quality»

[273] Safety was very important. It would be detrimental to the development of hydrogen as an energy carrier if an accident happened. The Utsira plant is compact and complex and it contains explosive zones, advanced equipment and regularly has unskilled visitors. Safety has had the highest priority and there have been no reported accidents. The key for achieving this was indicated to be proper training of operator personnel, good working instructions for the whole system and clear distribution of responsibility on the site.

Hence a lot had been learned from operating the plant with real consumers, full scale and all the components, yet greater operational stability and robustness in the system needed to be achieved to be competitive with wind-standalone systems that are the main competition (Nakken et al. 2006a). With the experience from the initial demonstration period, the partners were able to put together more specifications in terms of requirements and demands to a system with hydrogen production from renewable energy sources.

6.4.2 Extending the demonstration

Up front the Utsira project had been given a delimited time frame where the demonstration period of the wind-hydrogen combination was to run for 2 years to get operational experience. Wind turbines were running since their installation in the fall of 2003 and the project running since the inauguration July 1. 2004. The Utsira plant became one of Hydro's most profiled projects ever with awards and a series of journalists and TV crews visiting the island, and this attention was part of the argumentation to continue the project. The research and demonstration argumentation was that there was still a lot to learn and improve, to optimize operation, and since the technology combination was still not at a point where it could be commercially launched.

That Hydro and Enercon was to continue its Utsira project was published on Hydro's website by the end of 2005[274]:

«The combined wind power and hydrogen facility on Utsira has become a globally recognized landmark in the development of new energy systems based on hydrogen. By continuing this project we hope to get even more experience and vital knowledge about combining wind and hydrogen," says Ulf Hafseld, responsible for business development in Hydro's unit for new energy. The demonstration project on the island Utsira off the coast of western Norway started operating in summer 2004 and was scheduled to run two years. Hydro and its partner Enercon have now decided to extend the project until spring 2008….There is still much valuable experience to gain, together with the need to test new components and solutions for use on future facilities. Among other plans is testing a new internally designed electrolyser technology at the facility ….The Utsira project has provided us lots of valuable experience in an area that the entire world is interested in and where Hydro is at the forefront of development. We now want to make some adjustments and try out new technological solutions to optimize the facility»

[274] *Hydro continues Utsira Project*, Nov. 25, 2005 http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2005/November/16889/

The attention that the project had earned came across in the quote below:

«Since the Utsira project started up in 2004, representatives from the energy industry, media and tourists from around the world have visited. In 2004, the Utsira project won Platts Global Energy Award for best project within renewable energy, a very high distinction for all of us who work with energy»

The decision to continue Utsira was publicized within the Hydro organisation in the Hydro internal magazine - HI Hydro Innside[275]. The Utsira experience was indicated to have generated momentum for other alternative energy projects.

«Right partnerships: "Creating the right partnerships with turbine suppliers both short and long-term is crucial," comments Eide. "We need a supplier that sees the same commercial potential as we do….Hydro's combined wind and hydrogen power project on the western Norwegian island of Utsira has generated a lot of positive attention – and momentum for alternative energy projects. Eide was project manager of the test project, which was recently extended until spring 2008. "If we can make Hywind successful, the potential for more viable alternative energy supply becomes even greater. The people working on this project are very passionate and have respect for the challenge it entails. It's really fulfilling to know you're making a difference. At Hydro we're not just talking about it, we're doing it!" (ibid)

The plan for the extended period of demonstration was outlined as follows:

[275] HI Hydro Inside, The global magazine for Hydro employees – no.1, 2006:36

Main focus – demonstration period 2nd phase

- Improve the system, make it more robust, more efficient and reduce the cost
- This will together with market evaluations provide a basis for considering commercialisation
- The plan is to end the demonstration in December 2008

Source: Fjermestad Hagen (2007) http://www.europeanislands.net/docs/Utsira_Project.pdf

Technical aspects still needed refinement, the system optimised, and a renewed partner agreement was entered with Enercon also with the intention to cooperate in the marketing of the Utsira type system. Cost reductions needed to be achieved to become a competitive product in the future[276]. In an article from 2007, there was an indication that the company expected a competitive solution to be available in five to ten years[277].

The decision to continue or terminate the demonstration project was, by several Hydro representatives in the Utsira team, discussed as a matter of finding new system dimensions from which additional experience and learning could be achieved.

«We have a license to operate the windmills and 2 ½ years to operate the demonstration plant. Then there has to be a point in keeping the demonstration up and running when you have achieved a certain level of learning on the new concept. Then it may be more appropriate to continue the learning process on additional aspect and possibly at a different location with different conditions. It has to be consideration for the innovation and development and not an obligation to a local community. We are doing this to learn...although the profiling and public relations aspect is important; it is not the main intention. It has to be relevant to continue from a

[276] At the ISLENET conference in 2006, it was indicated that the cost of energy in the Utsira project was about 1 euro/kWh, and that 5-10 years into the future, the estimated cost of energy was 35 euro cents / kWh, which would be competitive with extreme places in the world. Typical diesel cost was presented as 20-25 euro cents / kWh. http://www.managenergy.tv/metv/portal/_vi_real_300_de/index.html?showSlides=true&search=torgeir+nakken+&submit=go

[277] In an interview on the StatoilHydro homepage (28-11-2007), researcher Torgeir Nakken indicated that the goal is to make the concept commercially feasible. "It looks like we can be competitive with conventional remote-site power supply – diesel or combined wind and diesel generators – in a five to 10 year perspective. The solution was projected to be suitable for isolated communities across the world. "The concept is applicable to isolated communities worldwide. Greenland, Canada, Alaska, Siberia, Australia, and numerous Pacific, Mediterranean and Atlantic islands are all viable candidates." http://www.statoilhydro.com/en/NewsAndMedia/Multimedia/features/Pages/HydrogenSociety.aspx

development point of view and for that it may be relevant to add new elements to the project»

For the continuation of the Utsira project, a new and more effective hydrogen engine/generator was discussed as a bridging solution until more durable fuel cells perhaps becomes available. The continuation planned to start in the fall of 2006 was also linked to the technology development path undertaken by Norsk Hydro Electrolysers/Hydro Hydrogen Technologies[278], where a goal has been to develop electrolysers that are well suited for operation in combination with renewable energy sources. The plan was to link the Utsira project with the PEM development path (proton exchange membrane (PEM) electrolysis technology discussed in appendix IV) by integrating the new electrolyser technology. The plan was to use the Utsira site to test the electrolyser as a part in the autonomous system, and when adding new components to a research and development project, new operational challenges would emerge in terms of how to optimally run the system.

The extended demonstration period was to test the PEM electrolyser, developed to have higher efficiency, smaller footprint (in terms of size and space requirement), and higher operational flexibility that, in a matter of seconds, would make it possible to utilise a greater share of the excess wind power to produce hydrogen. The PEM installation was expected to enhance hydrogen production, to secure more hydrogen in the system and thereby stabilise and balance the system[279].

In an Utsira context these attributes were considered promising and installation was planned during the fall of 2006. Technical problems however created a setback that made it necessary to stall sales, redesign the system and to prolong the testing phase. At the Hydrogen and Fuel Cell Hannover Fair in May 2007, it was announced that the new electrolyser technologies would be on the market during 2008, and that the PEM electrolyser would be installed at the wind/hydrogen plant on Utsira during

[278]Norsk Hydro Electrolysers (NHEL) changed name to Hydro Hydrogen Technologies effective 1/10/2006.

[279]The PEM electrolyser was launched at the Hydrogen and Fuel Cells Hannover Fair, April 2006 and from the product folder, the following characteristics were described: "The dynamic range of the electrolyzer (5–100 percent of maximum capacity) makes this the perfect choice for applications with large variations of input power, or gas output requirements, typically found in wind and fuelling station applications. This allows the system to fully utilize the large variations of power from a renewable source. Typically, the electrolyzer will have a response time from 5-100 percent of fractions of a second."
http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2006/April/15492/,
http://www.hydro.com/library/attachments/en/press_room/inergon_folder.

the first half of 2008[280]. It was indicated that the PEM electrolyser was in its last stage of testing as administered by Hydro and also with assistance from Institute for Energy Technology (IFE) in a joint project (REELYPEM[281]) supported by the Research Council of Norway. Hence the time frame for the Utsira demonstration was pushed out as there were unanticipated set backs and delays in PEM technology development, where Hydro decided to extend the testing period[282].

At the time of the conclusion of my field work (fall 2007), the plan was that the Utsira project was to remain in operation throughout 2008 to use the plant for system improvements, profiling purposes, as a test station for new components to learn more, and to develop a competitive backup product. At the ISLENET conference[283] (2007), activities for 2008 was outlined with the focus areas presented in the figure below[284], also expanding the project to include transportation and mobility related activity.

---

[280]Hannover messen: Smått og godt fra Norge, *15.5.2007,* http://www.prosessindustrien.no/print.asp?menu=6&id=4408

[281]REELYPEM (Hydrogen Production from Renewable Energy Prototyping and Field Testing of a PEM Electrolyzer), project period 01.01.2006 - 31.12.2007 Project number: 174080, http://www.forskningsraadet.no/servlet/Satellite?c=Prosjekt&cid=1193731614452&pagename=ForskningsradetNorsk/Hovedsidemal&p=1181730334233. The overarching objective of the REELYPEM project was to design and build a prototype Proton Exchange Membrane (PEM) electrolyser adapted specifically for operation in renewable and distributed energy systems. The electrolyser was to be demonstrated and to test its performance under conditions that come as close to reality as possible. Project partners were Norsk Hydro and IFE and the project was planned in two steps. Firstly, by continuing and coupling the academic research base and new understanding of PEM cell construction, a pilot atmospheric PEM electrolyser should be build in IFE's hydrogen lab and tested under real and simulated operational conditions. The purpose was to establish parameters for optimal operation in distributed and renewable energy systems.

[282]With the merger of StatoilHydro, the PEM project was transferred from Hydro Oil and Energy to StatoilHydro.

[283]Elisabet Fjermestad Hagen presented at the conference. ISLENET held its 2007 Conference with focus on Renewable Energy Sources and the Rational Use of Energy on 9-10 October 2007 in Brussels. Presentations were made on the use of technologies that are more appropriate for island communities with the view to building technology platforms that will strengthen inter-island cooperation.

[284] As I have not interviewed company representatives about the project since September 2007, I am unable to go into more detail on the status of these activities.

Source: Fjermestad Hagen (2007)

In some of the final interviews in my study (pre- merger Oct. 2007), it was also indicated that although there was no formal decision on the matter, there were suggestions that the merged StatoilHydro would continue the project. It was indicated that the project, in addition to having more learning and potential for improvement, also was so profiled and had become an icon with symbolic importance to the company and the world around.

In a brochure from the merged StatoilHydro titled: *StatoilHydro – a long experience with hydrogen*, it was indicated that "the project was planned to run until 2008, though this may be extended". This was also put on an Utsira postcard from StatoilHydro:

StatoilHydro

Utsira – stand-alone energy project

A small community living on the remote island of Utsira, 18 kilometres off the west Norwegian coast, receives all of its energy from renewable sources as part of a unique StatoilHydro demonstration project.

Two conventional wind turbines supply the 220 inhabitants with their energy most of the time – but wind energy is intermittent. As part of this pilot project, 10 households have been connected to a stand-alone system which utilises some of the surplus wind to produce hydrogen with water electrolysis. When the wind is too light or too strong for the blades to turn, these 10 households receive their electricity from stored hydrogen, using a hydrogen generator and a fuel cell for power production.

Project status

The wind turbines were installed in 2003, and the hydrogen and other stand-alone equipment the following year. The project has been on stream since 2004 and is planned to run until 2008, though this may be extended.

Main Components:	Technical parameters:	Supplier:
Wind turbines	2 * 600 kW	Enercon
Flywheel	5 kWh	Enercon
Master synchronous machine	100 kVA	Enercon
Hydrogen engine	55 kW (top load)	Continental
Fuel cell	10 kW	IRD
Electrolyser	10 Nm^3/h H_2, 48 kW	StatoilHydro
Hydrogen storage capacity	2400 Nm^3 Hydrogen	StatoilHydro

The project owners are Norwegian StatoilHydro and Enercon from Germany.

www.StatoilHydro.com

Source: http://www.electrolysers.com/

Finally in an article in Norway’s leading technology magazine (Teknologisk Ukeblad / Technology Weekly) an article from June 2009 restated the intention to continue the Utsira project:

«StatoilHydro is running a demonstration plant on Utsira showing how wind power may produce hydrogen by using an electrolyser and storing the hydrogen as a compressed gas. Electricity is re-generated using the hydrogen in a combustion engine or a fuel cell when needed. The plant has supplied ten households with renewable power since 2004 and StatoilHydro is continuing the Utsira plant and will use it actively to develop the next generation of more effective and robust hydrogen technologies»

6.4.3 Learning from partnering throughout the demonstration

In addition to the technical experience gained from realising and operating the Utsira project, there has also been valuable experience from bringing different organisations together on the project. As mentioned previously there were strict demands on the project to adhere to all Hydro standards or what is referred to as corporate social responsibility including safety issues. One such requirement was that when the suppliers or partners were on site, then a Hydro representative also had to be on site to be responsible for safety. Making the partners adhere to these requirements was needed.

«Well the challenge with Enercon was that it was a different kind of company than Hydro as they operate in a slightly different way. In Hydro everything is large, formalistic, we have procedures on all kinds of things, and everything has to be decided in a straight line and often a long one … With Enercon if they think it is smart to do something then management decides to do it… We have experienced a difference in culture and that things are done differently. We had to work on information and to follow Hydro procedures as it is a Hydro plant… like getting them to tell us when they are on location… well they do that now but we had to tighten things up a bit. But in spite of the differences in company structure and decision making structures, it has worked out fine. But getting an acceptance of us being big and that everything is not handled in the head of one person, is sometimes hard. Some companies think we are ponderous and difficult to handle»

In an interview with the fuel cell company / an IRD representative[285], a comment was that the negotiations and contracting with Hydro were extensive and time consuming. This was a large company with 'an ocean of lawyers' and documents, and that Hydro was very detailed in their specifications and demands on information. To a smaller company with chemists and engineers working with development, and without a legal department, that was a comprehensive task. On the other hand, two Hydro representatives from the Utsira team indicated that this was the admirable thing about IRD, that they were willing to take the chance and get the contract to supply the fuel cell.

«They took the chance and offered the product at a price that would not generate income and they had to apply for funding elsewhere to cover what it actually cost them to deliver. But they were eager to supply and to get the experience. That was admirable because we had talked to other suppliers…we would not have had a fuel cell if it was not for them… if so we would have had to pay at least double or much more to have it integrated … We appreciated that they took the chance and supplied so that we could explore this and learn. … They are also interested in making this work but they have had fewer resources to follow up and keep it going, and that is what we depend on»

The importance of having a partner constellation with a common understanding on the status, purpose and premises of the project was also mentioned when discussing operational experience. A research and

[285] Søren Jacobsen 27-10-04, Innovation Research & Development IRD Fuel cells

development project is not just ‘plug and play’ but requires continued development efforts and commitment:

«There is one thing that has proved important for the cooperation to have gone well. About a year after the inauguration we had an evaluation meeting to sum up our experience. At the meeting Enercon praised the cooperation pointing out that they had previous experience with a system solution that was a prototype that had not been tested in all regards, and the buyer did not understand that it was an R&D plant. Enercon mentioned that when they supply a part into something bigger, into a plant constellation, then even though their wind turbine is working, it has to function within the bigger system. To them it was an important point of agreement that Hydro realised and accepted that this was a demo and that development is step by step….

… We have had problems with the fuel cell and the engine. There was a one year guarantee on the fuel cell but after that we have not made any demands. We have been rather lenient… there are also things about the engine that could have been addressed but they have cooperated, been there and been willing to help us. That is why we think it is ok, the most important thing is to make it function and we cannot achieve that if we are very harsh and demanding, then they will stop picking up the phone… The cooperative constellations are important when you try to bring new technology to the market, it could have gone wrong in a different constellation with different actors, and a different mindset. That is important learning, that you need a more lenient attitude, a common understanding and that the most important thing is to make it work and that it will take time.”

Finally a Hydro team member pointed to the value in the partner that may not be entirely specified in a contract in advance:

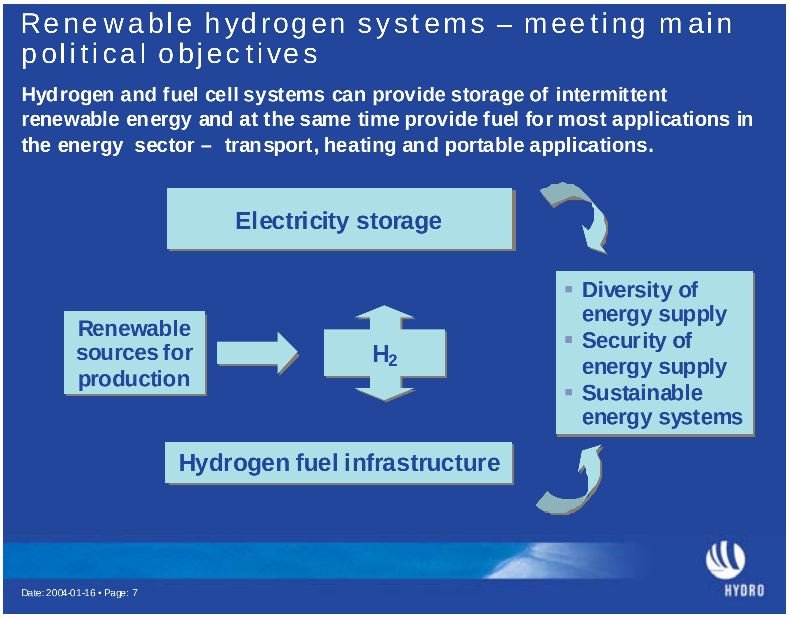
«The important thing is their effort, engagement and commitment to the research project; the fact that they are present, making it work and that they don’t throw in the towel when there are problems; that has been most important…. We know them now and know what they stand for. At Utsira, they have spent more hours and months than was conceived. They do that with no complaints, bickering or bills. It is a partnership and we take an equal share of the burden”… “We have had very good collaboration with Enercon, but that is also because they are very interested in making this work to develop a marked for their wind turbines… but we could never with a contract or in any other way have made them do what they are actually doing willingly because it is in their own interest… they have not stuck to the writing in the contract but willingly spent resources to make it function and to learn…. Enercon has spent a lot of resources on the project, they have never given up and they have put their mind to making it work and to continue»

6.5 Utsira and business development

The project purpose was to demonstrate new technology and system solutions for an energy supply system based on renewable energy and to demonstrate how renewable energy coupled with hydrogen could provide a safe and efficient energy supply to isolated areas or areas not having a sufficient energy supply infrastructure. During the demonstration period, the main goals of the demonstration were: making the installed components in the autonomous system function together; deliver power with the expected quality and reliability to the customers; cost reductions, technical/ operational simplifications and optimisations; and commercialisation and marketing activities (Hexeberg 2005)

To provide a basis for evaluation of new market opportunities was explicitly mentioned as a key focus of the demonstration project. How to take the project further in terms of business development was also a key topic with the main partner Enercon, especially to build a positive relation and dialogue so as to establish a common understanding of commercialisation. Should they do only this project or more? There were different ways in which continued cooperation could be considered and this needed to be discussed while undertaking the Utsira project. Hence the partnership also shaped and trickled into business development and market building activities.

Market trends that potentially trigger demand were contemplated in terms of growth in renewable power, lack of electricity, security of supply, and the replacement of diesel or LPG (liquefied petroleum gas*)*. However there was no market or automatic receiver sink for this type of system mainly because the solution and its offering needed to be made known and to be coupled with potential customers e.g. in terms of regions, policy makers, companies. In a project presentation from 2004, the benefits of the renewable hydrogen system were envisioned by linking the system to political objectives where hydrogen and fuel cell systems, as enablers of renewable energy sources, could have a dual function and be means to meet main political targets.



Source: Eide and Moe 16-1-2004

Localities where the Utsira type system could be contemplated was: 1) non-grid island societies and remote areas in developed countries; 2) non-grid remote areas and islands in transition economies and developing countries; and 3) distributed generation for grid-connected societies with a high share of intermittent power. This was also pointed to in the application for the license to the energy plant in November 2002:

*«The planned wind-, energy plant on Utsira will demonstrate how renewable energy (wind) in combination with hydrogen and a fuel cell and possibly a hydrogen engine can provide safe and effective energy supply in areas without electricity infrastructure, for example on islands, remote areas and developing countries, and areas with insufficient infrastructure. Such a supply system may enable local generation of renewable power as an alternative to large scale power production and extensive transmission lines. Hydrogen as a storage medium for electric energy may also be of interest to large wind parks in the future. It may enhance the value of wind power while also producing hydrogen to other energy purposes» (*Haugaland Kraft & Hydro Energi 2002*).*

6.5.1 Towards applications and markets

Continuing the Utsira project was about continuing the particular area of business relating to the use of hydrogen in renewable energy systems (chapter 4). In an interview with one business developer, one comment illustrated that the Utsira type project and area of business did not gain support automatically inside Hydro. What came across was the lack of affiliation with Hydro's traditional energy business, and so efforts to continue activity in the area had to be advocated:

«… I argue that this is interesting for Hydro Electrolysers; yes Hydro business alright but small and not in the centre of Hydro business. Here I have tried to provoke a bit and made an overhead with a drawing of a customer who wanted to buy an Utsira type project, to which our answer was: "Sorry, we only had one"…. I did that to get a discussion going. Because if that is our answer, then we have spent 40 million and a lot of profiling and next year we are done and close it down. That won't work, we cannot do that, we have to continue…. I think it will be possible to develop interesting business based on this, and this shall be developed in connection to the electrolyser business. The knowledge and competence shall reside there and then it may become big business to them. So it has been decided to continue the project, and there is interest and indications that we will identify and decide on a new project»

Continuing Utsira in some form and shape was discussed as part of strategy revisions and continuous updates. Frequent strategy revision was a way to adjust the course and activity to a moving target as one member of the Hydrogen group described it:

«Along came hydrogen that everyone thought would solve all our problems before an X number of years. But X was not known and obviously if there is a strategy to get on a train that we think is going to solve the problems of our time, then obviously there will be a lot of strategy. How are we going to do this? How are we going to take our share of the market when it comes? And 'when it comes' has been continually put off. We thought it would be three years and then there is another 5 years and cars are coming first, and now Utsira is probably closer than cars in a way…So the reason in a way is that you have believed something about the future, and then the future has continually been moved out, and then you plan a new strategy to stick it out until the future is here, and the future has also shifted course. So strategising is about trying to hit the target and to stand your ground. Obviously a moving target is easier to hit in the short term than a moving target in the long term, there you have to change course and sometimes dramatically, that is my understanding and how I would describe that we have to make new strategies all the time»

Although frequent (2001,2003, 2005, 2006) and time consuming, strategy review processes were one way to clean out among alternatives and to sharpen the focus in terms of what applications, what should be Hydro's role, and with what deliveries. Opportunities do not hang loose waiting to be recognised, rather ideas on applications and a context of use must be committed to and developed in which the Utsira type technology offering became relevant. Discussing continuation was a point in time or a 'round about' where new and multiple directions were contemplated. As part of business development and new energy activity, there were frequent hydrogen strategy reviews so as to adjust activities to a moving target, as one of the hydrogen developers described it.

New Energy strategy revisions were adapted approximately every third year, and as part of prepatory work to the New Energy strategy process, proposals on project activity and evaluation of focus were ongoing in the Hydrogen group. At the time, the New Energy unit was established in 2003 (chapter 4), there was an associated strategy revision of the overall hydrogen focus and a renewed goal statement to position Hydro as a future innovative and safe hydrogen producer/supplier, and to maintain Hydro's position as a leading European energy player shaping the future Hydrogen Society. However, as it related to Utsira activity, one business developer indicated that in 2003, the predominant focus was on the transportation area and the process did not envision nor afford much interest in making opportunities visible in the area of stationary energy such as the Utsira type project. Advancing interests in the stationary segment was received like "water on the goose", it simply dribbled off.

«Back then I tried to propose that "we can do this, therefore and why" but it was like pouring water on a goose. But then there have been projects and Utsira became a success and that changed the attitude towards this by making the interest in it visible. When you get a lot of attention and others say that they wish to do the same, that this is exiting; then you get a whole different position in the attention span inside the company. And while this happened, we also realised that the large market in transportation may not materialise until 15 years from now. Hence we have a more balanced approach to our opportunities including our equipment used with others, building products and markets in the stationary area»

Hence, the internal sentiment towards Utsira type activity and the attention to opportunities in this business area changed with the achievements in the Utsira project. With the massive external interest and attention indicating that this was worthwhile, something that ought to be done and pursued, the internal attention was boosted. Simultaneously, the indication that the large scale transportation market was unlikely to materialise in large commercial scale for another 15 years or so, also favoured the development of a more balanced approach to opportunities. Hence the reception by the world at large - including the value and relevance attributed to the Utsira type technology combination, production system and the potential role in future energy - interacted dynamically with and fed back into Hydro's hydrogen activity by providing supportive argumentation for new projects and activities in the stationary energy area with hydrogen in renewable energy systems.

As an outcome of a New Energy strategy revision in 2005, it was decided that effective from the early parts of 2006[286]; Hydro's hydrogen activity should be organisationally restructured and unified under the management of Norsk Hydro Electrolysers (NHEL),[287] although still an integrated part of the New Energy unit in Hydro Oil and Energy. The purpose of hydrogen activity was still to be twofold namely to position Hydro as an energy company in hydrogen energy and to create a viable electrolyser business more short term. But experience hitherto in hydrogen energy had shown that the aim of creating a viable electrolyser business and the aim of making Hydro visible and creating an option in a future hydrogen market were entangled. Opportunities emerged in a pre-commercial market where products, systems and services were demanded that were more comprehensive than supplying electrolyser technology. Opportunities and activity were emerging in between or in the overlap between the traditional industrial applications, electrolyser supply, and the long-term envisioned market for hydrogen as an energy carrier.

In relation to the integration of hydrogen business development under NHEL management, a process of reviewing ideas, initiatives and activities that targeted the twofold purpose of Hydro's hydrogen activity was initiated so as to narrow down initiatives to be pursued in early markets for hydrogen technology. Questions addressed in the strategy review concerned how to pursue both purposes and how to exploit and create a commercial position from participation in early markets for hydrogen technology that entailed more than electrolyser supply. Discussing alternative roles in terms of Hydro's involvement in demonstration projects was also a central aspect

---

[286] "From 1 February 2006, hydrogen business development and our electrolysers business will be under joint management, headed by senior vice president Knut Harg. This will strengthen Hydro's effort to commercialize early opportunities in new hydrogen applications, says Harg." http://www.electrolysers.com/hydrogentechnologies/svg03816.nsf/UNID/E1DA4B95F5C3DFF8C1257417005263FC?OpenDocument&lang=no

[287] Up until 2006, the responsibility for Hydro's hydrogen activity had been divided. The Hydrogen Unit in New Energy was responsible for long term business development and Norsk Hydro Electrolysers was responsible for business as a supplier of electrolyser equipment primarily to the industrial market but also toward demonstration projects in early hydrogen energy markets. February 2006 a hydrogen strategy review process was conducted in the spring of 2006 which came to guide activity until the merger of StatoilHydro (October 2007).

e.g. to be a supplier of technology, a supplier of a system solution, being operator of a system, owner or part owner, being a supplier on commercial terms or a partner and developer financing parts of a project. Conceptualising hydrogen alternatives did not start from scratch but was part of reviewing, sorting through initiatives and narrowing down and building on activities already in progress. The idea generating process was summarised as follows:

«During the early work of the hydrogen business development group, a series of diverse concepts for hydrogen technology application have evolved… Some involve carrying on experiences reaped through participation in demo-projects (Utsira, Reykjavik, Berlin etc.), others are ideas that have emerged in cooperation between the Research Centre in Porsgrunn and with the external environment»

As part of the review and preparation of initiatives, several continuation alternatives for an Utsira type of system were considered, that is project ideas and concept alternatives had emerged in relation to the interest shown in the Utsira project and through contacts from interested parties in this type of system. Over the spring of 2006, a set of concepts and ideas were chosen by the Hydrogen Group to be prepared and developed further in groups with participants from the Hydrogen group, the Research Centre, and Electrolysers. To be positioned for a future with hydrogen energy was considered to require investments in solutions and applications with different time horizons on profitability. Especially in the absence of the grand transportation market, other applications and early markets were considered important to generate marketable concepts and maintain credibility among stakeholders like decision makers in public and private sectors. Electrolyser technology developments / product lines were already well in progress (chapter 4), and cooperation in the development of products, technology solutions and markets was conceived as one way to reduce exposure and to be a springboard from which hydrogen activity and company involvement could be broadened.

With this in mind, the ideas and applications explored in the strategy review were considered promising. Criteria used for choosing focus areas were profitability in the near term (5 years), willingness to pay and hence involvement closer to commercial terms; coupling to competences like technical experience and technology development; and linkages to the twofold purpose of hydrogen activity namely to positively expose and position Hydro as an energy company in hydrogen energy and to create a viable electrolyser business more short term. The outcome of the review process concentrated and prioritised hydrogen activity in six focus areas where four related to the continuation of Utsira type activity in stationary energy systems and two concerned transportation initiatives on the supply of hydrogen fuel and / or complete hydrogen fuelling stations[288]. The collectively derived focus areas became the hydrogen strategy pursued since the latter part of 2006[289].

Next, I will describe the focus areas and ideas related to the Utsira type of system that emerged through contacts with interested parties while Utsira was in its construction and operational demonstration period.

6.5.1.1 Particularities in market development and building applications

One business developer indicated that on the part of Hydro working towards a commercial solution on the Utsira type of system, the plan was that while the research and development period was in process with adjustments and testing to make the technology combination work; then uses and markets needed to be worked up, and how to move towards commercialisation had to be considered. Parallel to the demonstration there were aspects linked to business development in the Hydrogen group that they needed to know more about such as the question of uses and eventual markets. Concrete questions concerned: where an Utsira type of system could be sold, what role Hydro should take in proposed projects, could something be done on commercial terms? Should only the electrolyser be sold or the integrated plant system, what partners and what customers did they want to have, how to move along? Project ideas and concept alternatives emerged through the attention and interest in the Utsira project and through contacts from parties interested in an Utsira type of system or product[290].

A common aspect to the contacts and enquiries into the Utsira project was that there was great interest in getting as much "free" help as possible coupled with separate intentions to source system components and take on the integration in the respective projects. Another aspect was that the interests were diverse in terms of how an Utsira type of system would be

[288] Utsira-related activity illustrates the strategic area of business involving the use of hydrogen in stationary renewable energy systems and not transportation. Alternatives in the other strategic area of transport systems and the use of hydrogen in transportation will not be discussed because I have narrowed down my study of demonstrations to the case of Utsira.

[289] The recommendations on hydrogen activity were discussed with the management group in New Energy, before being submitted to management in Norsk Hydro Electrolysers for decision. Recommendations were also submitted to Markets in Hydro Oil and Energy for evaluation of criteria for participation in projects and in considering the long term hydrogen venture.

[290] The Utsira 'product' is an integrated energy solution using wind power, where hydrogen based energy storage makes it possible to satisfy demand and compensate for differences in supply and demand from the wind generator. The alternatives to such a system have commonly been diesel generation in non-grid remote areas, or battery storage for small scale application as back up power.

used[291]. Some project enquiries were in the category of demonstrations others on commercial terms expecting a level of technological maturity and proven reliability; finally enquiries showed that there was little understanding with regards to the cost and technology status of an Utsira type of system.

Due to the many enquiries and the interest in Utsira know-how and information, more systematic work was initiated in 2005 to use the interest as part of commercialisation efforts and in the work toward "the next project". Business building was intended to emerge through communication of Utsira information and experience.

6.5.1.1.1 Islands and remote areas

The first continuation of the Utsira system or "product" in a stand-alone renewable energy system involved trying to decide on what could be the next project, location and / or island. Reliable and affordable storage of electricity is a pre-requisite for using renewables in remote locations and laying the basis for developing a future decentralized energy supply system.

Two approaches were in the works by 2005. *One* was to apply for an EU project which was labelled PRODI-RES (Promotion and Dissemination of Renewables).The project was labelled PRODI-RES because the project was submitted under a <u>Pro</u>motion and <u>Di</u>ssemination type project call, but also to echo the spirit of Prodi, Romano Prodi, who was President of the EU Commission (1999 to 2004) at the time the High Level Group presented its visionary report on actions to promote hydrogen energy in the EU (June 2003)[292].

In the EU project proposal, the idea was to establish a small partner group with Hydro, Enercon (wind partner in the Utsira project), Eltra (independent transmission system operator in the Western part of

[291] Hydrogen systems to stabilise the grid; increase utilisation of renewable electricity production and the renewable energy share of energy supply; electricity solutions to remote areas and as an alternative to cable connection for islands; renewable energy storage in remote area with existing and excess wind capacity. Project enquiries were different in their demand for e.g. total system integration, Utsira know-how, or electrolyser components; the connection of electrolyser and fuel cell to wind power system to produce hydrogen for a range of purposes, show storage and use in electricity generation; replacing diesel generated power; using wind power to produce hydrogen to produce ammonia.

[292] It was under Prodi that the concept of the hydrogen economy became a strategic priority for sustainable development and pathways to hydrogen oriented energy was considered including the prospect that hydrogen is one of the few energy vectors that allows for the introduction of renewable energy to the transport sector http://ec.europa.eu/research/rtdinfo/42/01/article_1316_en.html

Denmark[293]), and EDA (*Azores*' electric utility, Electricidade dos Açores, S.A. (*EdA*). This group of four would be the core project group that in turn was intended to establish dialogue partners with parties that had expressed an interest in the Utsira project. The purpose was to engage the dialogue partners in an active dialogue where Hydro and Enercon would inform about what was going on in the Utsira project and thereby share experience and learning from Utsira while the parties would inform about their particularities and localities e.g. wind measurements, the energy consumption and demand side, political framework conditions, and as part of the project, the different localities would be modelled and investigated. Hence the EU project idea intended to establish a promotional platform for the exchange of information and for sharing Utsira experience to parties interested in renewable hydrogen systems. While profiling Hydro's competence in the area, the project would also be part of assessing and working up future customers because the exchange of information was intended to assist concept development, planning, and decisions on construction and use of the Utsira type of system and the management of renewable electricity generation and storage. The value proposition in the project was that the experience and learning from the demonstration could provide valuable input to new partners wishing to install or increase their share of renewable power.

The other approach pursued while awaiting EU response, and in the event that the EU project would not get funding (which turned out to be the case), involved cutting back on the number of partners, profiling and communication efforts. It involved a more Hydro internal process with the same intent as in the first approach, namely to work towards the 'next Utsira' project. The key activity was still to establish contact with a number of interested parties, dialogue partners that had approached Hydro to get information on Utsira and had expressed interest in a wind hydrogen project. It involved early discussions to understand their requirements and sorting through the potentiality for Hydro involvement in their proposed projects. The target was to evaluate multiple prospects and work up at least 10 actual project candidates since the enquiries were variable in terms of maturity and content, and since many projects were likely to turn out to consist of more interest than finance. From the multiple project candidates some would be considered suitable for follow up and more detailed study.

[293] Eltra is now part of Energinet.dk that operates and maintains the electricity and gas transmission grids. Energinet.dk is the result of a merger between Eltra, Elkraft System, Elkraft Transmission and Gastra. The merger took place on 24 August 2005 with retrospective effect from 1 January 2005. Operate and maintain the electricity and gas transmission grids.

The ambition was that the next project should be a zero-cost project at no cost to Hydro i.e. where the investment required would be paid for in terms of grants, customer payment and sale of energy. By the end of 2005, some thirteen Utsira type candidates were explored and out of these 4 projects were studied and discussed in more detail where two concerned wind-hydrogen concepts as a stand-alone system for an island to replace diesel power and as an alternative to replace a cable to a mainland grid; a third concept concerned a wind-hydrogen-ammonia combination and value proposition (discussed below); and finally, a fourth project idea concerned grid balancing and load shifting (discussed below).

Evaluating the enquiries on an Utsira type of system for remote locations and islands involved considering the requirements of the customer against the achievements and development during the Utsira demonstration. The aim was to get to a point where enough had been learned to be sure that it was realistic to bring down costs and have a reliable system before pursuing different projects and applications. As indicated above, there was little understanding with regards to the cost and technology status of an Utsira type of system, maybe not surprising since Utsira was the first autonomous system tested in full scale. Hence when potential customers indicated they were interested in information on the profitability of the Utsira demonstration and that a project would be of interest provided technology was proven and commercially viable; it was simply too early to pursue such prospects because system development was not quite there yet. Another example was project prospects where reliability was the key requirement and where the customer was not prepared to look at it as a demo. In such contexts and with such requirement, it was considered to be premature to offer the stand-alone system before it had been fully tested and proven to operate reliably, which was planned to be the outcome of the ongoing demonstration period on Utsira. A final example of this was when the wealthy Russian business man, Mr. Roman Abramovitsj, also called Mr. Chelski (as the owner of English soccer club Chelsea) showed an interest in the project already in June 2004 even before the grand opening on July 1st, 2004[294]. As one Utsira project developer pointed out:

«Well Roman Abramovitsj came and wanted to buy this kind of plant; he was the governor in a remote area of Russia and needed electricity so he wanted this type of system. He is not used to being told no, so he came anyway. We told him that for now it was enough with the one plant on Utsira. We told him no because having the Utsira project was enough, enough challenges. This is a research and development project, a test site that we are supposed to learn from, and we do not need two plants to learn the same. It would we

[294] http://www.aftenposten.no/nyheter/okonomi/article815002.ece 22. juni 2004 kl.18:36

even harder to travel to Russia to make adjustment than it is to travel to Utsira. Possible in Moscow or Leningrad but far away up in Siberia…We need to take some steps at a time, learn and believe that costs can be brought down, test the new electrolyser, then we will be in a different shape to see and decide if and what to do with this commercially»

Another consideration emerged when enquiries came from potential customers that also wanted a strategic relationship with Hydro e.g. other wind generator manufacturers. Such enquiries forced a review of how this would impact the continued relation and partnership with the Utsira partner Enercon. Choosing a partner had repercussions on relations with other partners and the type of involvement and project that could be undertaken. This meant considering whether or not to enter into discussions on stand-alone integrated system with other wind generator manufacturers that also wished to do the control and integration. To enter into such partnerships was seen as incompatible with the partnership arrangement with Enercon. Instead such prospects could be considered for follow up as possibilities for electrolyser and component sales. Hence the partner constellation had to be considered and participation in projects was considered either as integrated systems, supplying the electrolyser on commercial terms, or to enter into a paid agreement for support and technical services.

By the fall of 2006, the positive profiling and attention gained by the Utsira project was interpreted to reflect an international interest in this type of system solution. However the commercial launch of the concept still depended on further development to reduce cost and to build in the experience gained from realising the Utsira project. Competing with other solutions such as diesel-backup would require a more reliable and less expensive fuel cell, and another aspect to be developed further was the systems integration wherefore the cooperation with Enercon was considered to be of key importance to the continuation of the Utsira concept.

It was decided to extend the operational period on Utsira through 2008 and to use it as a test site for the PEM electrolyser to get experience with PEM operation. A renewed partner agreement was entered with Enercon to continue cooperation in development of the integrated stand-alone system as well as cooperation in the launch of the Utsira type of system. A common understanding and aspiration of the companies were to move from wind with diesel backup to wind with hydrogen backup systems in the future. In addition to islands, renewable-hydrogen energy systems could also be considered in regions where there was high decision- and cost barriers to grid expansion, typically in less developed countries but also in mountainous regions. In this type of location the issue would be the same as on an island, namely that hydrogen would be an option for storing intermittently generated electricity. Such a system could be called a "hydrogen battery" but as seen from the Utsira project, it would be a highly integrated, flexible production/ storage system.

I finished my study in the fall of 2007 where my last interview was September 19th 2007 before the StatoilHydro merger was realised October 1st, 2007. On the new StatoilHydro homepage an article on the Utsira project was published on 28-11-2007 titled: "The First Hydrogen Society…in StatoilHydro, our hydrogen society has been running since 2004. Here's the story of Utsira". In the article, Torgeir Nakken (the engineer responsible for the technical aspects in the Utsira demonstration period) made the following projection on an Utsira II project:

«The next wind-hydrogen plant might be built on the Faroes," Nakken reveals. "If the project moves ahead, we could supply up to 100 homes." ………The next decision milestone is in early 2008, following the completion of a feasibility study in December. If successful, large-scale demonstrations like Utsira will pave the way for a future hydrogen marketplace. Many improvements must still be made, but we've now identified many of the corrective aspects – edging us ever closer to closing the gap»

Finally, Torgeir Nakken made the presentation: *Experiences from the wind-hydrogen plant at Utsira* at the Hydrogen and Fuel Cells Conference (April 2008) at the University of Birmingham[295]. In the presentation, the project period and experience were highlighted and as part of the presentation the most tangible future Utsira 2 type project was mentioned as seen in the slide below. The timing and realisation date was undetermined at the time of writing this thesis.

[295] http://www.fuelcells.bham.ac.uk/documents/14Nakken.pdf

Source: Nakken (2008)

6.5.1.1.2 Grid balancing

Another continuation of Utsira type activity, involved exploring and analysing the possibility of using hydrogen production to regulate an electricity network, in other words, to use hydrogen production to balance the grid. In electricity markets, the transmission system operator will be responsible for keeping the power system in balance that is balancing the transmission network by balancing consumption and production. This means being responsible for the physical management and control of the national power system. Technically this means that when there is a balance between the supply and the consumption of electrical power, the frequency of the voltage e.g. in the Nordic power system is 50.00 Hz. Practically, it implies that if there is too much electricity in the grid, then somebody has to cut production, and in the balancing power market, the participants bid a price to alter production or consumption, and the market is used when any imbalances arise in the power system. An Utsira type concept variant was conceived as relevant to the balancing power market in terms of purchasing electricity when there is excess and combining this with hydrogen production (e.g. based on electrolysis) and contrary to cut hydrogen production when there is shortage in the grid. In regions with high shares of renewable electricity, that by nature is intermittent and likely to produce without respect for consumption and demand, a coupling with hydrogen production would allow for a better utilisation of the renewable power production at times when the production of these sources exceeds electricity demand/consumption. The main point was to produce hydrogen through electrolysis at sites where a temporary or structural overproduction of renewable electricity existed which could not be effectively distributed through the electric grid.

In a paper written within the context of the European Hydrogen and Fuel Cell Technology Platform, and the Initiative Group on Financing & Business Development, the grid balancing challenge was described in the following way:

«Large RES (renewable energy sources) developments in sparsely populated areas like West Ireland, Scotland or North Norway may put additional strain on grids with limited transfer or interconnection capacity. The challenge of efficient management and balancing of the grid can be particularly acute in areas with a high share of wind and local combined heat and power (CHP) plants, which are often based on RES (biomass) and typically operated based on heat demand. Here "down-regulation" can be required as well as "up-regulation", which leads to disconnecting the most intermittent sources, namely those from wind. The challenges of handling such amounts of wind and distributed generation (DG) have been expressed in the following way by Eltra – the transmission system operator in Western Denmark»

> *"As a result of the increased share of DG, about 50 percent of the production capacity has moved to the local grids. Consequently, it has become more difficult to predict and control the total electricity generation. Strong interconnections and efficient international power markets have so far prevented major malfunctions. However, impacts on power markets, system operation and security of supply are causing concern. Area prices have become more volatile due to fluctuating wind power and congestion in the grid. Keeping proper balance between consumption and generation has become more difficult, because the demand profile is determined by consumers, wind generation depends on wind only, and local CHP plants are controlled by heat demand and time-of-day tariffs. On top of that, increasing problems with security of supply have been identified."*

Source: Pedersen et al 2005 referenced in Fjermestad Hagen et al. 2006a

As this was/ is an existing challenge in the western part of Denmark, discussions were initiated with partners in this locality, and Hydro's technology development of the PEM electrolyser (Proton Exchange Membrane (PEM) see appendix IV) was considered particularly suitable for this kind of performance and application due to its flexibility and short response time, which made it possible to react to load changes on the grid. Albeit technically viable and within reach, the greatest challenge with this type of application concerned the question: what to do with the hydrogen? The main challenge was to find a large-scale buyer of the hydrogen. Here several alternatives were weighed such as mixing it with natural gas or feeding it directly into CHP production (combined heat and power production). The hydrogen could be sold in existing hydrogen markets used as industrial gas or feedstock but again the challenge was finding the 'customer' and making cost comparison with alternate hydrogen production methods. Alternatively, the hydrogen could be used as a transport fuel, in addition to balancing the grid, and would thereby also provide opportunities for an early infrastructure for hydrogen in transport. The grid balancing opportunity and synergy with renewable energy sources were summarised in the following way (Fjermestad Hagen el al. HFP April 2006a).

«If the H2 is used as transport fuel, this application, in addition to balancing the grid, would also provide opportunities for an early infrastructure for hydrogen in transport. Depending on the actual market place, the costs of balancing the grid (or market value of the additional regulating power) can be exploited so as to constitute a cost "rebate" on renewable H2 in the transition phase of a hydrogen energy market. This enables a lower opportunity cost for producing hydrogen at times of weak demand in stationary use, improved renewable energy management and diversification of final use of renewable energy sources (RES)»

Work on this concept was in the works through the middle part of 2006 when it was set aside to pursue other paths more actively. It was set aside as business and project development was linked to a Danish project initiative in an early planning phase and hence with less control in the hands of the Hydro organisation in terms of the time horizon and realisation. Further, although the cost of producing hydrogen would be lower in this type of grid balancing context (by exploiting the variation in electricity prices), there was uncertainty in terms of the linkage to the economics of grid operation and the economics of the user side. The following quote points to reflections at the time of decision on this Utsira type continuation concept:

«We found a customer for the hydrogen, but I was still uncertain. It was a new project initiative by Danish partner Elsam in the planning phase, and they were likely to plan for several years….in terms of budget, my budget framework was cut and then I had to make a choice. I selected other activity at the expense of this application. I felt that we were not quite there in terms of understanding mechanisms and profitability. It is an interesting concept and we know more now but it is too early to spend money on this, so now it is used more as 'food' for presentations»

It was decided that no active ownership or operational role should be taken, but contact with the Danish project initiative and partner constellation should be maintained to develop competence and possibly contribute to system solutions in a demo- as well as future large-scale installations. A change in role could be considered once project experience and documentation from the Danish project would become available.

6.5.1.1.3 Back- up and emergency power

A third continuation of the Utsira type activity (renewable hydrogen energy systems) was a higher cost 'niche' application based on the potential hydrogen represents as a medium for storing and generating electricity. It involved the development of a regenerative system to replace batteries in locations without grid connection. The system would combine a fuel cell and an electrolyser - in this case Hydro's PEM electrolyser suitable for smaller system sizes - connected to a renewable energy source, which compared to Utsira would be in a new direction with solar energy. The system would further require an integrated product including a control system, hydrogen storage, and power electronics, and the system would have to be as maintenance free as possible due to installation in hard to access and remote areas.

The project variant originated from an intended profiling project associated with the construction of Hydro's new head office at Vækerø with the intention to have a small hydrogen and fuel cell generation system on-site to showcase innovative technology solutions. A researcher working on assignment in relation to this showcase project was also linked to the work of Elisabet Fjermestad Hagen in the Hydrogen group, responsible for the continuation and commercial aspects on Utsira. The idea emerged that the showcased technology solution could also be oriented toward the telecom market, using a hydrogen fuel cell system for power backup. Accordingly, one market building area became to scale down the renewable hydrogen system to a power generation application for remote systems like weather stations, telecom base stations, and cellular communication networks with unstable power supplies and / or in need of backup.

A project idea was fronted to Telenor and subsequently developed into a Scandinavian project proposal submitted to the Nordic Energy Research with Nordic partners including Telenor, Sony-Ericsson and the Danish fuel cell company IRD (the fuel cell partner in the Utsira project), a municipality, and university milieus. The partner constellation represented the value chain in the proposed system but also reflected the strategic requirements of the Nordic Energy Research Programme. However, as rules changed at the expense of capital goods (support could not be spent on capital goods), there was little incentive for the industry and technology partners to pursue the project and the application was withdrawn. Instead, bilateral efforts between the industry partners, Telenor and the Hydrogen group in Hydro was pursued with focus on the development of a prototype.

The challenge with this type of application and potential market was to determine the role that Hydro should play in the value constellation and product offering. At first, the thinking revolved around pursuing this as a Hydro idea and a Hydro product but with more exploration the position became that this could become a market for the electrolyser business and that Hydro should not be responsible for product development / product integration nor in the business of selling e.g. base stations to Telenor or Ericsson. Pinning down the contribution, the outlook shifted to finding partners to take on product and market responsibility, responsible for product development in terms of the integration of the system and for selling the final product. The Hydro contribution in this type of development path was by 2006/2007 narrowed down to entering into alliances with relevant technology partners and offering to supply the PEM electrolyser including development into a suitable size.

6.5.1.1.4 Renewable energy for ammonia

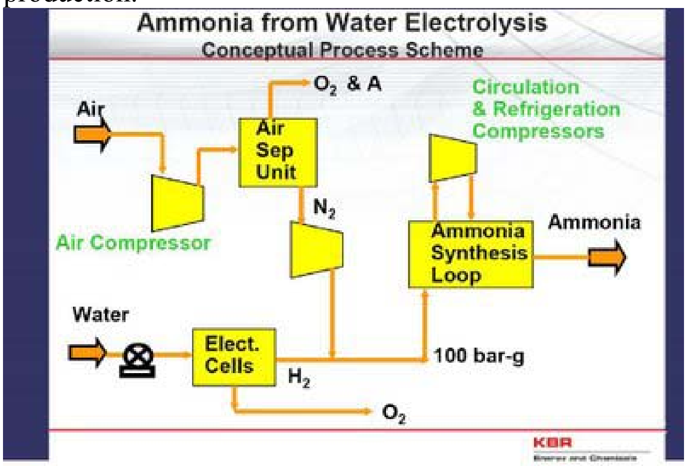
A fourth continuation of the Utsira concept came to be referred to as: *wind-to-hydrogen-to-ammonia*, *renewable ammonia*, and in the US it was also referred to as *freedom fertilizer* or *fertilizer from wind*[296]. In the exploration since 2005 to see how Utsira could be continued, an idea and connection to a US pilot project emerged in the process of being in touch with authorities and parties interested in the Utsira project. A researcher with Hydro's Research Centre in Porsgrunn worked closely with the Hydrogen group in New Energy on the continuation of Utsira related activity, and in this context, contact was established with the University of Minnesota. The University of Minnesota was central in promoting a Wind-to-Hydrogen-to-Ammonia concept and a pilot project involving renewable hydrogen production through wind powered electrolysis (combining wind power with an electrolyser to produce hydrogen). The project's aim was to provide a renewable alternative, locally produced, to part of $300 million of ammonia derived from fossil fuels and used as nitrogen fertilizer in Minnesota agriculture. The drivers[297] behind the US interest in the concept were to

[296] http://windnh3.blogspot.com/2008/04/blog-post.html, http://sites.google.com/site/wwwfreedomfertilizercom/

[297] Wind to Ammonia Drivers

1. Declining domestic ammonia production 2. Stranded wind resource due to low transmission capacity 3. Volatile natural gas market (drives ammonia production costs up) 4. High regional demand and robust infrastructure for anhydrous ammonia 5. Need for increased food, energy, and economic security 6. Successful policy and business models for community owned energy (biofuels and wind energy) 7. Provides a clear path towards a hydrogen economy

http://www1.umn.edu/iree/e3/e32007recap/presentations/reese_e3_2007.pdf stimulate wind development yet to diminish the need for additional transmission capacity, security of supply, and the trouble with high ammonia prices in the US agricultural regions[298]. The project idea was that hydrogen would be used in the industrial production of ammonia, which could then be used in fertilizer production and in other applications. A further elaboration of the concept also envisioned that the ammonia used in fertilizer production in turn could be used in the production of energy crops which in turn could be used in the production of ethanol / bio fuel. Wind to Ammonia participants included industry and public partners, Norsk Hydro being one of them, and the relevance of Norsk Hydro in the project was in terms of connecting hydrogen production (electrolysis) with the renewable electricity production.



Source: http://windnh3.blogspot.com/

Hydro participation in the pilot project was one way to explore the position and role of Norsk Hydro Electrolysers (Hydro Hydrogen Technologies since Oct. 2006) in the process from electrolysis to ammonia. Participating in the pilot would predominantly be to participate as a supplier of electrolyser technology, but would also be a way to learn about this 'wind-hydrogen-ammonia' value constellation and to build cooperative relations with technology suppliers in ammonia synthesis where several engineering and

[298] Natural gas is the current hydrogen source for anhydrous ammonia through a process called Steam Methane Reforming. Natural gas cost and use are projected to rise throughout the next 20 years as domestic production will concurrently decrease (DOE, 2003). Fifty percent of nitrogen fertilizer is imported and 28 percent of domestic fertilizer plants have shut down due to high domestic natural gas prices. Utilizing natural gas in the production of anhydrous ammonia also contributes to green house gas emissions. In contrast, wind energy is perhaps the cleanest source of energy, continues to decline in production cost per kilowatt hour, and is becoming competitive with even the cheapest sources of fossil fuels.

construction companies (e.g. Haldor Topsøe in DK) offer proprietary designs for ammonia synthesis plants.

The US based pilot project was one variant path springing from Utsira activity and the wind-hydrogen-ammonia type application would provide additional experience in large scale hydrogen production that at the same time require more flexible production technology adjusted to the variability in renewable power supply / power prices. Another aim of the participation was to determine the adjustments and modifications needed on the electrolysers to this type of application and to US norms and standards. As it involved the selling of electrolyser technology, one may argue that this merely involved the entering into a new market segment in industrial applications for the electrolyser business. However, a central point is that it is unlikely that this opportunity would have emerged without the profiling and continuation efforts associated with the Utsira demonstration project. The idea and participation in this type of wind-hydrogen application emerged in connection with dialogue partners / parties showing an interest in the Utsira project and Hydro's experience with the Utsira wind-hydrogen combination.

The continuation of Utsira type activity and the pursuit of applications and contexts of use, illustrate that such materialize from undertaking the Utsira project in the sense that path alternatives emerged in relation to the realisation of the Utsira project. Contacts emerged and were conduits to new ideas and new activity. Potentialities and applications materialized from undertaking the Utsira demonstration and were intertwined with technology development, operational experience, encounters that turned up, as well the efforts to communicate about the demonstration and the value of the Utsira type system.

6.5.1.2 Participating and mobilising business development through international arenas

Attendance and efforts have also been put into participation in international fora to build interest in this kind of hydrogen area and application, as well as to build relevance - and argumentation for demonstration activity.

6.5.1.2.1 Participation in conferences

The project was presented in 2002 at the World Hydrogen Energy Conference in 2002; in 2003, 2004 and 2006 at the European Wind Energy Conferences (EWEC), at the International Hydrogen Energy Congress (IHEC) in 2005, and the World Hydrogen Energy Conference in 2006, the

ISLENET[299] conferences 2006 and 2007, and the Hydrogen Islands Initiative launched by ICHET[300] in 2007. Presentations have focused on different issues as linked to the development period that the Utsira project was in. In 2002 and 2003 the focus was on a conceptual study (Glöckner et al 2002) and on design, impact assessments, and planning (Nyhammer et al 2003); in 2004 focus was on aspects related to construction and commissioning of the Utsira plant (Eide et al 2004). In 2005 and 2006 it was lessons learned, sharing operational experience, and arguing for activities like promotion and dissemination of Utsira experience (Fjermestad Hagen et al 2005, Nakken et al 2006a, and 2006b), and in 2007 focus also included the continuation and extension of the Utsira demonstration project (Nakken 2007).

While Hydro was working with market development and the conceptualisation of applications, communication at conferences tried to build relevance for demonstration activity and the Utsira type of system. Work towards "the next project" and business building were intended to emerge through communication of Utsira information and experience. While applying for the EU promotion and dissemination project (as mentioned in the section on islands and remote areas) presentations tried to convey the relevance of Hydro's initiative. This was illustrated in the paper at the International Hydrogen Energy Congress (IHEC, Fjermestad Hagen et al. 2005):

«New renewable energy is an important mean for achieving European energy policy targets for increased diversity of energy supply and reduction of CO2/greenhouse gas emissions. Renewable power is by nature intermittent and a large installed wind power capacity causes imbalances in the power grid and local, load-balancing solutions are being sought. In remote areas and isolated regions renewable power is considered an environmentally friendly alternative to costly imports of fossil fuels and the challenge in such cases is also to secure stable power. Solving grid issues and using energy storage, is key to finding good solutions for a high share of renewable power … Therefore the promotional value with respect to renewable electricity generation that is embedded in existing and innovative renewable power sites with energy storage systems – such as the island of Utsira off the Norwegian coast – is considered to be high … Hydrogen with re-electrification systems with hydrogen fuel cells or generator is a new innovative near term solution as back-up system for wind power. Compared

[299] ISLENET is a network of European island authorities promoting sustainable and efficient energy and environmental management. http://www.islenet.net

[300] ICHET (International Centre for Hydrogen Energy Technologies) started in May 2004. The International Centre for Hydrogen Energy Technologies (UNIDO-ICHET) is a United Nations Industrial Development Organization project whose statutory mission is to demonstrate viable technologies for the implementation of a hydrogen inclusive economy as well as to facilitate their widespread use, more particularly in developing countries.

with all other storage systems hydrogen offers an additional value since the storage medium itself – hydrogen – can be used as fuel for transport and other energy applications. In non-grid communities therefore, hydrogen technologies in combination with renewable energy offer total energy solutions, eliminating the import and use of fossil fuel ... Hydro has now initiated an activity, where the aim is to establish a promotional platform, sharing the experience from Utsira. Dialogue partners around the world interested in similar renewable hydrogen systems are identified for a structured exchange of information that may help target groups through the initial phases of concept development, decision-making, planning, construction, optimal use and management of renewable electricity and storage»

The value proposition was that the experience and learning from the Utsira demonstration could provide valuable input to new partners wishing to install or increase their share of renewable power; Hydro would be a reference point or an informational hub for this type of technology system and it would be part of a review process and investigating new locations for a possible next project.

Emphasis in conference papers was also put on the value of practice as well as the relevance of demonstrations as seen in the excerpt below from the IHEC paper (ibid):

«The experience from an existing new and innovative plant such as Utsira wind-hydrogen demonstration plant can be of value for the establishment of future renewable power systems and help in the planning of new sites. Promotion and dissemination of concrete project results as well as planned development for new sites will provide useful and necessary information and contacts for further and more detailed transfer of know-how and experiences»

The value of practice and the relevance of demonstrations were also communicated in a EWEC conference paper:

«We think that more large scale demonstration projects like Utsira, and dissemination of key lessons learned from them, is important in order to: prove the technology, improve public awareness and acceptance; improve cost competitiveness, reduce market barriers» (Nakken et al. 2006a)

And in the excerpt below from the World Hydrogen Energy conference in 2006:

«We believe that if successful, large-scale demonstration projects like Utsira can prepare the way for a future hydrogen marketplace and we will therefore continue to initiate and participate in demonstrations of

sustainable energy solutions using hydrogen as an energy carrier. We trust that these demonstrations will help improve public awareness and acceptance, improve cost competitiveness of renewable energy, and reduce market barriers for new energy and technology solutions in general and hydrogen technology in particular» (Nakken et al. 2006b)

With presentations at conferences arranged within the ISLENET framework in 2006[301] and 2007[302], a connection was established to the European islands network (some 20 million people are living on non-grid islands, Hagen et al 2005), which is a network supported by EU institutions and associated with the EU Commissions Sustainable Energy Europe campaign[303]. The Utsira project was presented with technical and operational experience and also with reflections on the value proposition of the Utsira type of system to island communities above and beyond standard cost comparison per kWh with the main competitor that is diesel aggregates. Here there is the mention of the avoidance of diesel transportation costs, renewable power being sought for environmental reasons, not using fossil fuels, and the value in becoming energy independent and to secure energy supply long term. Further there is the spinoff from visitors that contribute to local activity. Over a 1000 visitors came to see the Utsira plant in 2005 as well as 2006. As Nakken (ISLENET 2006) pointed out: "we are talking about techno- and hydrogen tourism". Ideas were also presented on what may close the competitive gap, namely to think of more ways to exploit more of the available wind resource / use more of the surplus energy in the system e.g. to consider the plant together with other island needs such as pumping or heating water, water irrigation, desalination of saltwater, other utilisation of the hydrogen like fuel for transportation, which would be useful to the island community, and which would improve the efficiency of the Utsira type system. Increase in oil and gas prices, valuation of a green image, and the introduction of policy measures (renewable energy support / CO2 tax) were also announced to make an impact on the competitive standing of the Utsira type system.

---

[301] ISLENET 2006 Sustainable Energy Systems for European Island Communities, *Utsira Operational Experience*, Torgeir Nakken 28/3/2006
http://www.managenergy.tv/metv/portal/_vi_wm_300_en/index.html?showSlides=true&search=torgeir+nakken

[302] ISLENET 2007 Island networking and focus on technologies, *Hydrogen Technologies*, Elisabeth Fjermestad Hagen 10/10/2007

[303]A European Commission initiative in the framework of the Intelligent Energy – Europe programme http://www.sustenergy.org

In 2007, at the Energy from the Edge Symposium[304], Nakken (2007) also focused on the extension of the Utsira demonstration. What was going on "inside the fence" (inside the plant and technology combination) with planned activities for 2008. And what was going on "outside the fence" in terms of work with the Utsira island to discuss spin of activities with the local authorities and local representatives from trade and commerce, and the research group Polytec to brainstorm ideas on how Utsira could build upon and benefit from the wind-hydrogen plant with the objective to secure long term residence and growth at Utsira. And finally what was going on with the Utsira concepts in terms of planning an Utsira II project, a next project candidate where a feasibility study was being conducted by Statoil, Hydro and Enercon as partners in a possible wind-hydrogen project at Nolsøy in the Faroe Islands.

Contemplating the contexts of use, framing a need for the Utsira type of system, and presenting such ideas to potential stakeholders have been ongoing and parallel activities to the handling of technical challenges in the Utsira plant. Presenting at international conferences were arenas to present such ideas, to explain about the technology combination and solution, and to get others interested in the Utsira type of system and interested in pursuing work to advance the use of hydrogen in renewable energy systems.

6.5.1.2.2 Participation in the EU arena

Internationally, business developer Elisabet Fjermestad Hagen (EFH) was particularly involved in EU activities on hydrogen and fuel cells by participating in the European Hydrogen and Fuel Cell Technology Platform (HFP). The HFP was established on recommendation from the High Level Group that drew up visionary recommendation on a European hydrogen future in 2003[305]. The HFP[306] operated since January 2004 with a large

[304] The Nordic Council of Ministers for Energy made a decision to investigate the possibilities for an enlarged cooperation on energy issues with Shetland and Canada – the neighbours to the West. As a result of the decision the Task Force for Renewable Energy in Sparsely Populated Areas approached the Shetland Islands Council and Nunavut. The interest in establishing cooperation was mutual and the decision was made to join forces in planning and implementing a Nordic-North Atlantic-Arctic Symposium on renewable energy in remote communities. The three parts and Nordic Energy Research organise the Symposium with the title "Energy from the Edge". The Energy from the Edge Symposium on renewable energy in isolated locations was held in Shetland on the 11th-13th September, 2007.

[305] The EU Commissions Directorate General for Research and Energy set up an Advisory Council as a continuation of the process that began in October 2002 with the appointment of the High Level Group on hydrogen and fuel cells.

[306] The European Hydrogen and Fuel Cell technology platform was established building on the work of the High Level Group on Hydrogen and Fuel cells, a think-tank type of initiative consisting of 19 members (balanced with large and small/medium industrial enterprises and

stakeholder group responsible for defining a common long-term EU vision on hydrogen as an energy carrier. The task of the HFP was to identify and recommend research initiatives and to draw up a strategy and action plan for the introduction of hydrogen and fuel cell technology. EFH was one of six people appointed to the HFP's Executive Council to the Advisory Council of the HFP since the Advisory Council[307] became rather large (35 when established 1/12/2003[308]). The appointment recognised Hydro's involvement in the field of hydrogen. EFH was known from Hydro's hydrogen development activities; from leading an expert group looking into the use of hydrogen and zero-emission technology in the Norwegian transport sector[309]; and known as one of six experts appointed to the national hydrogen committee (June 2003) to make recommendations on hydrogen as a future energy carrier to the Norwegian Ministry of Oil and Energy and the Ministry of Transport and Communication by June 2004[310].

In the EU context, the role of the Executive Group was to create a dynamic within the technology platform to pull the various initiatives together, move the process forward on a continual basis, and to think along new lines to look into business opportunities and applications of interest in

---

research institutions formally launched in Brussels on 10th October 2002), and the HLG report: 'Hydrogen energy and fuel cells – a vision of our future' issued 2003. The European Commission facilitated the establishment of a European Hydrogen and Fuel Cell Technology Platform aimed at accelerating the development and deployment of these key technologies in Europe. The platform should assist in the efficient co-ordination of European, national, regional and local research, development and deployment programmes and initiatives and ensure a balanced and active participation of the major stakeholders (i.e. industry, scientific community, public authorities, users, civil society). It should help to develop awareness of fuel cell and hydrogen market opportunities and energy scenarios and foster future co-operation, both within the EU and at global scale.
http://ec.europa.eu/research/energy/pdf/hlg_vision_report_en.pdf
http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_hlg/article_1146_en.htm02

[307] The HFP had an open and accessible structure allowing participation of active stakeholders (e.g. member of the advisory council, participant in steering panels or initiative groups, participant in platform operations) yet required a level of commitment to ensure that initiatives were taken forward in a dynamic manner. People in the advisory council are personally elected but with a letter of support from their organisation indicating that the person is allowed to spend at least 5% of his or her work time and have travel expenses covered. The first meeting of the Executive Group was April 5, 2004. The Executive Group as well as the Advisory Council convened approximately every other month

[308]http://circa.europa.eu/Public/irc/rtd/eurhydrofuelcellplat/library?l=/publicsarea/advisorysco uncil/acslists121203pdf/_EN_1.0_&a=d

[309]Set up by the Norwegian Ministry of Transport and Communication

[310] The main recommendations in the NOU 2004:11 "Hydrogen as the energy carrier of the future" are that a national hydrogen programme should be established, emphasizing research, development and demonstration of hydrogen technology related both to the transport sector and stationary energy supplies. The programme should be a part of a primary hydrogen strategy that utilizes hydrogen vehicles, information and training, safety and the certification of hydrogen technology.

addition to evaluating initiatives within research and development. In achieving this, key aspects were to oversee the quality of proposals and the quality of support to ensure appropriate progress in platform activities. The Executive Group as well as the Advisory Council convened approximately every other month and a key initiative of the Advisory Council was to organise two panels to develop strategy document in two areas. A Strategic Research Agenda (SRA, July 2005)[311] and a Deployment Strategy (DS August 2005)[312], which combined was intended to guide research and the development actions of the European Hydrogen and Fuel Cell technology platform and also to feed into the policy arena. The two strategy documents were considered to be prepatory documents for the EU Commission in the definition of hydrogen activity under the 7th Research Framework Programme, large-scale demonstration projects and to provide recommendations for the core content of a possible Joint Technology Initiative (JTI) in the field.

Holding a central position in the HFP provided valuable insight into developments in hydrogen energy in Europe. EFH was in a position to survey activity, what was going on and to attempt to influence what was evolving in terms of concrete proposals and to maintain a dialogue and link to the initiation process and representatives in the EU Commission. As part of HPF work and responsibilities, EFH was also in charge of the Initiative-group on Business Development (part of a Joint Group on Financing and Business Development[313]) with the purpose of providing recommendations to the Advisory Council and the EU. The Business Development Group prepared papers and reports on different topics like early markets, functional synergies between hydrogen and renewable power, bridging the gap from innovation to markets, regional efforts and private-public partnerships. Activities and topics were communicated at platform meetings and at seminars inviting attendance from the EU system e.g. Commission, EU Parliament and the European Investment Bank. Hence EFH was in a central position to observe EU processes and to shape and advice HFP activities and strategy papers, and to shape the way forward. To take the recommendations of the HFP technology platform further and advance hydrogen energy, the most central catalyst was the proposal for a Joint Technology Initiative (JTI)[314]:

[311]http://ec.europa.eu/research/fch/pdf/hfp-sra004_v9-2004_sra-reportfinal_22jul2005.pdf#view=fit&pagemode=none

[312]http://ec.europa.eu/research/fch/pdf/hfp_ds_report_aug2005.pdf#view=fit&pagemode=none

[313]http://circa.europa.eu/Public/irc/rtd/eurhydrofuelcellplat/library?l=/publicsarea/initiative_development/jg_fbd_-_torpdf/_EN_1.0_&a=d

[314] A ‘Joint Technology Initiative’ (JTI) is a legal entity proposed as a new way of realising public-private partnerships in relevant industrial research and: development fields at European

«The scale and ambition of the recommended actions of both the SRA (Strategic Research and DS (Deployment Strategy) will require the mobilisation of very high public and private investments. Since the existing instruments of European RTD funding do not seem to be sufficient, new dimensions are required. One potential tool for managing these different actions under a single umbrella could be the concept of a "Joint Technology Initiative" (JTI). This JTI can basically be seen as a large-scale public-private partnership» (HFP SRA 2005:101)[315]

When the JTI idea for a joint undertaking owned by industry and the EU Commission was advanced and discussed in the Hydrogen and Fuel Cell Technology Platform (HFP), one way to gather momentum was to orchestrate letters of support. Letters of Support to the JTI proposal were to be fronted by top management in the various companies participating in the (HFP), and were to be passed on to the EU Commission also with mention of the company projects and participation in previous EU activity. 50 companies (large actors like energy - , industry gas companies, the car industry and smaller companies) submitted Letters of Support including Hydro.

By being a part of the HFP, Elisabet Fjermestad Hagen (EFH) could follow the preparations leading up to the JTI decision and establishment in October 2008 including dealing with significant aspects such as the JTI organisation and how the industry grouping was to participate as well as prepatory meetings with the EU Commission. What the participation in the international EU arena triggered in parallel, was a process of evaluation inside Hydro to elicit Hydro's position, terms and conditions on the matter. In the context of the JTI preparation, EFH reflected on the importance of taking part in this kind of arena and dialogue:

«Gradually I have come to the conclusion that it would be foolish not to be a part of this albeit it is hard to specify upfront what you get out of it….what we do know is that this will cost us something because otherwise everybody could be a part of this. The negative side of this is that there will be an administration and everyone has to club together which means some initial expenditures before the 7th Framework Programme is up and running and project funding is distributed …. But I have given some thought to these processes, and if Hydro calculates on and hopes to get EU funding and

---

level and as a joint undertaking, and jointly owned by industry and the EU commission. Funding to come from industry and a portion of EU's 7th Framework Programme (FP 7) to coordinate activity and provide a stable funding stream for applied science.

[315]http://ec.europa.eu/research/fch/pdf/hfp-sra004_v9-2004_sra-report-final_22jul2005.pdf#view=fit&pagemode=none

support to our activities in the future, then we have to be part of this. If that is not the case, and we focus on selling electrolysers then there is no point in participating. On the other hand, when you are part of a group of actors trying to construct projects - because there will be a demonstration market in many years to come including what is referred to as Lighthouse Project and these may be needing electrolyser equipment deliveries - naturally, then it does not hurt that you are a part of the initiative and can say that you can supply on commercial terms. Hence it carries an incredible large circle of acquaintances and act as a point of contact in relation to potential customers. Besides it means that we may influence the kind of projects that will be supported…. This is important also to move toward implementation and concrete activity and beyond road maps and analyses… So I have come to the conclusion that I will advocate our participation and we will see what our management team from the hydrogen group, New Energy and to Markets wants to do»

As it concerned the Utsira project, EFH commented on the importance of getting into the EU arena to communicate about the relevance of the Utsira project:

«Utsira was not a politically driven project, on the contrary I was about to say. Politically in Europe, island communities, remote markets and areas with no grid connection have been viewed as niche markets, and there is little political pressure coming from an island ….. The tendency has been that when you talk about and label something stand-alone, then there is little interest and you feel like you are put in 'time out'… We have presented, talked about and made orientations; because we want to get the different groupings in the EU Commission to realise the market potential for this type of solution. There are so many islands in Europe that need this, also because of growing tourism. So the market is huge, and will be one of the first big markets in the hydrogen area, possibly also a European export product ….. Whether it will be profitable depends on technology, we are calculating alternative costs and the target is to get below 1/2 euro per kWh which is approximately what it costs with diesel transportation and generation»

Another example of efforts to convey project experience, and research, development and demonstration activity to the EU system was through Hydro's participation in an EU delegation's visit to Iceland. The event was arranged by the European Energy Forum[316] and took place in May 2005, at

[316] The European Energy Forum (EEF), a non-profit making association, was founded in the beginning of the 1980's, on the initiative of MEPs who wished to avoid energy decisions being based on inadequate technological, economic and geopolitical considerations or born of ideological prejudices. The European Energy Forum (EEF) organises discussion meetings

the invitation of the Ministry of Industry and Commerce of Iceland and the Icelandic Mission to the EU[317]. That Hydro was invited to speak at the event among speeches made by delegates from the EU Commission was an indication that Hydro was considered to be an organisation with expertise in the hydrogen area. This picture had been painted by being active in EU's Hydrogen and Fuel cell Technology Platform, undertaking concrete activities, and participating in several EU projects. Most concretely related to the Iceland trip was the Ectos project in Reykjavik on Iceland (renewable energy combined with the storage and hydrogen use in transport, see chapter 4). The EU delegation consisted of representatives from the Commission's Directorate General on Research[318] speaking on different hydrogen energy topics and members from the EU Parliament holding positions in different committees related to industry, energy, research, environment and climate change. Head of Hydrogen activities in Hydro, Ivar Hexeberg spoke about renewable energy sources (RES) and hydrogen production[319], and a main message was that both might be elements of the solution to the challenges that Europe faces in terms of meeting growing energy demand in a sustainable manner. Hydro initiatives were presented in the transport area and on renewable energy systems, and the Utsira demonstration project was explained and presented in detail.

Given that the Utsira project did not receive any EU funding, communicating about the relevance and content of the project in the European arena was part of activities to build an opportunity space for the technology solution. One such important event was when the manager of Hydro's Hydrogen group was given 12 minutes to speak about the specifics and technicalities in the Utsira project at the Annual Event in the European Hydrogen and Fuel Cell technology platform (March 2005). This was an important event and arena to be invited into to communicate about the relevance of the project, which in turn was part of building a position and a market for the technology solution. One thing was to get the use of hydrogen in renewable energy systems manifested as an interesting focus area, and another thing was the chance to profile Hydro in front of about 400 people.

---

between the various actors of the energy sector mainly in Brussels and Strasbourg, as well as delegation visits to energy sites. Participants to the events are Members of the European Parliament (MEPs), representatives of the European Commission and experts from companies, research organisations, associations and regulators involved in the Energy sector. The EEF has a tradition of welcoming to its events any MEP who wishes to be informed on energy issues since MEPs should have access to information on the subject, provided by organisations with unquestionable expertise. http://www.europeanenergyforum.eu/about-us

[317] http://www.europeanenergyforum.eu/archives/european-energy-forum/gas-matter/visit-to-iceland-sustainable-energy-use

[318] http://ec.europa.eu/research/fch/index_en.cfm

[319] http://www.europeanenergyforum.eu/upload/dv20050528-hexeberg

In addition to speaking about the specifics of the Utsira project, the manager also spoke about the value of demonstrations to show proof a marketable concept, technology development, and to help visualise where additional research was needed, and to generate public awareness.

Source: Hexeberg (2005)

Participating in European initiatives and the Hydrogen and Fuel Cell technology platform and working alongside with other companies, universities and research institutes in the preparation of strategy documents, put Hydro in a position to monitor as well as be part of the development of agendas, proposals and policy development in the EU by influencing the informational basis that the EU Commission was working from. It closes the distance to the people in the EU Commission and other EU institutions by allowing for dialogue in the prepatory work on hydrogen energy.

Participating in the EU and international policy arenas, research and project activities had a multifaceted purpose. EU activities and demonstration projects were means to develop competence and to explore performance requirements in real life situations. Projects were also a way to see how far development had come and what other organisations were doing. The realisation of development projects e.g. the Utsira project, crossed organisational boundaries where people, ideas, and objects from different spheres were coupled in new ways. Ideas were conceived and generated through processes of interacting with others, and partner alliances also emerged from EU activities and participation in the Hydrogen and Fuel Cell technology platform (HFP). Common visions and implementation strategies were jointly formulated and pursued, which was also why this arena was /is important from a business and market development point of view. What was the informational basis in these arenas, and whose knowledge and interests shaped these arenas? Decision makers cannot possibly be up to date on all developments in science and technology and organisations need to be part of these arenas to communicate about their particular expertise, and to explain about technology combinations and technology solutions. The Hydro organisation needed to be part of such network building arenas to be considered for business in embryonic markets, lighthouse projects as large-scale demonstration projects were and will be the early market preceding a wider integration and hydrogen use in energy markets.

6.5.1.3 Utsira as an arena for business creation

The core argument behind Hydro's hydrogen energy efforts was to build a future role as a large scale supplier of CO_2 neutral hydrogen. In the initiation process of a hydrogen energy venture (chapter 4), the central argument was to build on present strengths and lay the foundation to be a central player for on-site hydrogen production with electrolyser equipment as well as develop a position as a large scale hydrogen supplier including CO2 sequestration. In the absence of a large scale hydrogen energy market and with an uncertain time horizon to a large-scale hydrogen market, the challenge was to establish applications and contexts of use. In a pre-commercial market, the challenge was to make strategic choices in terms of positions in the development of demonstration projects and in the development of applications that represented commercial potential more near term while also pointing a way forward.

The Utsira project created an arena for nurturing business creation and the conception of new activity for the use of hydrogen in renewable energy systems. The discussion of the continuation of Utsira illustrated that the technology solutions, contexts of use and efforts to establish future markets were formed simultaneously and on an on-going basis. While realising the Utsira demonstration project with ownership, project funding, and technology development; the Hydrogen group explored alternative paths that evolved from enquiries into the Utsira project and the idea of wind-hydrogen / hydrogen in renewable energy systems. Such alternative paths and detours in turn needed exploration and choices in terms of the necessary technical development, Hydro's role in the value configuration, and a choice of partners. Project participation and the realisation of the Utsira project involved handling technical challenges, and seeing the project in a context of business development; further, the project also became a site where diverse Utsira continuation concepts were conceived and formulated.

The participation in international arenas worked in multiple ways. For one, communicating about the value proposition as well as the technical attributes of the Utsira type system and its relevance to certain stakeholders. Secondly, participation in international arenas also enabled the Hydrogen group to develop strategic information. Like the strategy documents developed in the context of the European Hydrogen and Fuel Cell technology platform that combined provided a basis for decision making, policy recommendations on concrete demonstration projects and actions to pursue hydrogen as an energy carrier. Finally, in addition to creating and influencing the informational basis on which decisions were made, this type of participation also facilitated contact with European hydrogen actors.

6.6 Communicating Utsira – vision and visibility

Realising and continuing Utsira also involved demonstration in terms of information and communicating the concept. Information was important to overcome the barrier of lack of knowledge about a new technology solution which in turn may curb demand for the solution. Information creates a general awareness among business, authorities and the public at large and boosts thinking about the development and use of sustainable technology solutions. Communicating about the Utsira project was part of showing proof of the concept, a way to enhance competence and knowledge levels, as well as to generate public awareness and allowing the public and key stakeholders to learn about the technological combination.

> After the plant was put into operation in 2004, Utsira became one of Hydro's most profiled projects ever. In 2006, more than a 1000 people visited the plant. International journalists, a pop star, a meteorologist, a Russian billionaire are among those visiting the plant.
>
> Source:
> http://www.statoilhydro.com/en/NewsAndMedia/Multimedia/features/Pages/HydrogenSociety.aspx

To an organisation wishing to be known as innovative and known for being in the forefront of a novel technology combination, communication was needed to establish a dialogue with authorities, other businesses and potential customers. Being part of demonstrations and public-private partnership projects and to be in dialogue with potentially interested parties about the novel combination, was also a way to get feed back and reactions that could be integrated in the continued development and refinement processes. There may also be reciprocal influence between offering and demanding technical change. When communicating about the new Utsira technology combination, this was part of an attempt to distinguish the new from the old, and to show what the new solution offered e.g. in terms of energy, environmental benefit, and energy independence. It thereby tried to raise the bar and also break the bar by saying that energy needs may be met differently and combined with other services (such as considering the plant together with other island needs such as pumping or heating water, water irrigation, desalination of saltwater, and other utilisation of the hydrogen like fuel for transportation), which gave/ will give renewable energy added value. Communication and information may also feed into the emergence of regulation and policies by creating expectations among regulatory authorities on what may be required and expected of organisations and what may be possible in the future.

6.6.1 Creating value through communication

An important aspect of the demonstration was to make the project known to the world. While preparing for the demonstration and communicating the project internally from the end of 2001 through the end of 2002, another main activity was presentations and profiling at a number of major events. The project was presented in many arenas and via multiple mediums, and communication activity started before the actual green light for the construction of the Utsira plant (granted in April 2003).

6.6.1.1 Events

"Utsira attracts attention in Hannover" was the title of an article published on Hydro's Internet homepage in April 2002[320] and the article highlighted that Hydro was displaying a model of the Utsira concept at the Hydrogen and Fuel cell / Hannover Fair (Arno A. Evers), which Hydro as the only Norwegian company had attended continuously since 1996 (through NHEL presence at the fair). At the Hannover Fair in April 2002, the profiling material from Hydro illustrated that the early communicative promotion of the project was moving full speed forward. A model of the Utsira project concept (see pictures below) was developed and fronted at fairs in 2002, visually portraying the planned Hydro project to combine wind power with electrolyser technology for hydrogen production, a storage unit and a fuel cell used to produce electricity in periods with not enough wind. The objective and central message was to show the energy independence of an island and that a local community could be solely supplied with renewable energy produced on the island itself. Head of Hydrogen, Norsk Hydro ASA Hexeberg[321] spoke at the fair indicating that in the area of wind and

[320] http://www.hydro.com/en/Press-room/News/Archive/2002/April/16145/
[321] http://www.live-fair.com/hm02/forum/hydro.html

hydrogen: “Norsk Hydro is developing a stand alone renewable energy system utilizing wind and hydrogen on the small island Utsira off the coast of Norway.

Source: http://www.live-fair.com/hm02/forum/hydro.html http://www.fair-pr.com/hm04/exhibitors/norsk-hydro-asa.php

Although this section will not include a complete review[322], the model was used actively. Considering only 2002, the model was used at the Hydrogen and Fuel cell fair in Hannover (April), ONS (Offshore Northern Seas, August), the Oslo Science Fair, the Hydrogen Fair in Hamburg[323] in October, and again in Bergen in November. At the international Offshore Northern Seas (ONS) conference and exhibition in Stavanger (August 2002)[324], CEO

[322] The model was used consecutively at international fairs also the year of the inauguration of the project (2004) where Hydro’s contribution to e.g. the Hannover Fair concentrated on the innovative project on Utsira, and 2005, and continued to attract visitors and interest. Presentation on Utsira – demonstrating the hydrogen society on renewable terms - was also held at the Hannover Fair in 2005 by the managing director of Norsk Hydro Electrolysers.

[323] http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2002/Oktober/14631/10. okt. 2002 *Utsira vekker interesse i Hamburg*

[324] http://www.hydro.com/en/Press-room/News/Archive/2002/August/16193/ *Reiten calls on youth at ONS*, 27.8.2002

Reiten mentioned the Utsira project when communicating about important projects:

«The ONS is significant in two ways – as a meeting place for Norwegian and international partners and authorities, and as an opportunity to say what's presently most important to us….The stand displays what we presently prioritize quite well. It conveys our emphasis on Ormen Lange, our leading technological role through the 3D visualization system CAVE and focus on hydrogen through the Utsira project»

The Hydrogen group was responsible for profiling the Utsira project at meetings, in projects, at conferences and fairs. Representation at such events aspired to communicate Hydro's involvement in hydrogen energy combining a representational stand, speeches, the Utsira model, and written material. A brochure from Hydro Energy (August 2002) manifested all pioneering activity and exploration up till then with details on hydrogen energy; its availability and characteristics, its relevance in light of growing energy demand and energy security; hydrogen activity pursued as research projects; and pioneering activity gravitating around the focus areas of fuel supply for transportation with electrolysers as part of new infrastructure solutions, and complete hydrogen solutions for remote areas covering the pioneering project on Utsira. As it concerns the Utsira project, combining factual data with elements of a story and a model that visualised the technical elements, created a projection of the vision and that the new energy solution was obtainable. Also illustrating the power of projection, an anecdote from Moe responsible for communication aspects in the Hydrogen group was that:

«One Hydro colleague was on a sailing trip in 2002 and intended to sail to the Utsira Island to show Hydro's wind and hydrogen plant to his friends. Luckily the weather was bad so they did not sail to there; this was in 2002, before the final decision that the Utsira plant was to be built, but I think the model was one of the reasons people thought this was already built»

6.6.1.2 The Internet, publications and international attention

In the initiation and planning phase, the Utsira project ideas had been presented in different arenas and as, previously mentioned, made its way into different publications on hydrogen (Bellona 2000, Dunn 2001, KanEnergi 2001, and Lovins 2003). Communication continued in various kinds of media. The Utsira project and vision of a new energy society was presented in February 2003 in the H2 CarsBiz Magazine[325]. "From a small island to the whole world" was part of the message indicating that the impact of the

[325] http://www.h2fc.com/reframe.php?top=/global/news.shtml&bot=/news/arch2003.shtml

Utsira project reached further than the island community itself as the technology employed on Utsira would be especially useful in areas with problems producing enough electricity or with insufficient electricity infrastructure for example remote areas in the US, Europe and in the developing world.

Hydro's project was mentioned in the leading Norwegian technology magazine Technology Weekly (Teknologisk Ukeblad) as early as December 2000[326], and described in detail in the same magazine in May 2003. The New Energy manager (Jørgen Rostrup, Renewables and Hydrogen) commented on the intentions of the plant that it was not meant to be a commercial plant but a plant supposed to build valuable experience in the building and operation of this type of plant. The relevance of an Utsira type of system (independent island supply of energy) was pointed to by mentioning the sea cable that would have to be renewed in 10-15 years time with cost estimates at 50-90 million NOK. Hydro's long roots in hydrogen was mentioned in the article, being a hydrogen producer for about 80 years with world class technology and hydrogen planned as part of the company's future strategy to be an environmentally friendly energy supplier to Europe. Other efforts of the New Energy unit were also described. Hence with the Utsira project as the point of departure, Hydro's other hydrogen and new energy activity were profiled as well. Utsira was also described in news papers in 2003, projecting the Utsira pilot project as part of a renewable revolution, a show case for the hydrogen society, and that Hydro, with the world's first full scale plant, wished to explore if wind power in combination with hydrogen could become a suitable energy solution in remote areas[327].

On Hydro's homepage the project was profiled in May 2003[328] with the project idea, the wind-hydrogen combination and that this marked the launch of a full-scale project and real-life presentation of a sustainable energy system based on renewable energy and a future-oriented plant. The project was also part of a May 2003 article on renewable energy where the New Energy manager indicated that it was "difficult to imagine a serious energy company not getting involved in renewable energy"[329]. In September 2003, in the context of the wind turbine erection on the island, the project was profiled in detail with project history, partners, execution schedule and the innovative challenge of putting the number of technologies together in an autonomous system. In November 2003[330], Utsira was presented as part of Hydro "looking ahead to the future", an article on Hydro's involvement in

---

[326] http://www.tu.no/nyheter/bygg/article4136.ece

[327] http://www.dn.no 17.7.03, page 14 "Tester ny vindkraft", http://www.bt.no 17.11.03, pg. 8 "Fornybar revolusjon på Utsira"

[328] http://www.hydro.com *Hydrogen society on the island of Utsira.*

[329] http://www.hydro.com *Yes to Renewable Energy*

[330] http://www.hydro.com *Looking ahead to the future*

new forms of energy running in parallel with the core activities of Hydro Oil and Energy. Projects, with a window to a future energy market, in which hydrogen, wind, and waves provide environmentally friendly power and show that it was technically feasible.

6.6.1.3 Inauguration and after

From 2004, the year of the opening and inauguration of the Utsira plant and onward, communication was stepped up. The project was described in the before mentioned Technology Weekly magazine and in major Norwegian newspapers (Aftenposten, Bergens Tidende, Aftenbladet, Haugesunds Avis, Dagsavisen, Adresseavisen Morgen, Varden, Dagens Næringsliv, VG)[331].

On Hydro's homepage, several news articles were published on the Utsira project in April 2004. Articles presented project facts and key information,[332] and indicating that Energy history was soon to be written on the island of Utsira summarising the project idea, content and aim. The inauguration of the Utsira plant was July 1st, 2004, and the opening and inauguration had attendance from the Minster of oil and energy, Thorhild Midvey and CEO Eivind Reiten[333], media from all over the world, about a 100 Hydro Energy guests, music and speeches. Several media were on-site including the German newspaper Die Zeit, BBC Radio, two Norwegian TV channels (NRK and TV2), Finnish broadcaster YLE, and the Arabic tv channel Al Jazeera. A lengthy article in July 2004 titled: "Lighting the way for the hydrogen society" was published as a feature story with the project description, the project history, the coincidental encounter between the Hydro representative on an Utsira hiking trip and Utsira's chief councillor

---

[331] Teknisk Ukeblad Magasin 22.4.2004:99 'Hydrogenkraft i gang', 19.8.2004:99 'Hydrogen Samfunnet er her', Teknisk Ukeblad Magasin 29.11.2005 'Energientusiast i vinden'; Aftenposten E24 22.6.2004 'Mr Chelski ser på norsk hydrogenprosjekt', Aftenposten 2.7.2004:2 'Vinden blåser liv i Utsira igjen', Aftenposten 14.12.2004:10 'Hydro-pris for satsing i havgapet'; Aftenposten Amagasinet 6.10.2006:40 'Viten-Tilbake til fremtiden', Bergens Tidende 2.7.2004:7 'Utsira først inn i hydrogenalderen', 26.2.2005:33, Bergen Tidende 'Hydrogen, bensin, og annet snop'; Aftenbladet 2.7.2004 'Koker på grønn energi'; Haugesunds Avis 17.6.2004 'Utsira i verdensvinden', Haugesunds Avis 2.7.2004 'Ordførerens store dag'; Dagsavisen Morgen 29.8.2004:10 'Hydro melder mer vind'; Adresseavisen Morgen 20.12.2004:11 'Fra fossefall til ørkensol'; Varden 18.7.2004 'Tilfeldigheter skapte unikt energiprosjekt'; Dagens Næringsliv 6.8.2005:38 'Kjemper med vindmøller'; VG 23.9.2006: Miljø-slik blir Samsø selvforsynt, Dansk øy dropper oljen'.

[332] http://www.hydro.com/en/Press-room/News/Archive/2004/April/17297/ Key information on the Utsira project
http://www.hydro.com/en/our_business/oil_energy/new_energy/hydrogen/winds_change.html

[333] http://www.hydro.com/templates/ArchiveNews.aspx?id=16614&epslanguage=EN 'Winds of change blow on Utsira's opening day'

Kirkhus working by the Utsira lighthouse, and interviews and commentary by Utsira people[334].

Internationally, in April 2004, Hydro's presentation of Utsira project facts[335] and an international press release (Associated Press 2004) titled "Wind-blown Norwegian island being used to test new clean energy system" was picked up and reprinted in international media like the Seattle Post Intelligencer, Fuel Cell Today, Fuel Cell Works, Energy-Efficiency.ru, The Sierra Activist, Emerging Technologies Emergic.org and MSNBC.com news services. The Utsira project was also described by the Magazine Solar Today in the May/June 2004 issue, described by the website Off-grid in August 2004, and by Green Futures.org in November 2004.

In December 2004, the international interest culminated. Hydro's wind- and hydrogen project on Utsira was honoured in New York when it won the Platts[336] Global Energy Award where Utsira was nominated in the category "Renewables Project of the Year". The Utsira project competed with nine competitors from five different countries, and the projects were assessed against a number of criteria, with a view to finding the real leaders in the area of renewable energy. On this basis, judges voted for the most visionary and the best executed renewables project over the year, and the Utsira project shared the prestigious price with another project from Bangladesh.

The international recognition in turn trickled into Hydro's communication efforts. On Hydro's homepage a news article from December 13th announced Hydro to be "The best this year in renewable energy". The Utsira project idea was summarised and presented as the world's first independent energy system using renewable energy and hydrogen using the principle that renewable power can be chemically stored in hydrogen and used at a later stage to deliver power to households. The head of Hydro's hydrogen group, Hexeberg commented that a lot of work has gone into the project and that it was encouraging to see that others also consider Hydro's work to be of value. "The fact that the project on Utsira was realized with its official opening on July 1st and is running according to plan is success criteria enough for us, but going right to the top in a tough

[334] 'Lighting the way for the hydrogen society' 19.7.2004, http://www.enviweb.cz/?secpart=obecne_archiv_ejcfj__, http://www.hydro.com/en/Press-room/News/Archive/2004/July/16614/

[335] http://www.hydro.com/en/Press-room/News/Archive/2004/April/17297/*Key information on the Utsira project*

[336] Platts is the world largest provider of information related to the energy industry publishing magazines, newsletter, Internet services and databases for energy industry. The Platts "Global Energy Award" involves an annual selection of the energy industry's most renowned companies, projects or individuals in different categories.

competition with impressive projects is a wonderful conclusion to an exciting year for everyone involved in the realization of the project".[337]

The project was also included on several pages in Hydro's Annual Report from 2004. One spot was part of the highlights from 2004 mentioning: "The opening of the world's first pilot facility for producing hydrogen from wind power on the Norwegian island of Utsira, and won Platt's 'Renewables Project of the Year' award". The project was mentioned as part of the section called 'Warming up to the 100 year anniversary' (anniversary was in 2005) where the Utsira project was mentioned in the section: "Meeting our greatest contemporary challenges, we've thought about the future – for 100 years. One of our most future-oriented projects is on the island of Utsira, where part of the small community became energy self-sufficient in 2004. The winds of western Norway do most of the work – along with Hydro's wind turbines and a hydrogen production station that provides power during calm periods". The project was also described under the title: "Future energy on exhibit…There's a window on the energy of tomorrow on the western Norwegian island of Utsira – the world's first hydrogen community. Wind is an unreliable ally, yet stable energy is one of the premises for a viable society. So what happens to power production when the wind is still? We solved this problem on Utsira, albeit on a small scale. Two wind turbines ensure stable power to 10 households, even when the wind doesn't blow. The solution: hydrogen. Surplus power from the wind turbines produces hydrogen, which is stored and used as fuel for a generator. We deliver a steady supply of power, even when the wind is still. 'Ingenious', say Utsira's inhabitants, almost impossible to believe, say others. Thanks to new technology and foresight, it's a reality." The text was accompanied by a picture of Norway's oil and energy minister, Thorhild Widvey, and Utsira's mayor, Geir Helge Rasmussen, from the inauguration day. Finally, the project was mentioned as part of the section on renewable energy sources: "Hydrogen plays a particularly important function in the utilization of renewable energy sources because it can be used to even out the production variables of wind power, solar energy and wave energy. Surplus production is stored as hydrogen and fulfils energy demand during periods of low production. Hydro has shown this is possible through its pilot project on Utsira. The project received the 2004 Renewables Project of the Year prize, awarded by Platts, the world's leading information provider to the energy industry" (Hydro Annual Report 2004).

Invitations were sent out to the press only prior to the inauguration. Since then, enquiries and interest from international press have come on an

---

[337] http://www.hydro.com/en/Press-room/News/Archive/2004/December/16699/ 'The best this year in renewable energy'

unprompted basis. There have been visits from the Danish newspapers Weekendavisen and Politikken and numerous magazines. TV stations with Danish TV2, German ARD (DasErste/'The first' German programme), Deutche Welle, an Italian TV station, BBC Radio has been there twice, and Chorean StateTV and Chinese TV making a science programme. A small anecdote told by Researcher Nakken at the ISLENET conference in 2006 was that Hydro in March 2006 received a DVD in the mail with the Chinese TV programme. The producer informed that this was only a small programme, and regretted to say that there were only 50 million Chinese viewers that saw the programme. 'Only' 50 million viewers is a relative thing considering that Norway has a population of about 4,7 million people.

6.6.1.4 Promoting the site - visits to the island

Another communicative aspect involved the number of visits to the island which has been around a 1000 people annually. To illustrate the diversity of the visits / audience some examples are included next.

One illustration of the attention given the project, is that the IEA (International Energy Agency)'s Hydrogen Implementing Agreement (HIA[338]) arranged its biannual meeting on Utsira (May 2005). 30 representatives from 19 countries came to Utsira to participate in the meeting that was co-arranged by Hydro, and the meeting was held on Utsira in order for the participants to see the wind power and hydrogen plant. In a summary from the meeting, it was expressed that a new activity considered for HIA work was to pursue possible cooperation linked to the wind/hydrogen combination, which illustrated how the Utsira project was used as an arena to launch interest and continued work on this type of technology solution[339]. On Hydro's homepage it was also indicated that researchers from Australia, attending the IEA meeting on Utsira, had found the plant interesting and were evaluating a similar unit for installation at a station on Antarctica. It was indicated that there is a lot of wind at the South Pole, but presently expensive diesel to power generators were used and that they would rather

[338] HIA has been active since 1977, and the linkage to the IEA (as discussed in chapter 9) had been established as early as 1998/1999 when the IEA fronted an initiative to get into dialogue with existing industrial users and producers of hydrogen (non-energy processes) to discuss research efforts that could facilitate the increased utilization of hydrogen and with the preparation and development of a future task for which Elisabeth Fjermestad Hagen was the Operating Agent (Hydrogen from Carbon- Containing Materials HIA Annex 16 2002-2005). http://www.ieahia.org/pdfs/1999_annual_report.pdf

[339]http://www.iea.no/oslo/iea-norge.nsf/Attachments/DBEB18390EE29D3CC12570C100762045/$FILE/Referat+fra+Utsira22052005.doc

use the Utsira principle of wind and hydrogen powering fuel cells during still periods.

After having generated international interest within the energy industry, research and investment communities, government agencies and media; then Hydro, Enercon and the Utsira municipality also arranged an Open House event on the island inviting locals and the public to come and visit the wind-hydrogen plant. The family event hosted more than 300 visitors, and the visitors were explained how the plant was working:

«Visitors were first curious about how it all works. Thorough explanations were provided. The guests also learned about wind power at nearby sites in Karmøy and Høgjæren, gas power at Kårstø and natural gas-powered automobiles. The event was intended as a family event where the organizers invited families to hike along Utsira's new Troll trail, which started at Utsira's main dock and proceeded to the wind/hydrogen energy site on the other side of the island. Down at the hydrogen plant, the Utsira music corps played as visitors ate waffles and drank coffee and soda pop, all sponsored by the organizers. The weather couldn't have been better for an open house throughout the entire weekend. Sunshine and very little wind. The energy plant ended up being the main meeting point for half of Utsira's 250 residents and the 300 visitors»[340]

A final illustration of visits, that also drew additional media attention to the island and the technology system, was when the lead singer (Morten Harket) of the internationally famous Norwegian band a-ha visited Utsira (May 2006). The visit focused on renewable energy, and news papers printed stories on the visit also indicating that this was not the first time that a celebrity visited the island. The world came to Utsira also when the Russian billionaire and Chelsea owner Roman Abramovitsj visited the island in 2004[341]. Harket's visit came about as a-ha had been involved in the celebration of Hydro's Centennial Festival in 2005 by being one of the main attractions in concerts (August/Oslo, October/Cologne 2005). In return of the collaboration, Harket was allowed to choose a Hydro site that he wanted to visit. The choice landed on Utsira to see the wind-hydrogen facility and to take a closer look at Hydro's efforts in renewable energy:

«I am keen to take a closer look at Hydro's work in the renewable energy field and Utsira is a fascinating project. Different areas call for different solutions," said a-ha lead singer Morten Harket when he visited Hydro's hydrogen and wind power facility on Friday…. I am aware of the

---

[340] http://www.hydro.com/en/Press-room/News/Archive/2005/April/16754/ *Open House at Utsira* 22-24 April 2005, 26.April 2 05

[341]http://www.haugesunds-avis.no/apps/pbcs.dll/article?AID=/20060516/NYHET/60516003, Morten Harket til Utsira 16.5.2006

considerable resistance to windmills here Norway," says Harket, who fronts the celebrated Norwegian pop group a-ha. "A lot of people are concerned about the noise and visual impact windmills will have on the environment, and also their possible harmful affect. My own impression, however, is that the windmills run surprisingly quietly and are a lot less intrusive than I would have imagined. There will be different opinions about this, but some people's objections pale into insignificance when you see them in the context of the environmental challenges the world is facing," says Harket.….“It’s good to see that Morten Harket has such interest and knowledge of renewable energy,” says Hydro’s Sjur Bratland. “We are delighted to have had the opportunity to show him our demonstration project on Utsira – it’s something we are very proud of,” says Bratland»[342]

And from one newspaper article following the visit, Harket drew attention to the relevance of the Utsira plant:

«The hydrogen project at Utsira is very interesting. There is a challenge in storing unstable wind power; there is more than enough power in the world, the problem is storage and transportation….The poor parts of the world has to use more energy to get out of poverty. A plant such as the Utsira plant is not the one and only solution but an example of what is possible» [343]

In a Hydro context, the Utsira project became a landmark for Hydro’s New Energy activity and as such provided an arena to advance Hydro’s hydrogen and renewable energy activities. With the many visits that involved presentation of the wind-hydrogen plant, this required organisational manpower to have Hydro people present making presentations on the island. The Hydrogen Group, Vera Ingunn Moe, responsible for profiling hydrogen and new energy, did a great deal of representational work on the island, further, due to his extensive knowledge about the project, Bratland has also been a central marketer of the project and has been sent out to present the project to prominent guests. With the great number of visits, Hydro staff from Hydro’s power plant in the western part of Norway, Røldal-Suldal, Nesflaten, also got involved in representational work. This part of the Hydro organisation was also given the maintenance responsibility, and geographically access was more convenient with a two hour drive to Haugesund from where the ferry goes out to Utsira. However, if a politician or cabinet minister was visiting the island to see the plant, it required the

[342]http://www.hydro.com/en/Press-room/News/Archive/2006/May/16980/*Morten Harket visits Utsira hydrogen facility*
[343]http://www.haugesunds-avis.no/apps/pbcs.dll/article?AID=/20060519/NYHET/60519002 Harket i vinden 19.5.2006

New Energy Unit to be present to be able to communicate other pertinent issues of relevance to the New Energy Unit.

Due to the many visits to the island, there was also a need to standardise the communication in the presentation of the Utsira project so that the same message was communicated regardless of the presenter. A presentation package and an accompanying story to be told were developed in 2005. To supplement the presentation of the Utsira project, a movie named: “The Lesson” was also made about renewables. The movie last about 4 minutes and was used at fairs and to conclude presentations at different events. The movie portrays a young boy observing the uses of energy in his daily life. In class, he listens to the teacher’s speaking about energy and his mind wanders off thinking about where the energy comes from and if it will last. The movie takes the boy to different Hydro energy sites starting 100 years back where hydro electric power gave Hydro its name and also showing the Tyin water fall. Then it moves into recent history and Hydro’s engagement in renewable energy sources and throughout his journey, the pupil witnesses how energy is made. Relating to Hydro’s hydrogen activity, the boy’s journey goes to Iceland visiting the fuelling station and riding a hydrogen bus, and ends up at Utsira where Hydro is out there pioneering ideas and road testing a vision. “Windmills powering the community, excess energy stored as hydrogen, so when the wind drops, supply doesn’t….Who is thinking about the future – we are ….It is a new way of looking at energy - the Hydro way”. The movie was produced by the Edge Picture Company and won the silver Award from the International Visual Communication Association in 2005 in the Public Relations category.

6.6.2 Communication from top management

Former Hydro CEO and then Chairman of the Board, Norsk Hydro ASA, Egil Myklebust was already mentioned as a central character in triggering a decision on the realization of the project by making a speech at the World Petroleum Congress in Rio de Janeiro (WPC) in September 2002. At another event, the jubilee conference for the Programme for Industrial Ecology at the Norwegian Technical University, Trondheim (31/3/2004), Myklebust also made explicit mention of hydrogen development, the role of demonstrations and the Utsira project in his speech:

«Let us see how an energy system based on renewable energy sources are built using Hydro’s project on Utsira. On Utsira there are 250 people. Electricity supply comes via a sea cable from the mainland. There are good wind resources on the island and the island may become self-sufficient with both electricity and fuels. However, renewable energy from windmills is unstable, the wind turbines cannot operate when there is too much and too

little wind, and demand varies during a day. Such variations may be handled by using hydrogen. In periods with excess electricity, hydrogen is produced using an electrolyser and water. Hydrogen is stored and used when needed in electricity production with a fuel cell when wind resources are not favourable. Hydrogen can be used as a fuel in cars and other vessel. Our Utsira project was officially opened spring 2004, taking a concept from the drawing board to practical reality. The technology used on Utsira will also be particularly valuable in areas without sufficient electricity supply and the project provides one illustration of how a renewable hydrogen society may work. The pilot project hence provides valuable lessons and learning. The island will still have its original electricity supply so that experimentation with the new system is possible.»

When speaking at the 18th World Petroleum Congress in Johannesburg in 2005, CEO Eivind Reiten spoke about what corporate governance and responsibility may be about, and as one illustration; he mentioned the Utsira project as highlighted below[344]:

«But to the company I am privileged to lead, Corporate Responsibility is integrated as a key element in standard processes such as business planning, performance review, leadership evaluations and appraisals and investment decision gates, to mention a few. As defined in a document that outlines our approach to business, The Hydro Way, the demands of business and society are interdependent. Business cannot succeed in societies that fail. Corporate governance or responsibility may be about: ….. Investing in research in renewable energy sources, or establishing test pilots, as we have done in a small Norwegian island community – Utsira - now energy self sufficient based on wind power and energy stored as hydrogen to ensure energy also on days with no wind…. Hydro has been a viable company for 100 years. I strongly believe one of the main reasons is that we have been able to combine profitable business with responsible business. As we all know, credibility takes years to build and hours to destroy»

Similarly, Reiten spoke at the OECD Forum 2005 Fuelling the Future: Security, Stability, and Development[345]. In his speech: Unlocking the World's Energy Potential, Reiten focused on the potential for a secure

---

[344] At the 18th WPC in Johannesburg 2005, Fjermestad Hagen and Hexeberg were also part of the Technical Programme under the track: Critical Energy Issues and Challenges in the Emerging Scenario of a New World Energy Order - A Radical Transition from Carbon Energy to a Sustainable Renewable Energy Portfolio, with a presentation of their paper: Renewable Hydrogen Energy Systems.

[345] http://www.oecd.org/site/0,3407,en_21571361_34225293_1_1_1_1_1,00.html

supply of energy and spoke about the keys that will help unlock the world's energy potential. One key mentioned was environmental development in which Utsira is explicitly mentioned again.

«*If we are to have viable long-term global development, it is vital that we invest the necessary resources in renewable energy. Let's not be blinded by high oil prices, but let high oil prices encourage us to invest even more in clean energy. We strive to combat emissions from our current operations and make fossil fuels greener. Keywords are: carbon capturing and storage; as well as renewable energy initiatives. Hydro has proven that it is possible to make reliable and sustainable energy solutions without harming the environment. In the first project of its kind, we supply a community off western Norway (Utsira) with electricity from a combination of hydrogen fuel and wind power. It's the world's first hydrogen-driven society. I believe it is an example of a society of the future. While I share the faith in renewable energy solutions, we have to remain realistic. Hydrocarbons will remain the dominant fuel in the foreseeable future*»

Anchoring support with the highest level of management was important to signal the relevance of the project both inside the organisation and to external stakeholders. A main role of top management and the CEO is to set a general direction for an organisation and focus on particular endeavours. Top management attention signalled an assessment of the importance of issues and priorities that in turn shaped action and heightened the internal focus on hydrogen demonstration projects. The external communication of involvement in hydrogen energy also heightened with media profile and attention when the CEO fronted the projects. What the CEO included in speeches built legitimacy and made the hydrogen focus area, the use of hydrogen in renewable energy systems, 'official'. Coming from the "horse's mouth", it signalled what the organisation is, does, and communicates about itself to the world, and signalled relevance and commitment to the project.

6.6.3 Contemplating profiling efforts

Continuing Utsira development involved demonstration in terms of the concept as well communicating information. As a part of a 'looking back' presentation and project evaluation held in March 2005, one lesson learned was that the Utsira project had become a profiling success and that a vision had been built. One project participant pointed to the role of communication and profiling efforts:

«*An additional learning aspect in the project is the aspect of profiling, why Utsira became a success when it was not an easy sell inside Hydro and a lot* *of people did not see the point in the project. One thing was that Hydro should not do the project; they did not see the point at all. But I think we have gained so much positive profiling and generated so much positive feed-back, because we have built a vision of how the future society may be with renewable energy and self sufficient energy supply. I don't know but I think this can be an explanation…. In presentations we have been visionary and highlighted all the positive aspects. An organisation like Greenpeace thought this was exiting because being able to store excess electricity from renewable energy opens up a lot of opportunities. So we didn't exactly put a lid on visionary explanations when we made presentations. We have had a very good team, Hydro is a very professional organisation in this respect and the Utsira opening was also very successful*»

Communication about the project involved: the practicalities in realizing the project, the operational experience, technology interfaces and interactions that had to be accommodated, evaluation of operational, economic, and market issues, and disseminating results to share good practice so as to enable stakeholders, authorities and communities to consider this type of technology solution as feasible and beneficial to their communities.

Moe (responsible for hydrogen and new energy profiling) indicated that efforts to profile the Utsira project was initiated before, during and after the realization by actively communicating on the Internet, the Hydro Intranet and communicating the history and the content of the project in diverse media to reach wide and diverse audiences. With projects that stand as an expenditure to Hydro and until a business area starts to generate income, one visible result to fare with was the profiling and public relations aspect. Persistently communicating in multiple media and at different events made a great deal of fuss about the project as well as about Hydro's involvement in hydrogen. Hence when activity did not create a return in the traditional sense, something else was fronted as a result that helped build relevance for the Utsira project and for hydrogen activity:

«*My motto was that we have to get the profiling right by being active on the Internet, the Intranet, brochures, seminars, conferences and fairs. Profiling and visibility is something tangible. Positive profiling is a visible result for Hydro until the activity starts to generate income*»

The international attention and interest in the project was not expected; but when the 'ketchup bottle principle' was used, you shake the bottle to get out some ketchup and suddenly out came a lot. Another central aspect in the profiling strategy was the element of story telling that was pursued. Profiling efforts were inspired by the thinking in the book "Dream Society" in which it is advocated that products, technologies and services have to appeal to the heart in addition to the mind to capture the greatest market share, and that there is a shift from need-driven information to story-driven imagination. Communication was pursued in a wide set of media to reach a wide audience and included the story element by incorporating the origin, realization, and life of the project instead of 'just' communicating the technical facts of the energy plant.

One of the business developers indicated that Hydro's Communications Division was very pleased with the Utsira project and that there was talk about the Utsira project being worth-while and that the investment had paid off just considering the public relations aspect. The value of profiling for Hydro has been stated in the Utsira project to be a multiple of the project cost. Trying to assign a monetary value to the public relations aspect of the activity, was important to the Hydrogen group working with hydrogen business development. This involved trying to assess the costs that all the publicity would have carried if the organisation would have had to pay for it. To try to ascertain the public relations value of the activity was important to document relevance and the value of the project and the hydrogen focus area, especially since hydrogen energy was/is so uncertain in terms of its time horizon and when it may be expected to turn into an income generating activity.

6.6.3.1 From project to concept

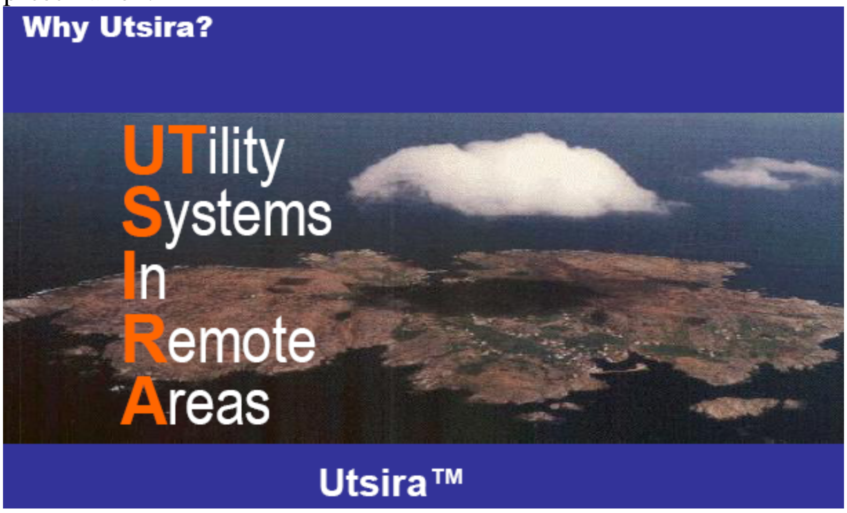
In discussing the value of the demonstration, one business developer also commented that:

«Demonstrating the first hydrogen society in the world, full circle, to produce hydrogen when there is excess wind energy available; provide electricity via a fuel cell when the wind slows or stops. Attractive vision: Utsira has enough wind power to be self-sufficient … It has been a good demonstration for the electrolysers. It has also been a good demonstration of Hydro's ability and willingness to undertake this type of project, and there has been an insane public relations effect, in a way Utsira has become an icon»

The Utsira demonstration project became part of the creation and manifestation of a vision. A vision of a possible future technological situation and hydrogen technology combination comprising production, storage, distribution and end-use, and in a wider sense this was also a picture of an alternative future world. Another indication of successful demonstration was when the demonstration project through its vision and visibility became a common reference point for local communities, scientists, companies and government agencies on a particular technology combination, and hence became a place-specific site for the exchange of information pertaining to this kind of combination. An indication of this is mentioned by a business developer:

«Well I am glad that one of the partners declined early on… that is previously Utsira was mainly on the map in Norway in terms of the weather and among some groups, but now in the EU Commission, for example DG Research, there they immediately know and talk about "yes an Utsira type project"… it has become a concept and the concept is linked to Hydro»

With references such as "an Utsira type project" in international arenas such as the EU, the Utsira project moved from being an 'island' to also being a concept' for this type of production system, which was reflected in the labelling of the project as: UTSIRA **- UT**ility **S**ystems **I**n **R**emote **A**reas. This was also emphasised when the manager of the hydrogen unit, Ivar Hexeberg spoke about the Utsira project[346] among other European hydrogen projects, at the Annual Event[347] of the European Hydrogen and Fuel Cell technology platform (March 2005). Hexeberg summed up project experience, focus of the demonstration, and the project status from island to concept was reflected in the illustration below, which was part of the presentation.



Utsira in this way seems to show that half the job in the hydrogen venture was to build the actual plant or technology combination, and half the job was to build a vision for the future. A comment from one business developer on

[346] https://www.hfpeurope.org/uploads/699/808/UTSIRA.pdf
[347] https://www.hfpeurope.org/hfp/hfp-annual-event_17mar2005

why the Utsira project received so much attention, pointed to the future promise and visionary element in the project:

«I think some of the success and why we have received so much positive feedback is that we have built a vision of how this future society can be with hydrogen, renewable energy and security of supply. Self-sufficiency»

6.7 Demonstration and legitimacy - connecting agendas

> The Big Power of Little Ideas
> The future cannot be known. The only thing certain about it is that it will be different from, rather than a continuation of, today. But the future is as yet unborn, unformed, and undetermined. It can be shaped by purposeful action. And the one thing that can effectively motivate such action is an idea – an idea of a different economy, a different technology, or a different market exploited by a different business. But ideas always start small….
>
> Peter F. Drucker (1983)

An organisation trying to advance hydrogen as an energy carrier must carve out a space for itself and its technological offering among other technological promises. Legitimacy[348] building seems to be an elusive aspect and outcome of both the performance of the technology combination and information and communicative efforts about the demonstration. Informational and representational activities were central to the 'marketing' of the Utsira technology combination. Communicating about the Utsira project generated awareness among business, authorities and the public at large, and allowed the public and key stakeholders to learn about the technological combination and its potential relevance in relation to particular functions, issues or concerns.

As seen in the section on particularities in market development and contemplating uses, there was a cross over of the Utsira technology combination to other contexts than island energy supply. Hence the Utsira project has a potential to become part of different contexts of use and relevant to different organisation working in other domains than energy. One market building area was to scale down the renewable hydrogen system to a power generation application for remote systems like weather stations, telecom base stations, and cellular communication networks with unstable power supplies and / or in need of backup. The Utsira technology combination was worked on as a back-up and emergency power solution and to replace batteries in locations without grid connection, and hence also gaining relevance to actors beyond the energy sector. Another market building area was hydrogen-to-ammonia, renewable ammonia to be used in

[348] Legitimacy is defined as a generalised perception that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions. *Sociopolitical legitimacy* refers to the acceptance by key stakeholders, the general public, key opinion leaders, and government officials of a new venture as appropriate and right. It has two components: moral acceptance, referring to conformity with cultural norms and values, and regulatory acceptance, referring to conformity with governmental rules and regulations (Aldrich 1999:230)

fertilizer production, where the technology combination gained relevance by being connected to composite concerns and agendas as seen in the drivers[349] behind the US interest in the concept, which incorporated the stimulation of renewable energy / wind development, security of supply and the trouble with high ammonia prices in the US agricultural regions[350]. Legitimacy building was one aspect in these application – and market creation efforts, as the organisation was trying to carve out a space for its technological offering among other technological promises also by linking the technology combination with different concerns and agendas. The Utsira system combination being rooted in the energy sector holds potential and may be connected and presented as a solution to the problems of other sectors / domains.

Over time, trends, environmental objectives, and political priorities change, and shifts in societal priorities and values affect perceptions of the “proper-ness” of technologies, the worth of a technology combination as well as expectations about appropriate energy company / corporate behaviour. To emphasize this point, the Utsira technology combination may be said not to contain any value in and by itself; rather it is the context in which it becomes a part, and the value that we ascribe and attribute it, that comes to express its value. Hence an energy carrier and a technology combination have potential but there are no predetermined travel points. The relevance of an energy carrier and the Utsira technology combination was tied to a process of valuing and connected to issues and concerns considered important in society e.g. the threat of future impacts of CO2 and other greenhouse gas emissions, and security of supply.

One comment by a business developer highlighted that the relevance of a technology solution and energy carrier was connected with agendas and socio-political priorities that in turn were dynamic and change over time.

---

[349] Wind to Ammonia Drivers: 1. Declining domestic ammonia production 2. Stranded wind resource due to low transmission capacity 3. Volatile natural gas market (drives ammonia up production costs). 4. High regional demand and robust infrastructure for anhydrous ammonia 5. Need for increased food, energy, and economic security 6. Successful policy and business models for community owned energy (biofuels and wind energy) 7. Provides a clear path towards a hydrogen economy http://www1.umn.edu/iree/e3/e32007recap/presentations/reese_e3_2007.pdf

[350] Natural gas is the current hydrogen source for anhydrous ammonia through a process called Steam Methane Reforming. Natural gas cost and use are projected to rise throughout the next 20 years as domestic production will concurrently decrease (DOE, 2003). Fifty percent of nitrogen fertilizer is imported and 28 percent of domestic fertilizer plants have shut down due to high domestic natural gas prices. Utilizing natural gas in the production of anhydrous ammonia also contributes to green house gas emissions. In contrast, wind energy is perhaps the cleanest source of energy, continues to decline in production cost per kilowatt hour, and is becoming competitive with even the cheapest sources of fossil fuels.

«In the context of Brussel's energy strategy, a year ago (2006 insert by author) the main focus was on energy supply security. Now (February 2007 inserted by author) all focus in on CO2 emissions reduction and climate change. Hydrogen probably had a stronger hand when the focus was on security of supply because it creates so many opportunities as hydrogen can be produced from so many sources. When focus is on CO2 it becomes easier to focus on other renewables and carbon capture and storage, and hydrogen easily falls outside the process and is not necessarily in the centre of attention»

That attention to hydrogen energy fluctuates, in turn means that the organisation working on a strategic demonstration project and development path must continually try to convince others and build momentum behind the technology offering that suits the development projects and resources available to the organisation. Legitimacy building becomes important in terms of building relevance for particular courses of action and to shape attention. The Utsira project became a site for legitimacy building efforts by connecting the technology combination with societal agendas and concerns in need of handling. To illustrate this point, I will mention efforts made in relation to three agendas: RES synergies, regional concerns and climate change.

6.7.1 RES synergies

Participating in the EU arena was one avenue to further consideration for the Utsira system by linking hydrogen energy with EU's renewable energy activities. Work within the European Hydrogen and Fuel Cell technology platform (HFP) sought to advance the complementary aspects between hydrogen and renewable energy. This was summarised in the Implementation Status Plan from 2006:

> Hydrogen and Fuel Cell technologies can play a significant role in Europe's new energ system. They can allow renewable energy to be applied to transport, facilitate distribute power generation, and help us cope with the intermittent character of renewables such a wind power. But if they are to make a significant market penetration in transport and powe generation, there will need to be research, development and deployment strategies in whic all the stakeholders are committed to common objectives. This was the ambition of th European Union when it created the Hydrogen and Fuel Cell Technology Platform.

More specifically, as part of HPF work and responsibilities, Elisabet Fjermestad Hagen (in charge of the HFP Business Development Initiative

Group as part of a Joint Group on Financing and Business Development[351]), was responsible for discussing early markets and functional synergies between hydrogen and renewable power[352]. As part of key outcomes of the Business Development subgroup, the stimulation of early markets was communicated as important to ensure that technological changes and customer adaptations may occur by working with early markets, pilot tests and R&D to improve products and lower costs. Among the early stationary markets and relevant to the Utsira project, standalone installed renewable energy supply units for isolated locations (islands, remote areas) were mentioned. Early markets were communicated as important to stimulate hydrogen and fuel cell activity so as to create a positive impact on investor perception, maintain credibility with stakeholder groups, and to create economic return for hydrogen and fuel cell companies in the short term, which in turn also would be a way to attract more investment and speed-up technological development. Another main concern was also to attract hydrogen and fuel cell component manufacturing plants to gain ground on US and Japanese initiatives, and to create employment.

EU policies on energy are anchored on three key goals – green house gas emission reduction, security of supply and job creation. The issue of supply reliability combined with the global and local environmental problems arising from the combustion of fossil fuels point to the importance of renewable energy, and in the EU there are ambitious targets for growth in the use of renewable energy sources (RES)[353]. Tapping into the renewable energy agenda was one way to further the legitimacy and relevance of hydrogen as an energy carrier in general and also of the Utsira system combination in particular. In a summary of the work by EU's HFP Business Development Subgroup (EU Hydrogen and Fuel Cell Technology Platform Business (2006), the interrelation between hydrogen/ fuel cell systems and

---

[351]With the purpose of providing recommendations to the Advisory Council and the EU http://circa.europa.eu/Public/irc/rtd/eurhydrofuelcellplat/library?l=/publicsarea/initiative_development/jg_fbd_-_torpdf/_EN_1.0_&a=d

[352]Communicated as part of the results from the business development subgroup in March 2006 and in a separate discussion paper in April 2006 (Renewables and hydrogen- functional synergies)

[353]In the White Paper: Energy for the future - renewable sources of energy an overall RES target was set to increase the renewable share of energy consumption to 12% by year 2010 (White Paper for a Community Strategy and Action Plan, COM(97)599 final (26/11/97) The Directive on the promotion of *electricity* produced from *renewable energy sources* in the internal market (RES-E Directive 2001/77/EC, 27-9-01) agreed on an indicative target to increase the share of electricity from renewable energy source (RES) to 21 % in 2010. Further, a new EU RES directive from 2009 agrees on binding targets to reach a 20% goal by 2020 (20% of total energy consumption to come from renewable energy sources by 2020 with new plants and increase in RES share from year 2005 (base year). and 10 % in transportation.

renewable energy sources was pointed to. Creating new hydrogen products, systems and applications were argued to create beneficial synergies benefiting the growth of renewable energy sources while also contributing to create an EU hydrogen / fuel cell industry. In the summary document of the key outcomes of the sub-group's work, the principal argument was presented:

«*The principal matter for introducing hydrogen in parallel with continuing to stimulate renewables is not only to ensure long term green hydrogen production, but also to improve efficiency and transportability of renewable energy sources, by utilising hydrogen as an efficient mean to store and transport energy and reduce the dependence of weather conditions and demand stability. This enables further flexibility to match the energy supply and demand, which is critical nowadays. In fact for many intermittent renewables, hydrogen could be the most intelligent energy supply / demand management tool…. With an integrated strategy at the European level, hydrogen and fuel cells can become efficient means to expand the scope of renewable energy sources and applications from stationary only – to transport and portable uses… In a hydrogen-based energy system, we could drive cars on wind energy or light our homes with solar power- even when the sun is not shining. Electric utilities could sell hydrogen vehicle fuel; fuel cell car owners would power their home and workplace by plugging their car when unused …. RES industries should engage in these new scenarios by given whole-hearted support to the hydrogen effort. Already in the emerging hydrogen markets there are clear win-win cases*» (Fjermestad Hagen and Hanssen 2006)

In a discussion paper fronted by the Business Development sub-group (EU HFP 2006), it was further elaborated that:

«*By functional synergies, we mean the combined capacity of renewable sources and hydrogen/fuel cell systems to create new applications, facilitate their integration in the energy system, and improve demand/supply management. By intelligent exploitation of the key benefits of each set of technologies, both paths can be leveraged….. Hydrogen in particular, because of its energy systems benefits and storability characteristics, offers to RES potential access to a wider set of markets than can be achieved by only promoting RES for grid electricity, or heat of local demand. Conversely, hydrogen ultimately needs to be produced using renewables, or otherwise CO2 neutral sources, to realise greenhouse gas emission reductions. Exploring synergies between renewables and hydrogen thus is well justified…. Hydrogen's flexibility stems from the fact that it can be produced from a number of energy sources by a variety of processing routes, stored and used in all demand sectors, covering not only stationary but also* *transport uses of energy. Hydrogen production can be adapted to local resource availability, and the storability of the energy carrier opens for satisfying any sector of demand…»*

The discussion paper highlighted the fundamental disadvantage of renewable energy sources as their intermittent nature. In small-scale applications, frequently off-grid or with only a small local grid present, intermittency of the source handicaps the development of RES based standalone power systems.

Hydrogen and renewable energy systems were mentioned as a new option for storing intermittently generated electricity and the basis for developing a future decentralised energy supply system. Further, compared with other energy storage system, hydrogen offers an additional value since the storage medium itself may be used as fuel for clean vehicles, stationary fuel cells and other energy application (EU HFP 2006)[354]. The Utsira plant combination was mentioned as a representative system providing operational data and experience for further development and commercialisation of standalone systems based on hydrogen storage (ibid), and the Utsira system was used as an example of a future system application where the system could be expanded to include hydrogen for transport and other energy uses providing a self-sustained reliable renewable energy system. A worldwide and potentially huge market for such systems was pointed to where hydrogen standalone systems could be an alternative to battery-based or diesel solutions; and with 25% of the global population being without access to electricity, autonomous renewable and hydrogen based systems were envisioned to address this potential while also replacing costly and polluting fossil fuels.

«In the end, it is price (cost of production + margin – subsidies – value of CO2 emission rights) that acts as a real driver to choose between energy sources. If 'green hydrogen' can be made competitive then the link between renewable energy sources and hydrogen will be strong at the production level»

Functional synergies were emphasised with hydrogen as a key component in the mode of decentralised energy production and as an enabling tool for more efficient energy management. Large-scale demonstration project were

[354] Starting with renewable power and using electrolysers, hydrogen storage and fuel cells a number of system applications were mentioned: renewable and hydrogen stand-alone power systems, grid balancing and as an alternative to installing new cables for transmission, and mobilisation of 'stranded' RES for the production of hydrogen in areas where hydrogen can be more easily be distributed than electricity i.e. use the hydrogen to move large occurrence of renewable power transported to the point of use.

also pointed to, to prove the technology, improve public awareness and acceptance, improve cost competitiveness, and to reduce market barriers (ibid). The potential applications and the relevance of the Utsira type system to the renewable energy agenda was communicated in the discussion paper and presented on several occasions to the Advisory Council and the General Assembly of the European Hydrogen and Fuel Cell technology platform (HFP), as well as to the European Commission in 2005, and it was transferred as input to the Implementation Panel of the HFP (EU HFP 2006a). In a hearing with the HFP platform and the European Commission on the current state of the hydrogen and fuel cell sector (EU Commission 2007b), hydrogen was mentioned as an enabler for the integration of renewable energy sources and as a contributor to the 20% RES (renewable energy sources) target set for 2020. The hearing report also mentioned that 30-40 % of the hydrogen production was expected to come from renewable energy by 2050.

Finally, Elisabet Fjermestad Hagen and Hydro researcher Torgeir Nakken were part of an EU Commission workshop (European Commission (2007a) on the contribution of hydrogen to reach European renewable energy targets held with five representatives from the EU Commission and 11 hydrogen and RES stakeholder representatives. In the report from the workshop, one section was devoted to the use of hydrogen in renewable energy system where hydrogen was given a prospective role in: balancing power grids, in back-up power generation as an alternative fuel to diesel, and as a storage media to cope with stochastic power generation (e.g. wind electricity production) of particular interest to ensure the high penetrations of renewable electricity. Illustrating an early market for the concept, autonomous RES-based energy systems were envisaged for remote areas, which besides addressing the specific requirement of these communities were described as living test beds for demonstrating and acquiring feedback on the coupling of hydrogen and renewable energy that provide knowledge of prime importance to the further penetration of these technologies at a larger scale. The Utsira demonstration project was used as the illustrative example and a recent study was referred to with an estimation of 500 000 potential customers (i.e. 500 000 systems) for remote RES-hydrogen electricity systems for remote areas across the EU[355]. Further, the technology combination was mentioned as a contender for export markets.

6.7.2 Linking up with regional concerns

Another example of legitimacy building efforts, by connecting the technology combination with agendas and concerns, was the linkage to

[355] http://www.hsaps.ife.no/Reports/HSAPS%20Publishable%20summary.pdf

island and regional concerns. Peripheral areas like islands have limited and /or no access to networks and are dependent on imported energy.

A significant number of the islands that belong to the European Union are remote and are not interconnected with the continental European energy networks. This fact, in interaction with the demand for energy autonomy, leads to their dependence on imported fuel oil, with the consequences of high power costs, transportation, and significant greenhouse gas emissions. As related to these agendas, Norsk Hydro participated in the RenewIslands project undertaken between January 2003 and December 2004, and financed by the European Commission, Directorate General for Energy and Transport[356]. Norsk Hydro was the coordinator of one of the work packages (WP3) focusing on feasibility studies on an integrated RES/Hydrogen/Fuel cell system facility and among other focus areas examining the introduction of a hydrogen energy system with an electrolyzer, compressed hydrogen storage, and fuel cell on an island. Various system configurations were simulated with corresponding costs and the simulations were carried out using software (HYDROGEMS[357]) developed by IFE in Norway (Institute for Energy Technology) on behalf of Norsk Hydro.

A higher penetration of typical renewable energy applications (solar and wind parks) is limited by the intermittent nature of renewables, so a solution to the problem of energy supply security requires energy storage to support renewable energy sources (RES) (Renewislands 2005). A combination of renewable energy and a reliable energy storage system of the Utsira kind[358] was discussed for implementation on arid islands and coastal regions showing renewable energy potential (and possibly also at the same time with sea water availability for subsequent freshwater production), and generally in regions suffering from total energy dependence on external sources with isolated electrical systems. The relevance of wind-hydrogen energy systems was also linked to a development agenda with many developing countries having a large number of settlements not connected to

---

[356] CONTRACT Nº. NNE5/2002/073 for Community activities in the field of the specific programme for RTD and demonstration on “Energy, Environment and Sustainable Development – Part B Energy Programme”.

[357] HYDROGEMS is a result of 7 years of modelling and simulation work on stand-alone power systems undertaken at the Institute for Energy Technology (IFE). The models have been tested and verified against various renewable–H2 energy demonstration plants around the world (Renewisland Newsletter 2005).

[358] The principal characteristic of a renewable energy-hydrogen system is its ability to store electricity produced from intermittent power production units such as wind turbines and solar panels. Electricity is unique among other commodities in that it requires instantaneous use when produced. Current storage techniques include e.g. batteries and pumped hydro, but both are too technology and site specific to see implementation on a wider scale. Batteries will only provide storage on an hourly basis (Energy Development as 1999)

a main electricity grid and with diesel plants giving bad-quality and expensive service often only during few hours a day. Depending on the location, different power sources could be considered (wind, PV, microhydro etc.) (review Energy Development as 1999).

The relevance of the Utsira project and concept for stand-alone systems in remote regions or islands is where energy costs are high due to high transportation costs of fossil fuels. The Utsira technology combination is suitable for localities around the world where the alternative cost of power is high and where there are abundant renewable energy sources.

With presentations at conferences arranged within the ISLENET framework in 2006[359] and 2007[360], a connection was established to the European islands network (some 20 million people are living on non-grid islands (Fjermestad Hagen et al. 2005b), a network supported by EU institutions and associated with the EU Commissions Sustainable Energy Europe campaign[361]. The Utsira project was presented with technical and operational experience and also with reflections on the value proposition of the Utsira type of system to island communities, above and beyond standard cost comparison per kWh with the main competitor being diesel aggregates. Here there was mention of the avoidance of diesel transportation costs, renewable power being sought for environmental reasons, not using fossil fuels, and the value in becoming energy independent and to secure energy supply long term.

The Utsira project and technology combination was used as an illustrative building block in energy supply in remote locations also contributing to tourism, economic activity and hence the viability of remote communities. As part of legitimacy building efforts, activities also sought to explore the real 'locational' value of electricity from renewable energy sources (as opposed to comparison with conventional power prices). Especially in the case of islands the social and environmental added-value of RES electricity is important so that it should be estimated and incorporated in the consideration of energy costs. Island frequently draw tourist, and one of the draw cards of islands used to attract tourists is the perception of a green and clean, picturesque environment (Newsletter 2005). At the opening

[359] ISLENET 2006 Sustainable Energy Systems for European Island Communities, *Utsira Operational Experience*, Torgeir Nakken 28/3/2006 http://www.managenergy.tv/metv/portal/_vi_wm_300_en/index.html?showSlides=true&search=torgeir+nakken

[360] ISLENET 2007 Island networking and focus on technologies, *Hydrogen Technologies*, Elisabeth Fjermestad Hagen 10/10/2007

[361] A European Commission initiative in the framework of the Intelligent Energy – Europe programme http://www.sustenergy.org

of the Utsira wind-hydrogen plant this aspect came across in a press release on Hydro's homepage[362]:

«Mayor of Utsira, Geir Helge Rasmussen, is proud that the little community will now be placed on the new energy map… It's important for us to be a green island. All the pieces of the jigsaw fall into place with this project, which makes us self-sufficient with renewable energy»

The increase in the number of visitors to Utsira was also illustrative of a locational value that may be linked to the establishment of the pioneering technology combination. On islands and remote regions, goals are similar to those found in most places such as sustainable development, security of supply and competiveness, and the interest in refinement, industrial competences or economic spin-off are common motivators behind renewable island initiatives like expanding economic activity from farming, tourism, fishing to also renewable energy. As islands and isolated locations may be used to test equipment and new technology combinations, this may provide additional spin-off effects e.g. through the visibility that may be gained from showcasing the technology and impact effects on the activities of islands.

6.7.3 Climate change and climate challenge

A final example of legitimacy building efforts by connecting the technology combination to societal agendas and concerns was the linkage to concerns about global warming. Envisioning the system as a means and as part of solutions offered to mitigate air pollution and the threat of climate change. As discussed in appendix I (Hydrogen in the Making), hydrogen energy re-entered the energy debate since the late part of the 1980s, where the threat of irreversible climate change, the climate conventions in the 1990s and the emissions reduction negotiations in Kyoto (1997) generated a renewed focus on greenhouse gas emitting activities, which in turn established a new rationale for hydrogen as an energy carrier[363]. Hydrogen re-emerged as a future energy contender and low carbon energy solution.

In presentations made on Hydro's engagement in New Energy, security of supply and environmental impacts were fronted as key drivers of

---

[362] Winds of change blow on Utsira's opening day

[363] 'The hydrogen economy', labelling a new way of delivering and using energy, is referring to a future where hydrogen will take the place of fossil fuels like oil, natural gas and coal in our energy systems. Hydrogen is intended to replace diesel and gasoline in the transportation sector eliminating the production of any harmful exhaust emissions from vehicles associated with the internal combustion engine (emissions of nitrogen oxides, carbon monoxide, CO2), and with new methods hydrogen may be used for the production of electricity and heating. Hydrogen will also allow for a more distributed energy production system as hydrogen in principle can be produced anywhere that you have electricity and water.

new energy development. With the expected rise in energy demand and the fact that fossil fuels cover 80 % of all energy use, the path is not sustainable, and will lead to an increase in climate gas emissions that most scientists agree will lead to global warming. From an environmental point of view hydrogen has been mentioned as superb as there are no CO2 or other harmful emissions during use as a fuel for transportation and power generation. The demonstration project at Utsira was presented, among other new energy pursuits, as the place where renewable energy and hydrogen supply emission free, efficient and secure energy to remote areas (UTSIRA is UTility Systems in Remote Areas)[364].

In 2007, former manager of New Energy (Rostrup) included the Utsira wind and hydrogen plant as part of his presentation on "A climate friendly energy policy – business opportunities for Norway?"[365] Another illustration of the connection between the Utsira project and the climate change mitigation agenda was seen when the island hosted a visit on the "Sky and Sea" lecture tour[366] conducted by an oceanographer at the Norwegian Meteorological Institute, Cecilie Mauritzen, also a member of the UN's Climate Panel, together with Siri Kalvig, meteorologist and founder of the Storm Weather Centre.

The purpose and focus of the lecture tour was to present in depth what is actually happening to the world's climate, to carry a climate debate and to discuss impacts, consequences and possible solutions. The lecture tour visited Utsira in June 2007, which also included shooting parts of a documentary that was to be presented on Norwegian television. "I chose Utsira as my last stop of the lecture tour because of Hydro's project facility and because I wanted to show my friends the sheer beauty of the place says and an enthusiastic Siri Kalvig", as summarised in a press release on Hydro's home page[367]: *Utsira shows the way to climate solutions*. Using Utsira as an example of a break through technology and a new direction came across in the following quote from the press release:

«Norway comes out best on the list of countries in regards to adjusting to climate change but pressure from the rest of the world will be prominent.

---

364 Hydro's Engagement in New Energy 12/4/2005

365 Rostrup, Jørgen C Arentz, Senior Vice President Hydro Oil and Energy Markets (2007): A climate friendly energy policy – business opportunities for Norway Vinterkonferansen 15.3.2007

366 The "Sky and Sea" lecture tour was arranged by the Norwegian Ministry of the Environment, the Norwegian Meteorological Institute and the Storm Weather Centre and visited 20 places in Norway.

367 http://www.hydro.com/en/Press-room/News/Archive/2007/06/17226/ *Utsira shows the way to climate solutions*

Norway must not rely on its oil wealth but should push on in new directions…We need breakthrough technology now. We must provide the right stimulation for youngsters to be attracted to the study of science. We need solutions, not just talk," stressed Kalvig in her lecture. "Hydro's Utsira project fits well in to this area," she said»

The Utsira mayor Geir Helge Rasmussen indicated that the municipality was now considering extending its ambitions in the development of a renewable society with zero emissions.

The Hydro representative on the island and the marketer of the solution at this particular occasion, Sjur Bratland, pointed to the specifics and the history of the project, explained how the wind-hydrogen solution was developed, how it works, and pointed to the visibility and publicity of the project:

«This project is proof in practice that it is possible to accomplish something. It also illustrates Hydro's ability to realize innovative solutions and get them to function. We have produced something so unique that people are still coming here to learn more three years after we started…. the decision to bring the Sky and Sea lecture to the island is an example of the continued interest in the project…. the Hydro project has received a lot of attention from the world press»

Hence relating the project to emissions and climate change, the Utsira project was used as a vision for sustainable energy with hydrogen as the energy carrier. The Utsira technology combination was illustrative of a building block and an enabling technology for the transition to a zero-emission society and offering a means to decarbonise energy supply.

6.8 Considering the success of the demonstration

Utsira experience has impacted the continuation of the hydrogen venture. As seen in the section on the particularities in market development and the building of applications, alternate courses of action and contexts of uses, in which the Utsira combination offer a potential value, emerged as part of demonstration activity.

> Innovation is not like most other business functions and activities. There are no reliable templates, rules, processes, or even measures of success. In a sense, each act of innovation is a unique feat, a leap of the individual – or the collective – imagination that can be neither predicted nor replicated. Innovation, in short, is anything but business as usual…… (Ellen Peebles, HBR on the innovative enterprise, 2003)

A returning issue in the planning of Hydro's hydrogen venture was to consider concepts and projects that represented commercial potential in the short term while also providing building blocks for the way forward and the long term hydrogen venture of the energy company. Demonstration projects were projects with Hydro participation and funding but were also partially funded by others (e.g. private-public partnerships, partners). As seen in the Utsira project, demonstration was relevant to develop the contexts of potential use / application in embryonic markets.

To evaluate the success of the Utsira demonstration, at the onset of the project the project manager pinpointed the purpose of the demonstration: *"We want to prove that this is possible, not economically viable, but technically possible."* Hydro's Hydrogen group considered the Utsira project to be a success, because they had proven it possible: *"It is up and running and the consumers get their energy".*

The main purpose was to make it work, make the components function together and to supply electricity with the right qualities. A Hydro researcher commented that Utsira was considered a success because they managed to do this, and the idea was to demonstrate and make it function technically. A business developer commented on the measurement of Utsira success:

« Seen with Hydro eyes I would definitely call it a success, we seem to have gotten answers on all the complications that we knew would lie ahead. The ten households on Utsira get their power from the system. I think it has been a great success, some will say that these successes are too costly, but in the larger picture, I don't see that. I think it is money well spent… at some point in time we will make a summation and decide the road ahead and the fate of the Utsira plant… Measuring the project in relation to economics and success was never the point, so to measure success has never had anything to do with economics, for that all the component prices need to come down, and that will only happen when you produce enough and make production plants with sizable production flow, and then it will become reasonable»

The demonstration was significant to understand performance requirements in real life situations and to find out where applied research was needed, which are aspects that cannot possibly be contemplated and resolved by extending feasibility studies and conceptual evaluation.

«When our engineers involved in the Utsira system operation presented all the experienced problems and how they have solved them, then the question came, well if you had had better time to think through all this in advance, could you then have made routines that handled all this? But they responded that there is no way you can think through it all and make routines because things have to be experienced and solved at the time the problem arises, that is what demonstrations are all about»

The international attention and publicity that the project received exceeded all expectations as suggested in the comment below (discussed in the context of choosing the wind system partner):
«We agreed on how it was to be built, function and that this was a 'high status' project. It was important that this should work as this could become a profiled project useful to both of our organisations, but none us dreamed about how profiled and how it would turn out….»

When it was difficult to quantify the value of a project in monetary terms, then something else had to be used in the argumentation for a demonstration project:
« It is not that if we cannot come up with a commercial opportunity with a given and satisfactory return, then we forget about the whole thing, hydrogen. That is where profiling comes in, because what we are doing on Utsira is not business but with long term engagement it may generate business, and then it provides extensive profiling, so profiling in the present compensates a lack of return»

The concrete experience and learning in the Utsira project fed back into the Hydro organisation, the continuation of hydrogen activity, and criteria development for subsequent projects. Evaluation criteria evolved while being involved in hydrogen energy projects and were used simultaneously with customary profitability and net present value calculations. In the context of strategy formulation, the Utsira project helped formulate criteria for the organisation's participation in demonstration projects. These involved consideration of opportunities to try out technological concepts deemed important to the continued hydrogen venture and development. Projects helping to position the company as a future supplier in hydrogen markets, and finally, albeit difficult to predict, projects that positively profile Hydro as an energy company.

7 Mechanisms of demonstration and the roles of the demonstration project – contributions based on the Utsira study

> "For the things we have to learn before we can do them, we learn by doing them "
>
> Aristotle

The second part of this thesis study has portrayed the Utsira demonstration project to explore the multifaceted roles of the demonstration project in company development processes and the mechanisms of demonstration. A focal organisation adds a focal point from where to explore the role of the demonstration. The Utsira demonstration project is the first full scale demonstration project of this type of technology combination driven by the initiative and vision of my study's focal organisation, Hydro, and realized in collaboration with partners selected to participate in the project.

The Utsira demonstration project has been a site for: private investment in an innovative project idea, for a concretization of a new technology configuration, and for activation of learning processes among project participants. The demonstration project is the hub where activities in multiple activity arenas are coupled. Having a demonstration project within a focal organisation as the point of departure was pursued to enhance the understanding of the strategies and efforts of private actors working to advance a new technological combination. The study has aspired to illustrate the intraorganisational efforts behind the realisation of a novel technology combination/ project by addressing where it came from and how it emerged in the company setting, what it took to get the demonstration project on its feet, and to consider the learning and demonstration aspects from pioneering an early and experimental project. What were the mechanisms of demonstration, the outcomes of the project on the part of the organisation, and the role of the demonstration in the organisation's innovation and development processes in the emerging hydrogen energy path?

The project was promoted by pioneers and in the pipeline long before a hydrogen business venture was established, hence the Utsira project had a long pre-history from 1998 before being committed to and granted acceptance to start in the spring of 2003. The demonstration project was supposed to run over 2 years to get operational experience. The embryonic idea for an Utsira type of project emerged as part of the pioneering and exploration activities of the technology provider, NHEL, into hydrogen energy in terms of becoming a market for electrolysers down the line.

The point of departure was an embryonic idea – using wind power to produce hydrogen. A demonstration project should be carried out with hydrogen as a facilitator of renewable energy in electricity systems. On the Utsira location, the idea was to explore how hydrogen may be an enabler for renewable energy sources to become the power source in an isolated system. A system that may be suitable for localities around the world where the alternative cost of power is high and where there are abundant renewable energy sources. The concept of local renewable energy systems based on hydrogen and renewable energy sources was also conceived as an alternative to investment in the installation of new transmission lines or sea cables. This was the rationale behind an island location for the demonstration project, and the Utsira demonstration project became a site for company development activities where demonstration and development processes were contained in a real world laboratory or experimental centre to rehearse the future. The future was built into the present by rehearsing it in a demonstration project.

I see no need to refresh memories with empirical summary at this point. Rather, I will move directly into the discussion of demonstration aspects, and the particular mechanisms by which the demonstration project has played a role(s) in company innovation and development processes.

7.1 The particular mechanisms of demonstration

7.1.1 Technology and market development

Technology and market development is the first mechanism of demonstration and role of the demonstration project in organisational development processes. New technology combinations do not sit on the shelf waiting for the proper price signal; rather new technological system need development over time from exploration of scientific and engineering ideas, through the development and enhancement of equipment, and to tuning and use in actual market settings. This concerns technological and material interactions as well as interaction with the market for technical solutions.

The Utsira demonstration project enabled evaluation of whether or not the technology combination would work in practice by providing experience in all phases from design and planning to operation and optimisation and market building activities unfolding while the Utsira project was in its construction and operational demonstration period; and finally, as a result of the response and interest in the Utsira project, the demonstration became a central building block in strategy refinements and the continuation of this particular hydrogen energy activity area.

For infrastructure innovation[368], it may be particularly relevant to explore the new technology combination in a place that serves as a contained real world laboratory – such as on an island with separate infrastructure. In the Utsira project, the point of departure was the idea to use hydrogen as an enabler for renewable energy sources in electricity systems. The initial relevance of the technology combination was to prove it suitable for isolated system around the world where the alternative cost of power is high and where there are abundant renewable energy sources. This was the main and initial value proposition, and therefore it was important to explore the new technology combination in a place that served as a contained real world laboratory for the innovation to demonstrate its relevance and attributes.

From a research and development perspective, the technical facets of the demonstration became part of the demonstration of relevance. Relevance was constituted through real world validation of components and systems, safety records; the real world performance of the system combination and established a reference point for the real world feasibility for the use of hydrogen energy. The relevance explored in technology development also went hand in hand with market development. Business opportunities for the Utsira technology combination had to be constituted. What needed to be done in practice terms for the new technology combination was that applications and potential markets had to be built. What customer would beat a path to the developers' doors to buy the technology combination? It was not obvious at the onset, and the path from mind to market was (and still is) lengthy.

The partners undertaking the Utsira project had to look for places to use the technology solution, so while being in the demonstration period, business development was explored in parallel. An import role of the demonstration project was that it was an arena for partnering strategies and for mobilising attention and action among others. Development across the main partners were realised while undertaking the demonstration project, and from this setting something new emerged independently of what was intended and planned for. Future collaboration was discussed in relation to potential contexts of use, potential markets and continuation alternatives for an Utsira type of system, which emerged while undertaking the project. The continued path and realisation of the technology combination depended on

[368] E.g. energy system innovation where new energy technology combinations face competition from hydropower or centralized large-scale power plants utilizing fossil fuels representing 'carbon lock-in' barriers. (The ''Carbon lock-in'' argument is that industrial economies have become locked-into fossil fuel-based energy and transportation systems through processes driven by technological and institutional increasing returns to scale. These technological systems have been established through a co-evolutionary process among technological infrastructures, organizations, society and governing institutions, ''culminating'' in what was termed a techno-institutional complex by Unruh (2000).

processes of adjustment, handling technical challenges and reformulating the project concept to different circumstances.

Market building activities were part of the demonstration by conceiving and focusing on locations where the technological system combination could provide significant value. Linking and weaving the technological solution to what may be construed as a situation, issue or challenge was part of demonstration activity. The focal organisation and the partners were not fully in control of this process, rather as the Utsira concept received international attention, the project concept in a way took on a life on its own, as other actors started to contemplate the relevance and value of the technology combination for their particular contexts. Potentialities and applications materialized from undertaking the Utsira demonstration and were intertwined with technology development, operational experience, encounters that turned up, as well as the efforts to communicate about the demonstration.

The Utsira development process was non-linear in the sense that developing, experimenting and the reformatting of the objective of the project changed or it was expanded as new contexts of relevance emerged and opened new paths and directions for development; as new developments dimensions were added during the demonstration period; and as other organisations and interested parties started to conceive new continuation concepts. Accordingly it is not only internally driven that new and diverse technology paths are created. Path creation was also driven from outside the organisational domain through the external coupling and the potential relevance of the technology combination to other settings entrepreneurs, and organisations that were also initiating new paths. Hence those controlling the demonstration project have less control over the process of integration that is the 'end station' or what may in the end become the context of use of the actual innovation.

7.1.2 Partnering strategies and learning in the organisation

Partnering strategies and learning in the organisation is the second mechanism of demonstration and role of the demonstration project in organisational development processes. A demonstration project is not a discrete event but a process that unfolds over time. It is a hub where activities in multiple 'activity arenas' require attentional resources, come together and from which the organisation learn about its own organisation and about others. Developing and promoting the Utsira technology combination provided learning opportunities and experience in terms of challenges that were not directly related to the cost or performance aspect and technology refinement. This involved experience with more decentralised supply technologies, the demands connected with a more decentral energy production on the producer and the customer. It also involved handling stakeholders in relation to the demonstration project and location, learning about regional agendas and pursuing spin off opportunities through engagement with the community, which in turn is another illustration of efforts to create relevance for the technology combination.

Inside the focal organisation, the demonstration project also played an important role as the experience gained during the demonstration influenced the strategic thinking and continued action in the area of hydrogen in renewable energy systems. Experience and the interest in the Utsira demonstration fed into the continued planning and revision of hydrogen activity and provided a new basis for action. The demo played a role in challenging voices of convention in terms of 'what business are we in" and "the way we do business around here'. With the concrete experience and learning in the Utsira project, evaluation criteria for subsequent projects were also developed. In the context of strategy formulation, the Utsira project helped formulate evaluation criteria for the organisation's participation in demonstration projects. These came to involve consideration of opportunities to try out technological concepts deemed important to the continued hydrogen venture; projects helping to position the company as a future supplier in hydrogen markets; and finally, albeit difficult to predict, projects that positively profile Hydro as an energy company. Hence the Utsira project paved the way for other creation oriented activities offering less certain and remote returns on investment by adding more qualitative metrics. This was important as uncertain technology concepts have little chance of being realised if subjected to measures of profitability and net present value calculations or return on investment customarily used on core business.

In relation to how business is done, building the Utsira research, development and development plant drew on the competence of several in-house organisational divisions, and the project was therefore a site where the existing organisational set up and its suitability for handling R&D projects became visible. Since the Utsira technology combination was created with others and thus networked at the core, the demonstration project was also an arena for practicing and handling collaboration. This involved handling location specific aspects, involving the local community to gain acceptance for the demonstration, and cooperate on the potential spin-offs to the community. In involved sorting out potential partners, setting expectations and demands to immature technologies, making it work, sharing and evaluating knowledge from the demonstration project, discussing future collaboration; were aspects that did not fit the customary handling of exchange relationships under contractual obligations.

The Utsira demonstration project was a practice site for working collectively as resources and activities of the organisation were linked with the intentions, resources and activities of others. Partners with the right equipment and competence were important, but having partners that had the right mindset about the potentiality and purpose of the project, and was determined and dedicated to make it work were equally important.

Finally, committing to partners in the Utsira demonstration also influenced the commercial strategy and the continuation of hydrogen efforts. The innovative aspect of the Utsira project was to take different technologies and make them function in a new configuration. The major challenge was handling the interfaces in the system, and developing the technology combination created linkages with the technology and competence of the other partners, in particular the main partner, Enercon. Technological interdependence carried the partner constellation into new situations. The relationship was important to cope with technological dependence, and also due to the realisation from operating the Utsira plant, that this kind of system will continue to be a very site specific product and hence a tailored offering to specific requirements of different geographical locations. Hence to be able to optimize and develop the Utsira stand-alone combination, a partnership agreement with Enercon was entered to continue development and to jointly pursue market creation for the demonstrated technology combination. Wherefore commitments to external partners are major constituents in the maintenance of a development path.

7.1.3 Vision, visualisation and visibility

Vision or visibility building is the third mechanism of demonstration and role of the demonstration project in organisational development processes. Realising and continuing Utsira involved demonstration in terms of information and visibility building to make the concept visible and to visualise the potential role of the technology offering in the energy system. Vision building was part of building relevance for the Utsira technology combination in different contexts of use. Alternative paths evolved from enquiries into the Utsira project and the idea of wind-hydrogen / hydrogen in renewable energy systems.

Information and visions are needed to create awareness among business, authorities and the public at large, and to boosts thinking about the development and use of sustainable technology solutions. When looking at the demonstration project as a real time laboratory or experimental centre for rehearsing the future, the demonstration project became a site for the creation of potent ideas and visions. The demonstration played a role through its creation and manifestation of a vision. A vision of a possible future technology combination comprising production, storage, distribution and end-use. And in a wider sense a picture of an alternative energy future with hydrogen as the energy carrier. The Utsira technology combination was illustrative of a building block and an enabling technology for the transition to a zero-emission society and offering a means to decarbonise energy supply.

The Utsira demonstration project also became a site around which to mobilise commitment, action and attention within the organisation and among others. Developing a shared vision was an important tool for aligning different partners and to stimulate resources and support. To a wider set of stakeholders than the immediate partners, the demonstration project became a real life site for visualisation, where seeing is part of believing. A real strength of the demonstration site was that it provided first-hand experience and allowed visitors to see that something is possible, and to develop an understanding based on that experience.

The Utsira demonstration project became a concept and came to provide a common reference point for local communities, scientists, companies and government agencies on the particular technology combination and hence it became a place-specific site for the exchange of information pertaining to this kind of combination. Through demo visions and visibility, the demo played a role in the emergence and creation of the business opportunity and the development path for hydrogen in renewable energy systems. The demonstration project became a site for the creation of potent ideas where the organisation is part of offering a solution to a situation or challenge e.g. sustainability, security of supply and energy independence, community empowerment, economic activity.

7.1.4 Communication efforts

Communication is the fourth mechanism of demonstration and the role of the demonstration project in organisational development processes. The visibility discussed above did not come about on its own. One demonstration aspect is that technical demonstrations require communicative efforts to gain visibility. The Utsira demonstration project became an arena for orchestrating communicative strategies to gain publicity and to connect with what was outside and beyond direct overview. There is no demonstration without an audience. The demonstration was a communication in its attempt to convey technical capabilities to an audience. Who was the audience and how should the significance of the project be articulated, were tasks and part of the action on the project. Communicating about the Utsira project was part of showing proof of the concept, a way to enhance competence and knowledge levels, and to become a reference point on a particular technology combination. Communication about the project covered the practicalities in realizing the project, the operational experience, technology interfaces that had to be accommodated, evaluation of economic and market issues. It also involved disseminating results to share good practice so as to enable stakeholders, authorities and communities to consider this type of technology solution as feasible and beneficial to their communities. Business building was intended to emerge through communication of Utsira information and experience.

There may be a sense of contradiction between engineering and communication because from an engineering and energy system point of departure, good solutions and technologies ought to sell themselves. However many technology alternatives compete for interest, while attention spans get shorter and shorter. The Utsira demonstration involved immense communications about the project, and the demonstration project played a central role in communicating the stake (usefulness, use, performance) of the new technology combination and the relevance of company- and partner resources to possible stakeholders. The demonstration profiled the organisation's hydrogen business venture in order to signal presence and activity to other actors. Financial investors, customers, the public and other organisations were audiences and possible stakeholders to whom the demo and technological system had to be made known.

The Hydro organisation participating in the demonstration was in itself a key audience. For a large organisation where voices of convention and resistance to this type of project existed, communicating activity on the Utsira project was part of relevance building and efforts to connect with both strategy and decisions inside the organisation so as to sustain activity. The success and interest that the project enjoyed helped sell the technology combination internally making it official that this was a business venture and hydrogen path that the company was pursuing.

Communication was also matter of associating with the political context, to sell ideas, issues and positioning the demo in the space of other technological solutions. The continuation of the demonstration and eventual and potential commercialisation of the technology combination will depend on surrounding conditions to be successful. To participate in international and national arenas and debate was a necessary part of demonstration activities in order to increase the likelihood of the technology combination to become part of a realized energy system transformation – when and if it materialises. Communicative activities served to clarify the potential role of the company's resources and skills in technology offerings and in the overall energy system. A central point is that it is not just the technical offering and specifications that count and trigger interest but also signification and the kind of values that a technology combination speaks to (low carbon energy solution, enabling energy independence and security of supply, mitigating environmental degradation, economic spin-offs). Part of the project's meaning evolved through communication where the technology combination was connected with visions, value propositions, issues and /or societal challenge.

Similarly, with extensive communication the project concept was made available and entered a market for demonstration projects and potential innovation partners. Other entrepreneurs, organisations, and public authorities could contemplate and attach the technology combination to their own entrepreneurial initiatives in different location but also within different contexts of use. Hence the demonstration project is a communicative entity that enters the debate and allows others to connect with the demonstration and technology concept to explore its potential and to particularize its relevance and application.

7.1.5 Demonstrations and legitimacy building

Legitimacy building is the last mechanism of demonstration and role of the demonstration project in organisational development processes. Legitimacy building is an outcome of both the performance of the technology combination, learning, visibility and communicative strategies in the demonstration.

Communication to nurture interest and generate acceptance of the technology combination was a major part of the action in the demonstration project. Communicating about the Utsira project generated awareness among business, authorities and the public at large, and allowed the public and key stakeholders to learn about the technological combination, and the synergies between hydrogen and renewable energy, and the potential relevance in relation to particular functions, issues or concerns. The value of the system was communicated and linked to agendas of value to the location and / or community. The actual usefulness and relevance of a technology combination can only be determined on the basis of real world demonstration. However to demonstrate technological feasibility is a necessary but not sufficient ingredient in establishing relevance and legitimacy. The technology combination also needs to be consistent with the qualitative enablers or constraints that emerge and follows from normative debates, issue and attention drivers in society.

The integration of a new technology combination and an energy carrier depend upon the extent to which its potential audiences learn about it and believe in it, and this also involves associating with the political context to sell ideas and to build up regulatory frameworks. Associating with international - and political arenas to link the technology combination with different agendas was part of creating relevance, creating more demonstration activity and hence pathways to potential future business. The Utsira project created an arena for nurturing business creation and the conception of new activity.

Legitimacy building relates to the other mechanisms of demonstration. It involves efforts to become a place-specific site for knowledge and the exchange of information on the technological combination, as well as efforts to advance the demonstration project as a common reference point for local communities, the general public, scientists, companies, and government agencies on the particular technology combination. Legitimacy building is an intangible aspect or product of all the previous points summarised as mechanisms of demonstration based on the empirical study: technology and market development strategies and the performance of the technology combination; partnering strategies and learning in the organisation and collaboration with allies; vision building; and communication. These were all component activities, part of what the demonstration did and why the demonstration was important.

7.2 Contributions to conceptual resources and disciplinary dialogue

7.2.1 On demonstrations and niche thinking

The mechanisms of demonstration may enhance our understanding of the role of the demonstration project to organisations pioneering the development of a new technology combination by looking into the dynamics, mobilisation, choices and evaluations made along the way in the realization of the demonstration project.

The recognition of the technological and material interactions and the importance of niches and demonstration are often summed up by referring to learning effects (see chapter 3). There is learning from actually using a technology, which allows project participants to experiment to make 'the thing' work, demonstrate technological feasibility, as well as to explore potential contexts of use. Through deployment of new technologies in demonstrations, actors learn how to produce and use the technology combination more effectively and may stimulate additional research and development by industry. Private industry research and development, 'learning by doing' and scale economies as more output is produced, lead to product refinement, improved system design, improved technical performance and is aimed at lowering costs with anticipation of larger market opportunities. This is why niche and demonstration development are important to stimulate market volume. Learning aspects highlight why experimenting and development in the formative phase are important and use indicators such as deployment of the technology, growth in sales and cost reduction per unit output as indicators on whether or not a demonstration initiative has been successful.

In addition to the cost and performance aspects frequently summarised as the learning aspect to industrial actors (Magnuson 2003, Kemp et al. 1998, Geels 2002, Raven 2007, Brown 2003), the Utsira study and the mechanisms of demonstration developed from the study, have shown that there is more to say about the role of the demonstration in organisational development processes on the part of the participating organisations pioneering a new technology combination.

The demonstration project staged a try out for the new combination and players in the try out needed to come together. Components had to be identified, sourcing or partners had to be considered and decided prior to the actual recombination of resources or technologies. Hence an extended period of exploration and partnering had to be handled inside the firm well before the diverse resources and components could be put together in the new technology combination. *This concerned collaboration and value creation with partners and the handling of technical and material interfaces with others.* While planning to undertake the demonstration project, the organisation gained insight into technologies developed by others, which involved assessing the state of the art in terms of competence of others and maturity of technologies. It allowed for exploration, assessment of future options and new configurations to combine knowledge, skills, and resources. The Utsira demonstration illustrated that *new knowledge and the new technology combination emerged at the interfaces between the different organisations, skills, ideas, and resources - and was materially connected to the actual intersection of the component inputs that the different partners brought to the table.*

The technological learning aspect concerned a range of activities: how to design and build the project together, prove that it could be done, make it function and operate the system to secure energy supply from the technology combination, efforts to optimise and improve technical performance and reliability, and to make the system robust. Extended demonstration activity and the decision to continue or terminate the demonstration project was a matter of relevance building in terms of finding new system dimensions from which additional experience and learning could be achieved. Local community concerns, profiling and the public relations aspect were considered, yet it had to be relevant to continue from a development point of view and exploration into adding new elements to the project was a key strategy.

Learning in the demonstration project primarily resulted from negative feedback from efforts to connect previously unrelated technologies, resources, activities or actors as problems and setbacks activated new insight and adjustments in the experimental setting. Successful demonstrations depended on lots of interacted adjustments and creative troubleshooting activities. The challenges that resulted from connecting previously unrelated technologies, resources, activities or actors were unpredictable, occurred in an unlimited number of dimensions and as such were a major part of technological uncertainty.

The demonstration project, in my study, was not a product of policy intervention, a public research, development and deployment programme outlining a prioritised activity or technology configuration. This established a golden opportunity to study the strategic importance of the demonstration project in an organisation's development processes. Albeit the perspective on technological niches encourage a focus on the interdependence of multiple actors, it is often difficult to ascertain from where the technology development in demonstration projects is observed. Most studies tend to pay more attention to the policy aspect and the role of government as a transition manager rather than to the role of a demonstration project as experienced by an organisation pioneering new technology development.

The study of the Utsira demonstration project has not provided a study of a grand societal transition and it is not clear whether the demonstration project and technology will become a success commercially. However, the study may still add to the insight typically advanced in clean technology studies. Because clean energy development is a large scale transformation, many technology studies seek to conceptualise multi-levelled dimensions in one framework. The problem highlighted is that it leaves unclear the process of linking up action and developments from the different levels e.g. demonstration, regime, landscape (see discussion chapter 3). It was indicated by Geels (2002) that novelty in demonstration projects originates at the microlevel of local practices where actors and organisations in precarious networks work on radical innovations but how does the arrow from niche to regime come about?" (2002, p. 1262).

The mechanisms of demonstration and the roles of the demonstration in organisational development processes, highlighted on the basis of my study, suggest that the demarcation and levels set up by researchers are rather artificial. The Utsira demonstration has illustrated that practitioners work with no consideration of, what researchers refer to as levels, while undertaking the demonstration. Technology development goes hand in hand with market building activities where the concept is linked to particular localities, commercial contexts, issues or challenges towards which the technology combination may be of value. Extensive communications as well as involvement in political arenas pointed out the importance of efforts to mobilise attention and action among others. Mobilising agendas, information, priorities, political visions and political development strategies were also part of the demonstration project. New opportunity emerged through demo visibility and from connection triggered interpretive processes among different constituents. Finally also illustrating that a demonstration project transcends boundaries or levels, is the point that interest and attention over the lifetime of the demonstration project's fed back into the intraorganisational dynamics as the demonstration became a central building block in interpretive strategy refinements and modifying the strategic orientation as practitioners sought to continue and extend path creation efforts. When incorporating time, the ideas, plans, and actions of a focal organisation are subject to change as mediated by experience gained in concrete demonstration activities.

7.2.2 On (Re)Combination

The demonstration project is a site where companies access and develop resources; it is at site for the process of recombination. The perspective on innovation as recombination was considered instructive as the innovative aspect of the Utsira demonstration plant was the new configuration of the individual technologies. All components, except for the fuel cell, used commercially available technology and the innovative aspect of the project was the integration and recombination into a new technical configuration, putting the elements together and making it function with the high number of interfaces in the system.

Building on a number of writers going back to Schumpeter (1934) and Usher (1929) (see chapter 3) that conceive innovation as recombination, the contemporary perspective advanced by Hargadon (2003) is particularly trying to generate practical insight into managing innovation processes. Opportunities for valuable recombination were suggested to emerge through technology brokering and bridging activities that result from connections between people, ideas and objects moving across divisions/groups/teams within the organisation, or on the periphery of the organisation and the technologies they might run across in their encounters in other markets or organisations. The proposition was that (in)/entrepreneurs are no smarter, no more courageous, tenacious, or rebellious than the rest of us – they are simply better connected and innovate by bridging otherwise disconnected domains and organize solutions that combine resources across them. Building an option for the future and scope of action had to do with bridging distant worlds and technology brokering (Hargadon 2003), when a firm pursues a strategy not necessarily to break with the past but to exploit it by harnessing the knowledge that reside in elements of existing technologies and to see how people, ideas and objects of one world can be combined in new ways to solve the problems of another. Hence an innovation process may not be a process of thinking outside the box so much as one of thinking in other boxes by bringing together previously disparate people, ideas and objects.

In the initiation of hydrogen energy, attending conferences and seminars, and having multiple points of contact put pioneers in a position to be better connected and to see new ways of combining their strategic resources with other organisations, ideas, and resources. Ideas and people from different places or contexts came into contact, which was a stimulus to consider how the company's hydrogen technology and competence could be integrated into new settings, and to recognize the potential for different connections and new combinations of resources. The Utsira demonstration project idea was advanced as pioneers started to recognise how resources of one domain could be bridged and used to satisfy the needs of another. Hydrogen and hydrogen producing technological systems could be taken out of the context of industrial applications and used in energy systems given that technologies were combined in new ways.

However while advancing the relational and coupling aspect in recombinant innovation; the ability for recombinant innovation was about bridging ideas, experience, and resources from different domains, and absorbing, adopting and adapting to this inside the organization, which maintain a sponge-like metaphor on the part of the organisation (discussed in chapter 3). This does little in terms of discussing the collaborative aspect in recombinant innovation when putting new combinations together with partners (where the people, ideas and objects/material resources reside), and where resources are connected in new technical configuration in action over time. The Utsira demonstration project was a point of rehearsal that may highlight joint action in the social and technical process of recombination. The connecting or collaborative aspect of this process of recombination has been explored in the demonstration project with its efforts to combine and connect resources, people and ideas in a new technical configuration.

Based on the Utsira study, my suggestion is that this is neither about bridging to other domains only to bring something back inside the organisation, nor is it a static state of affairs, where resources are looked upon as Lego blocks that do not change in shape when recombined in new configurations. Rather the resources that organisations bring to the table change in the course of action, with new connections and in new configurations. Garud and Karnøe (2003, p. 278) somewhat pointed to the transformative element: "technology entrepreneurship is not just about the discovery of pre-existing options by alert individuals or speculation on the future. Additionally, it involves the creation of new options through the recombination and transformation of existing resources". Still the language in terms of innovation consisting of new combination of *existing* ideas, capabilities, skills, resources etc., is rather mechanistic with resources implied as given 'things' and the same at different points in time. This view is challenged by my study.

Firstly, my study contributes to the notion of recombinant innovation by looking at *recombination as collaboration* instead of, absorption, adaptation and matching (chapter 3). The demonstration project is networked at the core, and resources are made valuable and rejuvenated (individually and collectively) when put together in the novel combination and in the course of joint action with partners. While undertaking the demonstration project, the resources of the contributing partners are reciprocally adjusted, and with actual demonstration and operational experience, development needs on the component technologies are identified. Attributes are defined as developers come to understand the performance requirements of this type of configuration in a real life situation. Collaboration on innovation processes such as a research, development and a demonstration plant also trigger learning about an organisation's set up and the customary way of doing things and its suitability for handling innovation through collaboration. With collaboration come technological dependence, and the importance of social features to handle connectedness, as well as having a partnership and partner constellation with a common understanding on the status, purpose and premise of the project. To successfully recombine partner competence and resources into a new technology configuration also require continued development efforts and hence commitment over time.

Secondly, in relation to the real world feasibility for the use of hydrogen in new domains, ideas are conceived and generated through processes of interacting with others. Several value propositions for hydrogen and renewable energy systems emerge during a demonstration, with an unforeseen branching of activity from conceiving contexts or locations where the technology combination may provide significant value. Hence the process of recombining resources and to build market opportunities also leads to a *recombination of purpose* as the project concept is linked to particular localities and commercial contexts in which the technology combination may be of value.

Thirdly, the extensive communications in media, at fairs and conferences as well as involvement in political arenas, show the importance of efforts to mobilise attention and action among others. Framing a need for the Utsira type of system, and presenting such ideas to potential stakeholders were parallel activities to the handling of technical challenges in the Utsira demonstration. Presenting the relevance of a concept in relation to issues and societal challenges, and explaining the content of the project and technology combination; involve efforts to get others interested in the Utsira type of system. Hence central to innovation as recombination is *the recombination of visions, priorities and development agendas* to build an opportunity space for a new technology combination, as well as to influence the informational basis based on which policy development, clean energy futures and implementation strategies are decided.

8 Final reflections on thesis

In this thesis I have sought to contribute to what other researchers have said about particular aspects associated with innovation processes. I have highlighted what other researchers have touched upon in less detail, and discussed additional insights based on and exemplified through my empirical study. I have participated in a social science debate in the sense that I see work as cumulative; where we build on and add to each others ideas and understanding.

An additional comment may be made in relation to the literature on collective action and process theories of technology emergence. Since the eventual outcome (technological innovation, industry emergence) is a collective achievement by multiple actors, the unit of analysis is usually demarcated as the interorganisational field. Innovation Journey authors indicate that understanding innovation processes requires one to address questions at a micro and a macro level, where the former concerns the behaviour of the entrepreneur and decision making on activities inside the company and the latter concerns deciding what functions to perform to build an industry infrastructure. *However what goes on between and how the micro and macro / levels are interrelated, if and how they form each other and are interlinked, is less attended to*

With the discussion of levels and the micro and macro point of view; the internal and external of the company are kept rather distinct and the point of crossing tends to be left unexamined. If focusing on interorganisational activity, what goes on inside the company tends to remain a black box, and if focusing on intraorganisational aspects, the impact of interorganisational dynamics on intraorganisational dynamics tend to be omitted. In the academic world, levels are matters of choice and convenience. However in terms of actual practice and an innovation process, this seems to artificially break up the processes and treat the innovation process in a series of separate activity spheres without considering that the organisation, via practitioners that handle innovative activity in configuration with others, are interacting responsively[369]. Company activity is nested in its situation and environment. Connections are conduits to collective framing processes, to the constitution

[369] Since humans do not always adapt to, or fit in, with each other, it might be useful to think of human relating not as adaptive but as responsive (Stacey 2007, p. 258). Responsive processes are defined as involving interaction of humans struggling for mutual recognition as participants. Here there is no external viewpoint and everything organisations do is as participants in some interaction with others. Individuals are fundamentally social practitioners and what they do, think or say takes form in the context of social practices, while these practises also provide the required resources, objects, skills and procedures (Stacey 2007, pg. 246).

of new resource configurations, and joint activities, but connections also trigger a spiral of taking stock, modifying the strategic orientation, and shaping path creation inside an organisation. Hence reality is dynamic with the blurring of boundaries and with a simultaneous outside-in and inside-out dynamics in the course of innovation processes.

This discussion adds to a debate in organisation theory on organisations in relation to their environment, and the assumption that organisations whose internal features best match and establish a proper "fit" with its situation / environment will achieve best adaptation (Scott 1998:96). Burns and Stalker identified *the organic model*[370] as less structured and appropriate to changing conditions / environments that give rise to fresh problems and unforeseen requirements for action that cannot be broken down or distributed automatically arising from the functional roles defined within a hierarchic structure (ibid, p.121). The organic model was more dynamic with variation in tasks and roles to fit the challenges arising from the organisational context. Burns and Stalker (1961) adopted an "open systems" view on organisations[371], which presuppose a continuing exchange of resources with their environments (Evan 1993, p. 5). No organisation is completely self-contained and cannot generate all the necessary resources internally. Hence to be innovative, an organisation or a cluster of organisations must favour interaction, permanent comings and goings, all types of negotiation, which allow for rapid adaptation (Burns & Stalker, 1961).

Yet the point that I wish to bring up in relation to the open systems view is that albeit it recognises the challenge of handling complex tasks, technology and markets; there is a predominant focus on organisational structural forms in response to demands of the context. For example with unpredictability and uncertainty, organisations adopt more adaptive and

---

[370] Burns and Stalker identified two "ideal" type organisations / management systems representing the two polar extremities of the forms such systems can take. One was the *organic model* and the other was *the mechanistic model* under stable, structural conditions / environments, which corresponds to the classical WeberianWeber's theory of bureaucracy concerned with the "ideal type" organisation capable of achieving the highest degree of efficiency and rationality. The term *bureaucracy* described the rational-legal organisation, and the ideal typical characteristics of bureaucratic authority were: jurisdictional areas governed by rules and regulations; hierarchically structured offices or positions; and management based upon written documents and requiring expertise, and governed by general rules. This type of organisation would be capable of attaining the highest degree of efficiency and be superior in stability, in the stringency of its discipline, and in its reliability, and thereby make possible a high degree of calculability of results for the heads of the organisation (Weber 1958 and also referenced in Evans, 1993, pp. 3-4).

[371] Open systems: systems capable of self-maintenance based on a throughput of resources from the environment (Boulding 1956, p. 200-207).

flexible structures and organic forms of organising[372]. However, the difficulties in achieving the "match" between the organisation and uncertain environments and situations are not addressed; and there seems to be a lack of attention to the actual organising process in the development of resources and how actors in organisations interpret, make choices, and handle uncertain and unpredictable situations. This was in a way similarly pointed out by Akrich et al. (2002, pp.189-190 with italics added by this author):

«Rigid and mechanical models, overly precise task and role definitions, constraining programmes, must all be avoided in order to innovate. These ordering words — "de-compartmentalisation", "creation of *ad hoc* structures", "adaptation" — which resonate like church anthems, are undoubtedly useful. *However, what remains is the thousand ways to interact and to choose whom to interact with…* The organic model (Burns & Stalker, 1961), inspired by biological metaphors, is insufficient to guarantee success. It describes an organisational climate, without which the evolutions necessary for the development of new projects become difficult, *but it says nothing about the innovation process itself*»

My empirical case study has looked into pioneer activity to build relevance and commitment to innovation processes and the development processes in a demonstration project with an aspiration to illustrate 'the processes themselves'. Inspired by the research methodological principles of science and technology studies, I did not assume any kind of upfront decision on what level or sphere to study, rather practioner's doings and activities settled the focus and illustrated the mobility in organising innovation activities. The study challenges demarcations of levels, micro or macro, internal or external, as well as the focus on structural form in a reactive mode to an organisation's circumstance or context. While recognising the interorganisational field's importance for the eventual success or failure of innovation activity; process theories of technology emergence must acknowledge that collective action in innovation processes ultimately consist of individual actors that constitute these processes by undertaking activities to enhance and gain resources, competencies and support necessary to develop new courses of action and business. On the other hand, innovation activity emerges with the activities of others and shapes the organisation's vision of the future that shape interpretations of action and events that lead to new action that lead to new events that…. in a never-ending spiral.

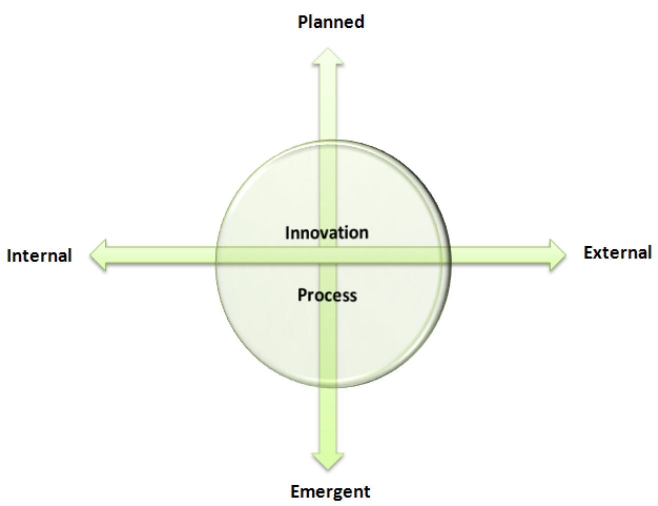
These are processes that do not respect boundaries and levels. Relating becomes the centre of attention; relating in which minds, objects and resources are simultaneously forming and being formed. Organisations

[372] The organic organisation has a much more fluid set of arrangements and is an appropriate form to changing environmental conditions which require emergent and innovative responses (Burns and Stalker 1961 summarised in Lam 2006, p. 118)

do not make choices in isolation, rather choices, intentions, decisions and strategies relate to what others are doing, together creating ongoing processes of interaction. In the organisation, intentions and plans are in the making, decisions are in the making and projects and continuation of activity are in the making and subject to new direction as a result of insight gained from being part of the action, exploration, and part of development activities. During a stream of activities the paths of independent entrepreneurs, acting out their own diverse intentions and ideas, intersect. Connections are conduits to resources, the development of new resources and also to collective framing processes where opportunities are defined and redefined collectively. Novelty arises in the dynamics of this interweaving in particular places at particular times.

To conclude, I think that the study of innovation and development activity must deal with and reflect the boundary dissolution or boundary crossing as discussed before and as suggested in the figure below. The figure is a result of my efforts to study the empirical complexity in organising innovation activities over time by following connections and the linking of activities.

Figure 9 Boundary crossing in innovation and development activities



With a focus on unfolding actions, attention is drawn to *the process itself*.
The focal point is an innovation process or project that is the hub that couples activities. It intends to draw attention to the actions, choices and motivations of individuals within organisations and acting across organisational boundaries. Although the activities of interdependent people and organisations obviously take place in a physical setting, there is no notion of the activities themselves being internal or external. Individuals and

organisations are involved in development activity by connecting with others and produce patterns of action and relationships through the combining of people, ideas, and objects. Technology and resources are constituted in same activity while also being part of what shapes the action and relationships. A central point is that the question of levels does not have to arise. What becomes is emergent and planned at the same time; planned as organisations go into an innovation process with intentions, visions, and desired goals. Emergent as there is an ongoing adjustment of plans and goals change, are moulded and reformulated during action.

9 Bibliography

9.1 Chapters 1-3 and 8

Abernathy, W.J. & Clark, K.: "Innovation – Mapping the winds of creative destruction" *Research Policy*, 14 (1985) pp. 3-22

Adam – web complexity futures – 23-09-05

Akrich, M., Callon, M., Latour, B. (2002): "The key to success in innovation part I: The art of interessement", in *International Journal of Innovation Management*, Vol. 6, No. 2, June, pp. 187-206.

Barad, Karen (2003): "Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter", *Signs: Journal of Women in Culture and Society* 2003, vol. 28, no. 3, The University of Chicago.

Benford, R. & Snow, D.A (2000): "Framing Processes and Social Movements: An Overview and Assessment", *Annual Review of Sociology,* August 2000, Vol. 26, Pages 611-639.

Berkhout, F., Smith, A., Stirling A. (2003): "Socio-Technological Regimes and Transition Contexts", SPRU – Science & Technology Policy Research Unit, University of Sussex, Working Paper Series, Number 2003/3.

Bijker, W.E. & Law, J. (1992): *Shaping Technology / Building Society – studies in sociotechnical change*, The MIT press.

Boulding, Kenneth E. (1956): "General Systems Theory: The Skeleton Science", in *Management Science*, 2, pp. 197-208.

Brown, H. S., Vergragt P., Green, K., Berchicci (2003): "Learning for sustainability transitions through bounded socio-technical experiments in personal mobility", *Technology Analysis & Strategic Management,* Vol. 15, No. 3, September.

Brown, S. (2002): "Research that reinvents the Corporation", *Harvard Business Review,* Reprinted in *Harvard Business Review on the Innovative Enterprise* (2003, pp. 129-154)

Burns, T. & Stalker, G.M (1961): *The management of innovation,* "Mechanistic and Organic Systems of Management", Chap. 6, pp. 96-125, London: Tavistock.

Callon, M. & Law, J.: (1997): "After the individual in society: Lessons on collectivity from science, technology and society", *Canadian Journal of Sociology*, 22(2), pp. 165-182.

Callon, Michel 1986. "Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St Brieuc Bay." Pp. 196-233 in *Power, Action and Belief: A New Sociology of Knowledge*, edited by John Law. London: Routledge & Kegan Paul.

Cañibano, C., Muñoz, F.F., Encinar, M.I. (2006): "Evolving capabilities and innovative intentionality: some reflections on the role of intention within innovation processes" , *Innovation: Management Policy & Practice,* 8(4): pp. 310 – 321.

Chia, R. (1998): "From complexity science to complex thinking: organization as simple location", *Organization* 5(3): 341-369, *Sage Publications*

Christensen, Clayton M. (1997): *The innovator's dilemma: when new technologies cause great firms to fail*, Harvard Business School Press.

Czarniawska, B. (2004): "On Time, Space, and Action Nets", *Organization,* Vol. 11(6): 773-791, Sage.

Dimas Stavros, Member of EU Commission, responsible for environment: "Climate change: Why a global response needs European Leadership", London 11 January 17, 2007.

Downs, G.W. & Mohr L.B. (1976): "Conceptual Issues in the study of innovation," *Administrative Science Quarterly*, 21 (4): 700-714 (Dec. 1976).

Evan, W.M. (1993): *Organisation theory and design*, New York: MacMillian, Introduction pp. 1-26.
Economist; London; Survey: Innovation in industry, February 20, 1999, Nicholas Valery, Volume 350, Issue 8107.

EU Commission (2007): *Limiting Global Climate Change to 2 degrees Celsius,* Communication in relation to the EU's Climate Change Package, 10 January 2007: Brussels http://www.europa-eu-un.org/articles/en/article_6666_en.htm

Eurobarometer - Energy: Issues, Options and Technologies, European Commission Directorate- General for Research, available March 6, 2003 http://europa.eu.int/comm/research/energy/pdf/eurobarometer_energy_en.pdf

Fagerberg, J., Mowery, D., Nelson R. (2006a): *The Oxford Handbook of Innovation,* Oxford University Press.

Fagerberg, J. (2006b): "Innovation: A guide to the literature", in *The Oxford Handbook of Innovation,* Oxford University Press. Eds. Fagerberg, J., Mowery, D., Nelson R.

Fiol, C.M. & O'Connor, E. (2003): "Waking Up! Mindfulness in the face of bandwagons", *Academy of Management Review*, Vol. 28. No. 1, pp. 54-70.

Foster, Richard N. (1986): *Innovation – The Attacker's Advantage*, McKinsey & Co., Summit Books New York.

Garud, R. & Karnøe P. (2006): *Path creation: a process of mindful deviation - A set of ideas to think about the role of human agency in entrepreneurship and change*, www.eiasm.org/UserFiles/pcpresentationnov2006.ppt

Garud, R. & Karnøe, P. (2003): "Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship", *Research Policy* 32:2 (2003) 277–300.

Garud, R. & Karnøe, P. (2001): *Path Dependence and Creation,* Eds. Lawrence Erlbaum Associates, Publishers.

Garud, R. & Van de Ven, A.H. (2002): in *Handbook of strategy and management*, London Sage, 2002, pp. 206-231 Eds. Pettigrew, Andrew, Thomas, Howard, Whittington Richard, Garud, R. & Van de Ven, A.H. (1989): ”*Innovation and the emergence of industries*”. In: Van de Ven, A.H., Angle, H., Poole, M.S. (Eds.), *Research on the management of innovation: The Minnesota Studies*. New York: Ballinger/Harper & Row

Geels, F.W. & Kemp, R. (2007) “Dynamics in socio-technical systems: Typology of change processes and contrasting case studies”, Technology in Society 29(4): 441-455.

Geels, F.W., 2002, “Technological transitions as evolutionary reconfiguration processes: a multilevel perspective and a case study, Research Policy*,* 31(8/9), 1257-1274

Goffman E. (1974): *Frame Analysis: An Essay on the Organization of Experience,* New York, Harper Colophon

Hammersley, M. & Atkinson, P. (1995): *Ethnography. Principles in practice*, Routledge: London and New York

Harborne P., Hendry, C., and Brown, J. (2007): “The development and diffusion of radical technological innovation: The role of bus demonstration projects in commercialising fuel cell technology”, *Technology Analysis & Strategic Management*, Vol. 19, No. 2, pp. 167-187, March Routledge.

Hargadon, A. (2004): *Implications for innovation strategies from historic technology transitions*, A report from the Public Fuel Cell Alliance, September.

Hargadon, A. (2003): *How breakthroughs happen – the surprising truth about how companies innovate*, Harvard Business School Press.

Hastrup, K. (1992): *Det antropoligiske project om forbløffelse,* Gyldendal.

Hendry, C., Harborne P., Brown, J. (2007): “Niche Entry as a route to mainstream innovation: Learning from the phosphoric acid fuel cell in stationary power”, *Technology Analysis & Strategic Management*, Vol. 19, No. 4, pp. 403-425, July, Routledge

Hernes, T. & Weik, E. (2007): “Organization as process: drawing the line between endogenous and exogenous views*”, Scandinavian journal of management.*

Hernes, T. (2008*): Understanding Organization as Process -Theory for a Tangled World*, Routledge

Hess, D. (1992)*:*”Introduction: The new ethnography and the anthropology of science and technology”*,* in *Knowledge and Society: The Anthropology of Science and Technology,* Vol. 9, pp.1-26.

Hirsch, P.M., Gillespie, J.J (2001): “Unpacking Path Dependence: Differential Valuations Accorded History Across Disciplines”, in *Path Dependence and Creation,* Eds. Garud, R. & Karnøe, P., Lawrence Erlbaum Associates, Publishers.

Hoffmann, P. (2002): *Tomorrow’s energy: hydrogen fuel cells and the prospects for a cleaner planet*, The MIT Press.

Håkansson, H. & Waluszewski, A. (2002): *Managing Technological Development- IKEA, the environment and technology,* Routhledge.

Håkansson, H. & Snehota, I. (1989): ”No business is an island: the network concept of business strategy”, *Scand. Journal of Management*, Vol. 5, No. 3, pp.187-200, Pergamon Press.

International Energy Agency (2006): *World Energy Outlook 2006*

International Energy Agency (2003): Creating Markets for Energy Technologies,http://www.iea.org/textbase/nppdf/free/2000/creating_markets2003.pdf

Jacobsson S. & Bergek, A. (2004): "Transforming the energy sector: the evolution of technological systems in renewable energy technology", *Industrial and Corporate Change* 13 (5) (2004) pp. 815–849.

Karlstrom, M., Andersson, B. A. (1995): *Selecting and Assessing Demonstration Projects: The case of Fuel Cells and Hydrogen systems*. ASEAT03, Manchester.

Kemp, R., Rip, Schot (2001), 'Constructing Transition Paths through the Management of Niches', in Raghu Garud and Peter Karnøe (eds.) *Path Dependence and Creation*, Lawrence Erlbaum: Mahwah NJ and London, 269-299.

Kemp R., Schot J., Hoogma R. (1998): "Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management", *Technol. Anal. Strateg. Manag.* 10 (2) (1998) 175–195.

Kemp, R. & Rip, A. (1998): "Technological change", pp. 327–399. In: Rayner, S., Malone, E.L. (Eds), *Human Choice and Climate Change*, Vol. 2. Battelle Press, Columbus, OH.

Koestler, A (1964, 1989): *The Act of Creation,* London Arkana

Kuhn, T.S (1962): *The Structure of Scientific Revolutions*, University of Chicago Press, Chicago.

Lam, A. (2006): "Organizational Innovation", pp. 115- 147 in *The Oxford Handbook of Innovation,* Oxford University Press. Eds. Fagerberg, J., Mowery, D., Nelson R.

Latour, B. (1987): *Science in Action: How to Follow Scientists and Engineers through Society*, Harvard University Press

Law, J. (2004a): *After method- mess in social science research,* Routledge.

Law, J. (2004b): *Enacting naturecultures: a note from STS*, Online paper published by the Centre for Science Studies, Lancaster University, http://www.lancs.ac.uk/fss/sociology/papers/law-enacting-naturecultures.pdf

Law, J. (2003): *Making a mess of method",* Online paper published by the Centre for Science Studies, Lancaster University, http://www.lancs.ac.uk/fss/sociology/papers/law-making-a-mess-with-method.pdf

Law, J. & Hassard, J. (1999): *Actor Network Theory and after,* Blackwell Publishing / The Sociological Review

Law, J. (1994), Organizing Modernity, Oxford and Cambridge: Blackwell.

Magnusson, T. (2003): "Commercializing Cleaner New Technologies: The Case of Microturbine Generators", *Technology Analysis & Strategic Management,* Vol. 15, No. 3, September 2003.

March, J.G. (1991): "Exploration and Exploitation in organisational learning", *Organization Science*, Vol. 2, No. 1, Special issue: Organisational learning: papers in Honor of (and by) James G. March, pp. 71-87.

March, J.G. (1981): "Footnotes on organizational change", Administrative Science Quarterly, Vol. 26, No. 4, Dec., pp.563 –577.

Morgan, G. (1983): *Beyond Method- Strategies for Social Research*, Sage Publications, Fourth printing.
Normann, R. (2001): *Reframing business – when the map changes the landscape*, John Wiley & Sons.
Patton, M.Q. (1990): *Qualitative Evaluation and Research Methods,* second edition, Sage Publications.
Peebles, E. (2003): *Inspiring Innovation,* Harvard Business Review (HBR) on the innovative enterprise, 2003, The Harvard Business Review Paperback Series, originally published August 2002.
Pickering, A. (1995): *The Mangle of Practice – Time, Agency & Science*, The University of Chicago Press.
Pickering, A. (1994): *After Representation: Science Studies in the Performative Idiom,* Proceedings of the Biennial Meeting of the Philosophy of Science Association, Vol. 1994, Volume Two: Symposia and Invited Papers, pp. 413-419, University of Chicago Press
Pickering, A. (1993): "The Mangle of Practice: Agency and Emergence in the Sociology of Science", *American Journal of Sociology*, Vol. 99, No. 3, pp. 559-89, Nov.
Poggi, G. (1965): "A main theme of contemporary sociological analysis: Its achievements and limitations", British Journal of Sociology, Vol. 16, pp. 283-294.
Poole M.S (2004): "Central Issues in the Study of Change and Innovation", pp. 3-31, in Handbook of Organizational change and innovation, eds. Marshall Scott Poole and Andrew Van de Ven, Oxford University Press
Poole M.S & Van de Ven (1989): "Using Paradox to Build Organization and Management Theories," *Academy of Management Review*, 15, 3 (October), pp. 562-578.
Porac, J.F, Rosa, J.A, Spanjol, J., Saxon, M.S. (2001): "America's Family Vehicle: Path Creation in the U.S. Minivan Market", in *Path Dependence and Creation,* Eds. Garud, R. & Karnøe, P., Lawrence Erlbaum Associates, Publishers.
Raven, R. (2007): "Niche accumulation and hybridisation strategies in transition processes towards a sustainable energy system: An assessment of differences and pitfalls", *Energy Policy* 35, pp. 2390-2400, Elsevier
Romm, J. (2005): The hype about hydrogen – Fact and fiction in the race to save the climate, Island Press.
Schumpeter, J.A. (1942): Capitalism, socialism, and democracy, New York, Harper & Row.
Schumpeter, J.A. (1934): *The Theory of Economic Development,* Cambridge, Mass.: Harvard University Press
Smith, M.J. (1998): *Social Science in Question*, SAGE Publications Ltd (reference to Norwood Hanson 1958 *Patterns of Discovery*).
Stacey, R. (2007): *Strategic Management and Organizational Dynamics: The Challenge of Complexity*, Fifth Edition, FT Prentice Hall.
Stacey, R. (2006): Complexity & Emergence in Organizations, presentation held at 9/3/2006, http://www.knowledgelab.dk/now/news/rs
Stern Review (2006): *Stern Review on the Economics of Climate Change,* Cambridge http://www.hm-treasury.gov.uk/stern_review_report.htm

Tushman, Michael L. & Anderson Philip (1997): *Managing Strategic Innovation and Change,* Oxford University Press.

Tushman, M.L. & Anderson, P. (1986): "Technological Discontinuities and Organisational Environments", *Administrative Science Quarterly, Vol. 31, Issue 3, pp.439-465.*

Utterback, J.M (1994): *Mastering the dynamics of innovation*, Harvard Business School Press, Boston Massachusetts.

Van de Ven, A.H & Hargrave, T. (2004): "Social, Technical and Institutional Change – A literature review and synthesis", pp. 259- 303 in Handbook of Organizational change and innovation, eds. Marshall Scott Poole and Andrew Van de Ven, Oxford University Press

Unruh G. C. (2000): Understanding Carbon Lock-in, *Energy Policy*, 28, 2000, pp. 817–830, p. 823.

Van De Ven, A.H, Garud, R., Polley, D.E., Venkataraman, S. (1999): *The Innovation Journey,* Oxford University Press.

Weick K.E., Sutcliffe, K.M., Obstfeld, D. (2005): "Organizing and the Process of Sensemaking", *Organization Science*, Vol. 16, No. 4, July–August 2005, pp. 409–421

Weick, K.E. (1995): *Sensemaking in Organizations*. Thousand Oaks Cal.: Sage Publications.

Weick K.E. (1990): 'Technology as Equivoque: Sensemaking in New Technologies', in *Technology and Organizations*, Goodman, Paul S. and Sproull, Lee S., Jossey-Bass Inc. Publishers, San Fransisco.

Weick, K.E. (1979). *The Social Psychology of Organizing* (2nd edition), Reading, Mass. Addison Wesley.

Yin, R. (1989): *Case study research: Design and methods* (Revised edition), Newbury Park, CA: Sage Publishing.

9.2 Chapter 4

Andersen, O. (2006): Hydrogen som energibærer i transport. Hva kan vi lære av CUTE, ECTOS og HySociety? VF-notat 11/06, juni 2006 Internett: www.vestforsk.no

Andersen, K.G. & Yttri, G. (1997): Et forsøk verdt – Forskning og Utvikling i Norsk Hydro gjennom 90 år. Universitetsforlaget 1997.

Andreassen, K (1993): "Norwegian hydro energy in Germany (NHEG)", *International journal of hydrogen energy*", Vol. 18, N. 4, pp. 325-336, Elsevier Oxford.

Automarine as (1995): *Hydrogen som drivstoff i transportsektoren i Norge*. Oppdragsgiver: Oslo og Follo Busstrafikk A/S.

Automarine as (1995): *Hydrogen som miljøvennlig drivstoff i Oslo og Akershus*. Oppdragsgiver: Stor Oslo Lokaltrafikk, 6/12/1995.

Automarine as (1997): *Sluttrapport forprosjekt – hydrogen som miljøvennlig drivstoff I Oslo og Akershus*. Oppdragsgiver: Stor Oslo Lokaltrafikk, 21/1/97.

Bellona, Thomas Palm (2000): *Zero emission transport possible*, 7/11/2000, available at: http://www.bellona.no/en/energy/hydrogen/18247.html

Bundesministerium für Verkehr, Bau-und Wohnungswesten (2003): *Staying mobile with hydrogen: Clean Energy Partnership established a public hydrogen filling station in Berlin,* 25.11.2003, Berlin.
Clean Urban Transport for Europe, Detailed Summary of Achievements, p. 23.http://ec.europa.eu/energy/res/fp6_projects/doc/hydrogen/deliverables/summary.pdf.

Dagbladet (2000): *Bilrevolusjon*, 1.11.2000, http://www.dagbladet.no/nyheter/2000/11/01/225930.html

Department of Energy Hydrogen Program (2006): *Hydrogen Production,* http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_production.pdf , October 2006-

Dienhart, H. & Siegel A. (1994): "Hydrogen storage in isolated electrical energy systems with photovoltaic and wind energy", *Int. J. Hydrogen Energy*, Vol. 19, pp. 61-66.

Dunn, Seth (2001): *Hydrogen Futures: Toward a sustainable energy system*, Worldwatch Paper 157, August 2001, Jane A. Peterson, editior, World Watch Institute.

Elam C., C.E. Gregoire Padro, G. Sandrock, A. Luzzi, P. Lindblad, E.F. Hagen (2002): "Realizing the Hydrogen Future: International Collaborations to Advance Hydrogen Energy Technologies",
Proceedings 14th World Hydrogen Energy Conference, Montreal, June 9-13.

Elam, C. C.; Gregoire Padro, C. E.; Sandrock, G.; Luzzi, A.; Lindblad, P.; Fjermestad Hagen, E. (2003). "Realizing the Hydrogen Future: The International Energy Agency's Efforts to Advance Hydrogen Energy Technologies", *International Journal of Hydrogen Energy*, Vol. 28, 2003; pp. 601-607; NREL Report No. JA-560-34419.

Energy Development as (2000): *Vind-Hydrogen System for Utsira Havstuer*, Report commissioned by Norsk Hydro, Haugland Kraft AS, Utsira Kommune, December 2000.

Energy Development as (1999): *Hydrogen Energy Systems for Islands,* 13/9/1999.

EU Commission (2007): Joint Research Center Directorate-General Institute for Energy, Energy Systems Evaluation Unit , *Report on the Workshop on the contribution of hydrogen to reach European renewable energy target,* Environmental Science and Technology, ets , April 19, 2007, published Brussels, 29 May 2007

EU Commission Communication (2007) Limiting Global Climate Change to 2 degrees Celsius": an in relation to the EU's Climate Change Package, 10 January 2007: Brussels
http://www.europa-eu-un.org/articles/en/article_6666_en.htm

EU Commission (2001): Communication from the Commission to the European Parliament, the Council, The Economic and Social Committee and the Committee of the Regions on alternative fuels for road transportation and on a set of measures to promote the use of biofuels, Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the promotion of the use of biofuels for transport, COM(2001) 547 final, Brussels, 7.11.2001. http://eur-

lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2001:0547:FIN:EN:PDF
EU Commission (2000) Green Paper-Towards a European strategy for the security of energy supply / COM/2000/0769 final. 20/10/2000.
EU Commission (1997): White Paper: Energy for the future - renewable sources of energy - White Paper for a Community Strategy and Action Plan, COM(97)599 final (26/11/97) http://europa.eu/documents/comm/white_papers/pdf/com97_599_en.pdf
European Communities (2003) ftp://ftp.cordis.lu/pub/sustdev/docs/energy/sustdev_h2_european_fc_and_h2_projects.pdf
Folkevett (2000): *Framtiden kjører på hydrogen*, published by Framtiden i våre hender (The Future in our Hands), text by Kjetil Mygland, published online 19.09.2002, Folkevett 6-2000 http://www.justmake.no/kunder/folkevett/index.php?back=1&artikkelid=364
Glöckner R., Kloed C., Nyhammer F. and Ulleberg Ø. (2002): *Wind/Hydrogen Systems for remote areas – a Norwegian case study*, WHEC 2002 - 14th World Hydrogen Energy Conference, 9-13 June, Montreal.
Hanisch, Carola (1999): "Exploring options for Co2 capture and Management, *Environmental Science and Technology*, Vol. 33, Issue 3, pp. 66A-70A, copyright American Chemical Society.
Hanisch, Carola (1999): "Powering Tomorrow's cars", *Environmental Science and Technology*, November 1,1999/ Volume33, Issue21/ pp.458 A-462 A, Copyright © 1999 American Chemical Society
Hansen, A.M. & Haugerød, T. (2006): *Deliverable No. 3 Quality and Safety Methodology,* Clean Urban Transport for Europe Project-No. NNE5-2000-113 http://www.fuel-cell-bus-club.com/modules/UpDownload/store_folder/Publications/CUTE_D3_Quality_Safety.pdf
Hofmann, H. & Kreuter W. (1998): "Electrolysis: The Important Energy Transformer in a world of sustainable energy", *International J. Hydrogen Energy,* Vol. 23, No. 8, pp. 661-666.
Ivy, Johanna (2004): Summary of Electrolytic Hydrogen Production Milestone Completion Report http://www.nrel.gov/hydrogen/pdfs/36734.pdf
Hydro Annual reports (1998- 2002) available at http://www.hydro.com/
Kruse, B., Grinna, S., Buch, C. (2002): *Hydrogen – Status og muligheter,* Bellona rapport nr. 6, 2002.
Kvamsdal, H.M. and Ulleberg, Ø., (2000), "Hydrogensamfunnet – en nasjonal mulighetsstudie", SINTEF Energiforskning report TRA5197, ISBN No. 82-594-1811-8, May 2000. A project of the Norwegian R&D Ministry in the NYTEK-Programme, IFE, NTNU, SINTEF and UiO.
Larsen, O. & Ruud, A. (2005): HydroKraft: Mapping the innovation journey in accordance with the research protocol of CondEcol. Working Paper no. 3/05, ISBN 82-90391-46-3, ProSus 2005, www.prosus.uio.no

Ludwig Bölkow Systemtechnik, Strategy and technology consultants for sustainable energy and transport systems, http://www.lbst.de/about/LBST_Brochure_en.pdf

Mostad, H.B. (2004): Hydrogensamfunn i Norge? ESST-seminar 2004-10-21, Power point presentation.

NFR & NVE (2001): *Nye Fornybare Energikilder*, revised edition, produced by KanEnergi AS.

Nordic Innovation Centre (2005): "Hydrogen in the genes", pg. 10, in *Innovate* (2005:2), ISSN: 1503-9676, www.nordicinnovation.net

Norwegian Research Council (2000): Area Natural Science and Technology, Annual report part IV: Research Institutes- Report from technical-industrial institutes. Available at http://www.forskningsraadet.no

Norsk Hydro Electrolysers Annual Accounts from 1999-2002 Brønnøysundregistrene, http://www.brreg.no

Norwegian Research Council (2000): Area Natural Science and Technology, Annual report part IV: Research Institutes- Report from technical-industrial institutes. Available at http://www.forskningsraadet.no

Norsk Hydro ASA, IFE, NTNU, MARINTEK, Vegdirektoratet, Ecotraffic Norge AS (2001): *Hydrogen and Fuel Cells in Ferryboats*, a feasibility study by The H_2-Ferry Project.

NOU (2004): Norwegian Official Report, "Hydrogen as the Energy Carrier of the Future", 2004:11

Overvik, T. (2004): *Technological foresights concerning - Hydrocarbons,* Statoil presentation by Terje Overvik, CAETS/NTVA Global Energy Foresights, 26-27 May, Stavanger.

ProSus (2005): *Exploring the Conditions for Adapting Existing Techno-Industrial Processes to Ecological Premises*, *HydroKraft: Mapping the innovation journey in accordance with the research protocol of CondEcol*, Working Paper no. 3/05

Ramback, G. & Haberman, David (1997): *Renewable, Hydrogen-based Energy for Isolated Communities Worldwide,* Spring Newsletter NHA News http://www.hydrogenassociation.org/advocate/ad22isol.htm

Rasten, Egil (2004): PEM electrolysis development at Hydro, power point presentation, 26.5.2004.

Rasten, Egil (2003): Vannelektrolyseprosess, Porsgrunn 30. juni – 2003, power point presentation.

Rasten, Egil (2001) Electrocatalysis in water electrolysis with solid polymer electrolyte. PhD thesis, Department of Materials Technology and Electrochemistry, Norwegian University of Science and Technology, Trondheim

Riis, Trygve, Hagen, Elisabet F., Vie, Preben J. S., Ulleberg, Øystein (2005): *Hydrogen Production - Gaps and Priorities,* HIA_HCG_Production_2005-03-15_rev1_final.doc, IEA Hydrogen Implementing Agreement (HIA).

StatoilHydro (2007): *StatoilHydro – a long experience with hydrogen*, available at http://www.electrolysers.com/ About us: publication: hydrogen.

Stor-Oslo Lokaltrafikk Environmental report (2001a): *Environmental report*, http://www.slnett.no/Documents/rapporter/miljø/Miljorapport_2001.pdf

Stor-Oslo Lokaltrafikk a.s. (2001b): *Med framtiden i tankene…,* Hydrogenbussprosjektet i Oslo Fase: 1999–2000, draft brochure, 30.03.01, prosjektleder Solveig Martinsen i SL.
Stor-Oslo Lokaltrafikk a.s. (1999): *Med Miljøansvaret i tankene, Hydrogenbusser – transport uten forurensning*, Stor-Oslo Lokaltrafikk, Hydro, Daimler Chrysler, Bertel O. Steen.
Stor-Oslo Lokaltrafikk (SL) Environmental report (1997): *Environmental report*, http://www.slnett.no/Documents/rapporter/miljø/Miljorapport_1997.pdf
Stor-Oslo Lokaltrafikk (1999): *Med miljøansvaret i tankene – Hydrogenbusser – transport uten forurensning.*
Sund, Bjørn Arne (1998)*: Utvikling av hydrogenkraft (HydroKraft*), Energi for fremtiden, konferanse rapport 7-8 mai 1998, Oslo, Cicero, red. Øystein Dahle.
The German federal Ministry of Transportation: *Fuel of the Future / Transport Energy Strategy,*http://www.bmvbs.de/en/dokumente/-,1872.9979/Artikel/dokument.htm
TÜV brochure (2003): *Hydrogen - a world of energy*, TÜV Süddeutschland Holding AG s, July.

9.2.1 Internet pages

http://www.co2captureproject.org
http://cordis.europa.eu/data/PROJ_FP5/ACTIONeqDndSESSIONeq112362005919ndDOCeq
http://www.daimlerchrysler.com/Projects/c2c/channel/documents/102771_broschure_e.pdf. Karl-Heinz Schlaiss, Fuel Cell Technology for transportation, Engineering and Technology for Sustainable Development, August 28, 2002
http://www.daimler.com/
http://dwv-info.org/e/news/mirror/wss/wse991.htm#Island, Hydrogen Mirror 1/99
http://dwv-info.org/e/news/mirror/wss/wse983.htm#Island, Hydrogen Mirror 3/98
http://dwv- info.org/e/news/mirror/wss/wse976.htm#Islandprojekt Hydrogen Mirror 6/1997
http://www.electrolysers.com
http://ec.europa.eu/energy/res/fp6_projects/doc/hydrogen/deliverables/summary.pdf.
http://ec.europa.eu/research/fch/pdf/hlg_vision_report_en.pdf
http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_hlg/article_1146_en.htm
http://www.fair-pr.com/h2fair/e/hm01-exhibitors/norsk.html
http://www.fair-pr.com/other/hm96/impressions.php Hannover Fair´96
http://www.fair-pr.com/hm02/exhibitors/hydro.html
http://www.fair-pr.com/hm02/forum/electrolysers.html.
http://www.ghw-mbh.de/english/06_print/index.html Gesellschaft für Hochleistungselektrolyseure*zur Wasserstofferzeugung mbH (GHW)*
http://www.hydro.com: *Hydrogen - fuel of the future*
http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2003/November/17290/
http://www.hydro.com: Rostrup, Jørgen, “YES to renewable energy - It's difficult to imagine a serious energy company not getting involved in renewable energy" (2003-05-09)

http://www.hydro.com/en/Pressroom/News/Archive/2003/September/16385/
http://www.4.hydro.com/electrolysers/library/attachments/Brochures/49444_Product sheet_1.PDF, High Pressure Electrolysers, Company Production Sheet
http://www.hydro.com: *Hydrogen - fuel of the future*
http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2003/November/17290/
Hydro Electrolysers: Hydrogen starts with ... 5/12/2003
http://www.hydro.com/en/Press-oom/News/Archive/2003/November/17290/
Looking ahead to the future, November 5, 2003
http://www.hydro.com/en/Pressroom/News/Archive/2003/September/16385/
http://www.hydro.com/en/Press-room/News/Archive/2003/May/16338/Yes to renewable energy, May 9, 2003
http://www.hydro.com/en/Press-room/News/Archive/2002/April/16134/
http://www.hydro.com *Hydrogen - fuel of the future*
http://www.hydro.com/en/Press-room/News/Archive/2002/April/16134/ "Time right for hydrogen"
http://www.fair-pr.com/h2fair/e/hm01/kongress-print.html
http://www.ieahia.org/pdfs/2001_annual_report.pdf ,
http://www.ieahia.org/pdfs/2002_annual_report.pdf
http://www.hyweb.de/index-e.html
http://www.hyweb.de/Politics/bavaria.htm#With%20new%20energy%20into%20the%20future%201997 26/6/1997.
http://www.lbst.de/gm-wtw
http://www.netinform.net/H2/Aktuelles_Detail.aspx?ID=2503
http://www.netinform.net/H2/Aktuelles_Detail.aspx?ID=2599 (26.06.1997)
http://www.netinform.net/H2/ GM 12/1/1998 and Toyota 30/10/97
http://www.netinform.net/H2/Aktuelles_Detail.aspx?ID=2527
http://www.windpower.org/da/pictures/lacour.htm

9.2.2 Interviews

Bjørn Arne Sund 02.02.2005
Christopher Kloed 13. 01.2005
Egil Rasten 21.09.05
Elisabet Fjermestad Hagen 13.1.2005
Helle Britt Mostad 18.11.2004
Klaus Schöffel 21.09.05
Vera Ingunn Moe 04.07.2007
Ove Christian Bugge 20.05.2008

9.3 Chapter 6

Adresseavisen Morgen (2004): *Fra fossefall til ørkensol,* 20/12/2004, p. 11.
Aftenbladet (2004): *Koker på grønn energi*, 2/7/2004.
Aftenposten E24 (2004): *Mr Chelski ser på norsk hydrogenprosjekt,* 22/6/2004.
Aftenposten (2004): *Vinden blåser liv i Utsira igjen*, 2/7/2004, p. 2.
Aftenposten (2004): *Hydro-pris for satsing i havgapet*, 14/12/2004, p.10.
Aftenposten Amagasinet (2006): *Tilbake til fremtiden*, 6/10/2010,p. 40.

Aldrich, Howard E. (1999): *Organizations Evolving*, Sage Publications.
Bergens Tidende (2004): *Utsira først inn i hydrogenalderen*, 2/7/2004, p. 7
Bergen Tidende (2005): *Hydrogen, bensin, og annet snop,* 26/2/2005, p. 33.
Dagsavisen Morgen (2004): *Hydro melder mer vind,* 29/8/2004, p. 10
Dagens Næringsliv (2005): *Kjemper med vindmøller*, 6/8/2005, p. 38.
Drucker, P.F. (1964): "The Big Power of Little Ideas," *Harvard Business Review*, 42 (May 1964), pp. 6-8
Dunn, Seth (2001): *Hydrogen Futures: Toward a Sustainable Energy System*, August, published by World Watch Institute paper 157.
Energy Daily (2008): "Norwegian island runs on wind power, even when all is still", Utsira, Norway, Agence France-Presse (AFP) May 13, 2008.
Eide P.O. & Moe V.I. (2004): *Realizing the wind-hydrogen project at Utsira,* power point 16.1.2004
Eide P.O, Fjermestad Hagen, E., Kuhlmann M., Rohden R. (2004): *Construction and commissioning of the Utsira Wind / Hydrogen Stand-alone Power System*, EWEC 2004, London, November 2004 http://www.2004ewec.info/files/25_0900_paleide_01.pdf
Energy Development as (2001): *Feasibility Study Wind-Hydrogen System at the island of Røst, Norway*.
Energy Development (2000): *Vind-Hydrogen System for Utsira Havstuer*, prepared by Energy Development for Norsk Hydro, Haugeland Kraft AS, Utsira Kommune, December 2000.
Energy Development as (1999): *Hydrogen Energy Systems for Islands,* 13.9.1999.
Energy Development as (1999): *Vind-Hydrogen System på Orten*, Juni 1999
European Commission (2007a): *Report on the Workshop on the contribution of hydrogen to reach European renewable energy targets,* European Commission Joint Research Center Directorate General, Brussels 29. May 2007
European Commission (2007b): *Report on the Hearing of the Hydrogen and Fuel Cells European Technology Platform,* European Commission Joint Research Center Directorate General, Brussels 15. May 2007.
Fjermestad Hagen E. (2007): *The Utsira project*, Hydro, Norway, http://www.europeanislands.net/docs/Utsira_Project.pdf
Fjermestad Hagen, E., Hanssen J.E, (2006): *Renewables and hydrogen – functional synergies*, The European Hydrogen and Fuel Cell Technology Platform – Initiative Group on Financing & Business Development, April 2006
EU HFP / EU Hydrogen and Fuel Cell Technology Platform Business (2006): *Key Outcomes of the Business development Subgroup work conducted between June 2004 and March 2006*, HFP Business Development Subgroup Final Summary – 17 March 2006 https://www.hfpeurope.org/uploads/1169/2150/Appendix_5_Final_Renewables_and_H2.pdf
Fjermestad Hagen E, Hexeberg I, Nakken T. (2005a): *Renewable energy systems.* 18th World Petroleum Congress, Johannesburg, South Africa, 25-29 September 2005

Fjermestad Hagen E, Øvrebø D, Hexeberg I. (2005b): *Hydrogen with renewable energy systems*, International Hydrogen Energy Congress (IHEC) 2005, Istanbul, Turkey, July 13 - 15, 2005 http://www.ichet.org/ihec2005/files/manuscripts/Elisabet%20Fjermestad%20Hagen-Norway.pdf

Glöckner, R., Kloed, C., Nyhammer, F., Ulleberg, Ø. (2002): *Wind / Hydrogen systems for remote areas, a Norwegian case study*, Proc. Of WHEC 2002 – 14th World Hydrogen Energy Conference, Montreal, 9-14 Jun. 2002 http://www.hydrogems.no/references/Glockner_etal_Abstract_WHEC_2002.pdf

Haugesunds Avis (2004): *Ordførerens store dag*, 2/7/2004

Haugesunds Avis (2004): *Utsira i verdensvinden*, 17.6.2004

Haugalandrådet (2007): *Sakspapir AU møte Haugalandrådet,* Haugalandet-Satsing på Fornybar Energi, 30/8/07 http://www.haugalandradet.no/dokumenter/38-07b_AU_refsak_Fornybar_220807.pdf

Haugaland Kraft & Hydro Energi (2002): *Konsesjonssøknad for Utsira vind-hydrogen prosjekt*, 15/11/2002.

Hexeberg, I. (2005): *Utsira Wind Hydrogen System*, Presentation at the Hydrogen Technology and Fuel cell Platform March 2005.

Hüttner, Tobias (2004): *Utsira and similar wind-hydrogen systems from a modelling perspective*, Hydro Oil and Energy Research Centre in Porsgrunn, 15-11-2004.

Hydro Inside (HI Hydro Innside) (2006): The global magazine for Hydro Employees – no.1, 2006:36

Hydro (2005): Hydro's Engagement in New Energy, 12.4.2005

Hydro (2004): Annual Report, http://www.hydro.com/upload/Documents/Reports/Annual%20reports/hydro_annual_report_2004_en.pdf

Hydro (2003): Vind-hydrogen-prosjektet Folkemøte, Utsira 16. september 2003

IEA Hydrogen Implementing Agreement (2005): Oppsummering fra IEA Hydrogen Implementing Agreement møte På Utsira 10-12. mai 2005, http://www.iea.no/oslo/iea-norge.nsf/Attachments/DBEB18390EE29D3CC12570C100762045/$FILE/Referat+fra+Utsira22052005.doc

International Research Institute og Stavanger (2008): Vestlandet som ledende miljøvennlig energiregion, Rapport IRIS - 2008/176, 05.09.2008

Isherwood W., Smith J.R., Aceves S.M., Berry G., Clark W., Johnson R., Das D., Goering D., Seifert R.(2000): "Remote power systems with advanced storage technologies for Alaskan villages", Energy, Volume 25, Number 10, October 2000 , pp. 1005-1020(16), Elsevier

Jacobsen, Søren (2006): Final project report 10 kWe PEM Fuel Cell generator for the Utsira project, 2/4/2004 – 30/6/2006, Project identification: PSO-Eltra 5449, Document no. UtsiraFCG10kW-REP-00-00-00-05, 12/9/2006 http://www.risoe.dk/rispubl/NEI/nei-dk-4955.pdf

KanEnergi (2001): *Nye fornybare energikilder*, published by the Research Council of Norway and the Norwegian Water Resources and Energy Directorate.

Lovins Amory B. (2003): *Hydrogen: the future of energy*, Rocky Mountain Institute Quest for Solutions (RMIQ) Public Lecture Given Institute, Aspen, Colorado, 6 August 2003, http://www.rmi.org/images/PDFs/Energy/E03-15_H2FutureOfEnergy.pdf

Moe, Vera I. & Eide Pål O. (2004): *Realizing the wind-hydrogen project at Utsira*, power point presentation 16-1-2004.

Myklebust Egil, Norsk Hydro ASA (2004): *An industry perspective on Energy and the Climate Challenge*, the Jubilee Conference for the Programme of Industrial Ecology, NTNU, Trondheim, 31. March 2004 http://www.indecol.ntnu.no/indecolwebnew/events/conferences/jubilee/presentations/Egil_Myklebust_IndEcol_31032004.pdf

Myklebust, Egil (2002): *Balancing the petroleum business and its social responsibility: Enhancing reputation and increasing competitive edge* Myklebust, Egil Chairman of the Board, Norsk Hydro ASA, Plenary Session speech WPC 17. http://www.hydro.com/en/Press-room/News/Archive/2002/September/16212/ http://www.world-petroleum.org/isc2004/File%20026/170_171_172_173_174.pdf

Nakken, Torgeir (2008): *Experiences from the wind-hydrogen plant at Utsira*, Hydrogen and Fuel Cells Conference at the University of Birmingham, (April 2008), http://www.fuelcells.bham.ac.uk/documents/14Nakken.pdf

Nakken, Torgeir (2007): *Utsira wind and hydrogen – whats next?*, Presentation at Energy from the Edge symposioum 12-13/9, 2007. http://www.nordicenergy.net/_upl/utsira_wind_and_hydrogen-whats_next_torgeir_nakken_(hydro_oil_and_energy_research).pdf

Nakken T., Strand L.R., Frantzen E., Rohden R., Eide P.O (2006a): *The Utsira wind-hydrogen system – operational experience*, European Wind Energy Conference (EWEC) Athens, Febr/Mar. 2006.

Nakken T., Frantzen E., Hagen E.F., Strøm H. (2006b): *Utsira – demonstrating the renewable hydrogen society*, World Hydrogen Energy Conference 16, Lyon France, June 2006.

Nakken, Torgeir (2006): *Utsira wind-hydrogen system: Lessons Learned,* Hydro Oil and Energy Research Centre, http://www.europeanislands.net/docs/Conference/TorgeirNakkenUtsira.pdf

Nyhammer F., Glöckner R., Eide P.O., Berg E., Førde, E. (2003): *Design and Optimisation of A Wind / Hydrogen Autonomous Power Systems on a Norwegian Island*, European Wind Energy Conference (EWEC), Madrid.

Pedersen J., Eriksen PB., Eltra (2005): *Long term Perspective on Applying Hydrogen as an Energy Carrier in Power and Energy Systems with a Large Share of Wind Power*", presented at the Fifth International Workshop on Large-scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, April 2005, Glasgow.

Reese, Michael (2007): W*ind to hydrogen to ammonia*, E3 2007 Conference, November 27, 2007, http://www1.umn.edu/iree/e3/e32007recap/presentations/reese_e3_2007.pdf
Reiten, Eivind (2005): Corporate governance – the factors that influence the image of the industry, World Petroleum Congress, Johannesburg, September 2005 http://www.hydro.no/library/attachments/en/press_room/wpc05_er_speech.pdf, http://www.hydro.com/en/Press-room/News/Archive/2005/September/16848/
Reiten, Eivind (2005): *Unlockin the world's energy potential*, OECD FORUM 2005 FUELLING THE FUTURE: Security, Stability, Development http://www.oecd.org/dataoecd/42/32/34825958.pdf http://www.oecd.org/document/51/0,3343,en_21571361_34225293_34822579_1_1_1_1,00.html
Renergi: Årsrapport 2007 Renergi (2004-2013) http://www.forskningsraadet.no/no/Nyhet/Hoydepunkter+i+RENERGI+2007/1208964101157
Renewislands (2005): *RENEWISLANDS Newsletter no. 2,* February 2005, http://www.rgesd-sustcomm.org/RenewIslands/ , (http://www.islenet.net)
Rogaland Fylkeskommune (2003): Møteinnkalling, Regional- og Kulturutvalget, 5/2/2003, Saksliste (Konsesjonssøknad for Utsira Vind- og Hydrogenanlegg Høringsuttalelse), http://152.93.253.10/innsyn/index.php?cmd=mdoc%20POSTKASSE%200300189501.
Rostrup, Jørgen C Arentz (2007): *A climate friendly energy policy – business opportunities for Norway*, Vinterkonferansen 15/3/2007 *StatoilHydro- a long experience with hydrogen*.
Teknisk Ukeblad Magasin, 11. 6.2009
Teknisk Ukeblad Magasin, 28.5.2002
Teknisk Ukeblad Magasin 29.11.2005 'Energientusiast i vinden'
Teknisk Ukeblad Magasin 19.8.2004:99 'Hydrogen Samfunnet er her'
Teknisk Ukeblad Magasin 22.4.2004:99 'Hydrogenkraft i gang'
Teknologirådet (2005): *Bærekraftig innovasjons- og teknologipolitikk*, rapport 2 april 2005, ISBN 82-92447-04-0, published by Teknologirådet
Varden (2004): *Tilfeldigheter skapte unikt energiprosjekt*, 18.7.2004
VG (2006): *Miljø-slik blir Samsø selvforsynt, Dansk øy dropper oljen,* 23/9/2006
Windblatt - The Enercon Magazine (2004): *Independent energy supply with ENERCON stand-alone systems*, Issue 5, pp.14-15, http//www.enercon.de
Windblatt - The Enercon Magazine (2003): Issue 5, pp. 6-7.

9.3.1 Internet pages

http://www.aftenposten.no/nyheter/okonomi/article815002.ece 22. juni 2004 kl.18:36
http://www.associated press.com (2004): *Wind-blown Norwegian island being used to test new clean energy system*, April 28, 2004

http://www.bellona.no/bellona.org/english_import_area/energy/hydrogen/18283, *Norwegian Hydrogen Projects*, Bellona, 08/11-2000,
http://www.bt.no 17.11.03, page 8, "Fornybar revolusjon på Utsira"
http://circa.europa.eu/Public/irc/rtd/eurhydrofuelcellplat/library?l=/publicsarea/advisoryscouncil/acslists121203pdf/_EN_1.0_&a=d
http://circa.europa.eu/Public/irc/rtd/eurhydrofuelcellplat/library?l=/publicsarea/initiative_development/jg_fbd_-_torpdf/_EN_1.0_&a=d
http://www.dn.no (2003): *Tester ny vindkraft,* 17/7/03, p. 14.
http://www.enercon.de/en/_home.htm
http://ec.europa.eu/research/rtdinfo/42/01/article_1316_en.html
http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_hlg/article_1146_en.htm02
http://ec.europa.eu/research/fch/pdf/hfp-sra004_v9-2004_sra-reportfinal_22jul2005.pdf#view=fit&pagemode=none
http://ec.europa.eu/research/fch/pdf/hfp_ds_report_aug2005.pdf#view=fit&pagemode=none
http://www.energy-daily.com/reports/Norwegian_island_runs_on_wind_power_even_when_all_is_still_999.html
http://www.enviweb.cz/?env=obecne_archiv_ejcfj&print=true Lighting the way for the hydrogen society, 19.7.2004
http://www.europeanenergyforum.eu/archives/european-energy-forum/gas-matter/visit-to-iceland-sustainable-energy-use
http://ec.europa.eu/research/fch/index_en.cfm
http://www.europeanenergyforum.eu/upload/dv20050528-hexeberg
http://www.forskningsraadet.no REELYPEM (Hydrogen Production from Renewable Energy Prototyping and Field Testing of a PEM Electrolyzer), project period 01.01.2006 – 31/12/2007, Project number:174080
http://www.forskningsraadet.no/servlet/Satellite?c=Prosjekt&cid=1193731614452&pagename=ForskningsradetNorsk/Hovedsidemal&p=1181730334233
http://www.fuelcells.bham.ac.uk/documents/14Nakken.pdf
http://www.haugalandradet.no/dokumenter/38-07b_AU_refsak_Fornybar_220807.pdf,
http://www.haugesunds-avis.no/apps/pbcs.dll/article?AID=/20060516/NYHET/60516003, *Morten Harket til Utsira,* 16/5/2006
http://www.haugesunds-avis.no/apps/pbcs.dll/article?AID=/20060519/NYHET/60519002 Harket i vinden 19/5/2006
http://www.h2fc.com/reframe.php?top=/global/news.shtml&bot=/news/arch2003.shtml Utsira - a Vision of a New Energy Society, 12/2/2003
http://www.haugalandradet.no/dokumenter/190608/Sak%2014-08%20Fornybar%20energisatsing%20for%20regionen.doc
http://www.haugalandradet.no/dokumenter/38-07b_AU_refsak_Fornybar_220807.pdf,
http://www.h2fc.com/reframe.php?top=/global/news.shtml&bot=/news/arch2003.shtml
https://www.hfpeurope.org/uploads/699/808/UTSIRA.pdf
https://www.hfpeurope.org/hfp/hfp-annual-event_17mar2005

http://www.hsaps.ife.no/Reports/HSAPS%20Publishable%20summary.pdf
http://www.hydro.com/en/Press-room/News/Historic-news-archive/2007/06/17226/ *Utsira shows the way to climate solutions*
http://www.hydro.com/en/Press-room/News/Archive/2006/May/16980/ *Morten Harket visits Utsira hydrogen facility*, 24/5/2006
http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2006/April/15492/,
http://www.hydro.com/library/attachments/en/press_room/inergon_folder.
http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2005/November/16889/ *Hydro continues Utsira Project*, 25/11/2005
http://www.hydro.com/en/Press-room/News/Archive/2005/April/16754/ *Open House at Utsira*, 26/4/2005
http://www.hydro.com/en/Press-room/News/Archive/2004/December/16699/ *The best this year in renewable energy*, 13/12/2004
http://www.hydro.com/library/attachments/en/press_room/utsira_facts_inauguration_1july2004.pdf*, Utsira wind power and hydrogen plant, Inauguration*, 1/7/2004
http://www.hydro.com: *Winds of change blow on Utsira's opening day*, 1/7/2004
http://www.hydro.com/en/Press-room/News/Archive/2004/July/16614/
http://www.hydro.com/en/Press-room/News/Archive/2004/April/17297/ *Key information on the Utsira project*
http://www.hydro.com/en/Press-room/News/Archive/2003/September/16403/ *Utsira – a hydrogen community show room,* 11/9/2003;
http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2003/November/17290/ *Looking ahead to the future*, 5/11/2003
http://www.hydro.com/en/Press-room/News/Archive/2003/May/16340 *Hydrogen society on the island of Utsira*, 9/5/2003
http://www.hydro.com/en/Press-room/News/Archive/2003/May/16338/ *Yes to Renewable Energy*, 9/5/2003
http://www.hydro.com/en/Press-room/News/Archive/2002/September/16212/ *Myklebust key speaker on sustainability in Rio*, Sep. 4, 2002,
http://www.hydro.com/en/Press-room/News/Archive/2002/April/16145/
http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2002/Oktober/14631/10. okt. 2002 *Utsira vekker interesse i Hamburg*
http://www.hydro.com/en/Press-room/News/Archive/2002/August/16193/ *Reiten calls on youth at ONS*, 27.8.2002
http://www.hydro.com/en/press_room/features/utsira lighthouse.html
http://www.hydro.com/en/Press-room/News/Archive/2002/April/16145/*Utsira attracts attention in Hannover* published 16.4.2002, http://www.live-fair.com/hm02/exhibitors/hydro.htm
http://www.ieahia.org/pdfs/1999_annual_report.pdf
http://www.iea.no/oslo/iea-norge.nsf/Attachments/DBEB18390EE29D3CC12570C100762045/$FILE/Referat+fra+Utsira22052005.doc
http://www.live-fair.com/hm02/forum/hydro.html
http://www.fair-pr.com/hm04/exhibitors/norsk-hydro-asa.php
http://lokal.utsira.kommune.no/siralappen/2007/microsoft-word-siralappen-nr-10.pdf,
http://lokal.utsira.kommune.no/siralappen/2007/microsoft-word-siralappen-nr-11.pdf.

http://www.managenergy.tv/metv/portal/_vi_real_300_de/index.html?showSlides=true&search=torgeir+nakken+&submit=go
http://www.prosessindustrien.no/print.asp?menu=6&id=4408
http://www.oecd.org/site/0,3407,en_21571361_34225293_1_1_1_1_1,00.html
http://sites.google.com/site/wwwfreedomfertilizercom/
http://www.spv.no/Om-Sparebanken-Vest/Vi-satser-pa-Vestlandet/Vestlandskonferansen/Vestlandskonferansen2008/~/media/88B6E2D7A35E4838BED68E7B2F8FF666.ashx
http://www.statoilhydro.com (2007): *The first hydrogen society*, published 28.11.2007
http://www.statoilhydro.com/en/NewsAndMedia/Multimedia/features/Pages/HydrogenSociety.aspx
http://www.statoilhydro.com/no/NewsAndMedia/News/2001/Pages/BlikketVendtMotUtsira.aspx
http://www.tu.no/innsikt/energi/article212860.ece "Storing energy from renewable energy sources", published: 10.06.2009
http://www.tu.no/nyheter/bygg/article4136.ece *Hydrogenøya Røst: Vindkraft kombinert med brenselcelle kan bli alternativet til å legge ny sjøkabel*, published 14.12.2000
http://www.tu.no/nyheter/energi/article21995.ece, *Hydrogensamfunn i havgapet*, 12.5.2003
http://turist.utsira.kommune.no/historie/dfdfdff?set_language=en&cl=en
http://turist.utsira.kommune.no/severdigheter/hydro/historie/view?searchterm=hydrogen
http://www1.umn.edu/iree/e3/e32007recap/presentations/reese_e3_2007.pdf
http://windnh3.blogspot.com/2008/04/blog-post.html
http://www.world-petroleum.org/publications/handbookold.htm The Utsira project aims to make a small island community energy self-sufficient, 2002
http://www.world-petroleum.org/isc2004/File%20026/170_171_172_173_174.pdf

9.3.2 Interviews

Ivar Hexeberg 16.11.2004
Bjørn Arne Sund 2.2.2005
Christopher Kloed 13.1.2005
Christopher Kloed 8.9. 2005
Dag Roar Christensen 8.10.2004
Dag Roar Christensen 20.6.2006
Elisabet Fjermestad Hagen 13.1.2005
Elisabet Fjermestad Hagen 14.3.2005
Elisabet Fjermestad Hagen 20.6.2006
Elisabet Fjermestad Hagen 13.2.2007
Elisabet Fjermestad Hagen and Torgeir Nakken 26.3.2007
Helle Britt Mostad, 18.11.2004
Klaus Schöffel 21.9.2005
Pål Otto Eide 9. 6. 2005
Sjur Bratland, 5.7.2007
Søren Jacobsen, IRD, 27/10/04.

Vera Ingunn Moe, 4.7.2007
Torgeir Nakken, 28.8.2007

9.4 Appendix I Hydrogen in the making

Abernathy, William J. & Clark, Kim: "Innovation – Mapping the winds of creative destruction" *Research Policy*, 14 (1985) pp. 3-22

Bellona (2002): *Hydrogen Status og muligheter,* Bellona report no. 6, Kruse, Bjørn, Grinna, Sondre & Buch, Cato

Biegler, Tom (2005): "The Hydrogen Economy", *the Skeptic*, Spring 2005, pp. 25-29.

Bossel, U., Baldur Eliasson (2003/2005): *The Future of the Hydrogen Economy: Bright or Bleak?*Original Version of 15 April 2003 updated 26 February 2005, http://www.efcf.com/reports/E08.pdf

Dunn, Seth (2001): *Hydrogen Futures: Toward a sustainable energy system*, Paper 157, August, World Watch Institute.

Dutzik, Tony (2004): *Making Sense of Hydrogen The Potential Role of Hydrogen in Achieving a Clean, Sustainable Transportation System* Copyright © 2004 Environment California Research and Policy Center

Eggert Anthony et al (2005): Hydrogen and Fuel Cells – Refining the Message - Refining the Message Initiating a national dialogue and educational agenda, presented at the National Hydrogen Association (NHA) Annual Hydrogen Conference, "Partnering for the Global Hydrogen Future", Washington, DC, March 29 – April 1, 2005. (Authors from the Institute of Transportation Studies Hydrogen Pathways Program University of California, Davis).

EurActiv.com (2006): *Hydrogen and fuel cells: fake promises?* Published: Thursday 26 October 2006, http://www.euractiv.com/en/transport/hydrogen-fuel-cells-fake-promises/article-159235

European Commission (2007): *Report on the Workshop on the contribution of hydrogen to reach European renewable energy targets*, Brussels, 29 May 2007, Joint Research Center Directorate General. Institute for energy systems' evaluation unit.

European Commission (2003): *Hydrogen energy and fuel cells, Final report of the High Level Group,* EUR 20719 EN, ISBN 92-894-5589-6.

European Commission (2002): *Staff: Working Paper Security of supply - The current situation at European Union level*, 14-11-2002, European Commission (2001): *Commission adopted a communication on a European strategy for sustainable development*, COM (2001) 264 final, May 15th, 2001.

European Commission (2000): *Green Paper: Towards a European Strategy for the Security of Energy Supply,* adopted by the European Commission on 29 November 2000 (COM(2000) 769 final.http://ec.europa.eu/comm/energy_transport/doc-principal/pubfinal_en.pdf

European Hydrogen and Fuel Cell Technology Platform (2006): *Renewables and hydrogen – functional synergies*, Initiative Group on Financing and Business Development, Discussion paper, April 2006

STOA/ ETAG European Technology Assessment Group (2007): ”Alternative Technology Options for Road and Air Transport”, *EUROPEAN PARLIAMENT Scientific Technology Options Assessment STOA report*, February.

FuelCell Works (2002): *Hydrogen: Fuel of the future*, The Journal Editorial Board, DEC/31/02 http://www.fuelcellsworks.com/Archives/December2002.html

Fuel Cell Today (2002): *Fuel Cell Systems: a survey of worldwide activity*, 14 November 2002. http://www.fuelcelltoday.com

Riis, Trygve, Hagen, Elisabet F Preben J. S. Vie, Øystein Ulleberg (2005): *Hydrogen Production - Gaps and Priorities,* HIA_HCG_Production_2005-03-15_rev1_final.doc, IEA Hydrogen Implementing Agreement (HIA).

Hydrogen Fact Sheet series – Safety - The National Hydrogen Association and Dept. of Energy. http://www.hydrogenassociation.org/

Hydrogen Fact Sheet series - Renewable hydrogen production using lectrolysis, http://www.hydrogenassociation.org/

Hydrogen Association (2000): PBS Series Features Hindenburg. http://www.hydrogenassociation.org/Advocate/ad52zepp.htm

Hydrogen Horizons (2007): *What is happening in hydrogen,* Issue , September.

Klassekampen (2007): “Takk, begge deler”, Åse Brandvold, 24.01.2007.

Klassekampen (2007): “Dropp planene”, Åse Brandvold, 22.01.2007.

Lash, Jonathan (2003): “Hydrogen”, Environmental Stories to watch in 2004 December 22, 2003. http://www.wri.org/publication/environmental-stories-watch-2004#

Lovins, Amory (2003): *Twenty Hydrogen Myths*, http://www.rmi.org/rmi/Library/E03-05_TwentyHydrogenMyths

Lovins, Amory B., Lovins L. Hunter (2002): ”Energy Forever”, *The American Prospect* 13(3):30–34, 11. February, www.prospect.org

National Renewable Energy Laboratory (2003): *The Next Generation Natural Gas Vehicle Activity*, U.S. Department of Energy, DOE/GO-102003-1779, September 2003.

Ogden Joan (2007): “Prospects for hydrogen energy”, Nobel Conference *Heating Up:The Energy Debate*, October 3. 2007.

Ogden Joan & Sperling Daniel (2006a): *The Bumpy Road to Hydrogen*, World Hydrogen Energy Conference, Lyon, France, June 15, 2006

Ogden, Joan (2006b): “High hopes for HYDROGEN”, *Scientific American,* Sep. Vol. 295, Issue 3, pp. 94-101.

Ogden, Joan & Sperling Daniel (2004): ”The Hope for Hydrogen” , *Issues in Science and Technology*, Spring 2004, pp. 82-86

Ogden, Joan (2004b): Hydrogen as an Energy Carrier: Outlook for 2010, 2030 and 2050 Ogden, Joan, "Hydrogen as an Energy Carrier: Outlook for 2010, 2030, and 2050," Proceedings of "The 10-50 Solution: Techonologies and Policies for a Low-Carbon-Future" Workshop, The Pew Center on Global Climate Change, and the National Commission on Energy Policy.

EU project (2006): *Preparing for the hydrogen economy by using the existing natural gas system as a catalyst (NATURALHY)*, December 2006 http://www.naturalhy.net/docs/Strategic_justification_NATURALHY.pdf
Physicsweb (1998): *Fuel Cells: power for the future*, http://physicsweb.org/articles/world /11/8/11
Rifkin, Jeremy (2003): “The hydrogen economy- after oil, cleanenergy from a fuel cell driven global hydrogen web”, *E / The Environmental Magazine*, Jan 01’03.
Santa Barbara News Press (2008): “Hydrogen study fuels possibilities”, Tom Avril, January 18, 2008, http://www.newspress.com
Smith, B. (2001): “Beyond ICE - Fuel cells may make the internal combustion engine obsolete - Brief Article - Statistical Data Included”, *Automotive Manufacturing & Production*, May, 2001
Tushman, Michael L. & Anderson Philip (1986): “Technological Discontinuities and Organisational Environments”, *Administrative Science Quarterly, Vol. 31, Issue 3, pp.439-465*
G.C. Unruh, Understanding carbon lock-in, Energy Policy 28 (12) (2000) 817–830.
US Fuel Cell Council: *Fuel Cells: Residential Applications*, 08/04 http://www.usfcc.com/about/Fuel_Cells_for_Residential.pdf
US Fuel Cell Council:: *Fuel Cells: Stationary Power - Industrial Applications,* 07/04 http://www.usfcc.com/about/Fuel_Cells_for_Industrial_Applications.pdf
US Fuel Cell Council: *Fuel Cells: Portable Power Applications,* 09/04 http://www.usfcc.com/about/Fuel_Cells_for_Portable_Applications.pdf
US Fuel Cell Council: *Fuel Cells: Transportation Applications*, 07/04m http://www.usfcc.com/about/Fuel_Cells_in_Transportation.pdf
Utterback, James M. & Abernathy, William J. (1975): “A Dynamic Model of Process and Product Innovation” in OMEGA*, The Int. Jl of Mgmt Science*., Vol.3, No.6, Pergamon Press, UK (1975).
World Energy Outlook (2006): *Energy, Technology Perspective- Scenarios and strategies to 2050*, International Energy Agency, November 2006.

9.5 Appendix II Factsheet electrolysis

http://www.instructables.com/id/SDSK8S3F5R8MQ4H/
http://www.global-hydrogen-bus-platform.com/data/File/Downloads%20-%20Public/Cute%20Brochure_Summary%20of%20Achievements_Electronic.pdf
http://www.nrel.gov/hydrogen/pdfs/36734.pdf
http://www.h-tec.com/html/web/education/english/technologie_elektrolyseur.asp?id=312
http://www.pege.org/greenwinds/pics/electrolyzer3.jpg

9.6 Appendix III HPE development

http://www.wipo.int/pctdb/images4/PATENTSCOPE/36/7b/f1/007bf1.pdf
http://www.wipo.int Intl. Pub. No. 2004/055242

9.7 Appendix IV PEM development path

Norsk Hydro's Annual report (2001)
http://www.forskningsradet.no (2008): *Snart klar for markedet,* RENERGI news 2007, p. 3
Interviews: Klaus Schöffel and Egil Rasten 21.9.2005
Rasten, Egil (2001): *Electrocatalysis in Water Electrolysis with Solid Polymer Electrolyte*, PhD thesis at NTNU, Norway

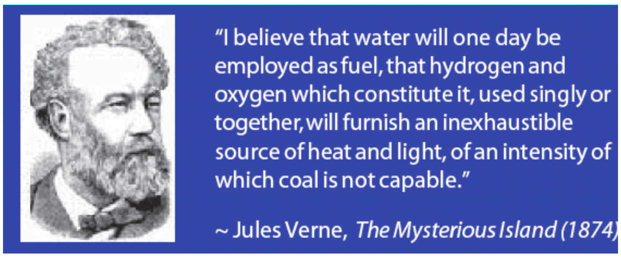
Appendix I | **Hydrogen in the making**

……Whether or not a transition in energy systems will be undertaken and how long it will take seems to be a matter of choice, not fate. Maybe hydrogen energy is an old idea whose time has come…..

10 Appendix I - Hydrogen in the making

I have decided to write an appendix on what it in fact entails when hydrogen is being considered as an energy carrier and is in the making. For one this gives the reader a better understanding of hydrogen energy as a kind of world building activity. Secondly, in the feedback from my committee at the midway defence of this thesis; one comment was related to my claim that innovation and technical development processes in hydrogen energy can be regarded as an uncertain development path – as processes of organising under uncertainty. The committee wanted me to say something about the degree of uncertainty, what it actually means. I hope this appendix helps to draw the contours around what the transition to hydrogen energy actually involves in terms of development challenges and the sense of a somewhat unknown time horizon. Empirical chapters in this thesis, based on interviews and empirical exploration, have exemplified how this world building activity and hydrogen energy uncertainty have been contemplated and dealt with in the organisation's hydrogen energy activities.

10.1 The coming of the hydrogen era?



Source:Hydrogen fact sheet- history of hydrogen

«A profound change is about to occur in the way we use energy. The modern age was made possible by the harnessing of coal, oil and natural gas. All of the advances of the past two centuries, whether they be commercial, political, or social in nature, are connected, in some way, to the massive power surge unleashed by the burning of fossil fuels…We have come to enjoy an unprecedented standard of living, and we owe our good fortune to fossil-fuel deposits formed millions of years ago. Manna, yes! But not from heaven, but rather from deep beneath the earth. Alas, all good fortunes eventually come to an end. If the fossil-fuel era is passing what can replace it? A new energy regime lies before us whose nature and character are as different from that of fossil fuels as the latter was different from the wood-burning energy that preceded it» (Rifkin 2003)

«The Stone Age did not end for lack of stone, and the Oil Age will not end because the world will run out of oil» (Sheikh Zaki Yamani, former Minister of Oil in Saudi Arabia; Don Huberts, CEO Shell Hydrogen; Amory Lovins, the Rocky Mountain Institute)

I don't know which energy expert should be credited with asserting the Stone Age quote first. It does not really matter either; the point is that the statement points to a recognition that things and technology change over time because advantages of other materials, alternative energy sources, and new technologies are explored and developed. Concerns of energy security and improved understanding of environmental impacts of fossil fuels have led to a growing interest and efforts to develop new sources of clean and abundant energy. Hydrogen is distributed throughout the world without regard for national boundaries; using it to create a hydrogen energy based economy - a future energy system based on hydrogen and electricity - requires technology, not political access. The world needs future energy sources that do not exacerbate the problem of global warming, are safe and seemingly available in infinite supply. Hydrogen may be the answer but its realisation as an energy carrier is still emerging.

10.2 Hydrogen history

The idea to use hydrogen as an energy carrier is not new. Experiments with hydrogen dates back centuries. In 1766, hydrogen was first identified as a distinct element. In 1800 English scientists William Nicholson and Sir Anthony Carlisle discovered that applying electric current to water produced hydrogen and oxygen gases. This process was later termed "electrolysis." In 1839 the fuel cell effect, combining hydrogen and oxygen gases to produce water and an electric current, was discovered by Swiss chemist Christian Friedrich Schoenbein. However it was English scientist Sir William Robert Grove that in 1845 demonstrated Schoenbein's discovery on a practical scale by creating a "gas battery" which is now considered the forerunner of the modern fuel cell and for his achievement he earned the title "Father of the Fuel Cell." In 1894 Danish scientist Poul LaCour worked with the idea to use the DC-electricity from his wind turbine to electrolyse water into hydrogen and oxygen, to store the two gases in big gas containers and use them for room lighting at Askov Folk Highschool which he did from 1895 to 1902[373]. Experiments and writings exist from Cambridge University from 1820 describing a hydrogen powered engine.

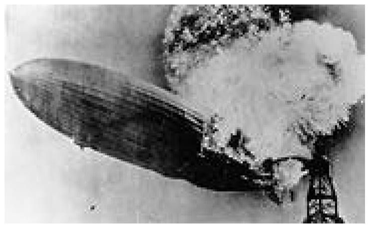
The most famous example well known in the hydrogen community is Jules Verne's prescient description in one of his books of how hydrogen will become the world's chief fuel:

"……and what will we burn instead of coal? Water replied Harding (engineer)…water decomposed into its primitive elements and decomposed doubtless, by electricity, which will then have become a powerful and manageable source, for all great discoveries, by some inexplicable laws, appear to agree and become complete at the same time. Yes my friends, I believe the water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish and inexhaustible source of heat and light, of an intensity of which coal is not capable. Some day the coal rooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces…."

[373]A central disadvantage of LaCour's plan was that he had to replace school windows several times due to hydrogen explosions when too much oxygen entered the hydrogen volume. http://www.windpower.org/da/pictures/lacour.htm

The Mysterious Island was written in 1874, just about 100 years before research into hydrogen began in earnest. Of course Verne did not explain what the primary energy source would be to make the electricity needed to decompose water. But in the overall context of nineteenth-century scientific knowledge, Verne's foresight was remarkable (Hoffmann 2002).

Interest and experimentation in the 20th century has been documented by Hoffmann (2002) who traced lectures, papers, articles and worldwide hydrogen activities in e.g. Canada, Europe, the USA, and Japan. From visionary work on hydrogen produced from water and renewables via electrolysis; converting surplus capacity to liquefied and stored fuel energy; sketching concepts for hydrogen-powered cars, trains, trucks and engines; using hydrogen as a fuel for aircrafts and an automotive fuel to remedy automotive pollution. Ideas, experiments and demonstrations have circulated but not materialised beyond that.



One of the earliest and fascinating efforts involving hydrogen was its use not only as a buoyancy medium but also a booster fuel for the Zeppelins / airship. Airships provided elegant transatlantic air travels in the 1920s and 1930s. The Hindenburg was a state-of-the-art airship built by the German company Zeppelin. It was designed to cross the Atlantic Ocean at the then unheard of time of 2.5 days. Holding seven million cubic feet of hydrogen, the airship made 10 successful trips between Europe and the U.S. in 1936. Its sister ship, the Graf Zeppelin, made transatlantic crossings from 1928 until its retirement in 1937 without a mishap. The fire that destroyed the *Hindenburg* airship at Lakehurst, New Jersey on May 6, 1937, killing one person on the ground and 35 of the 97 passengers, made "hydrogen" a negatively charged word in the popular consciousness and gave hydrogen a reputation as the last thing anyone would want to put in a fuel tank. Hydrogen was initially blamed for the disaster.

The retired NASA engineer Addison Bain - technical expert in propellants and gases who developed and tested hydrogen systems for more than 40 years - challenged the belief in 1997 after investigating the matter in the 1990s. Bain provided evidence that though hydrogen had contributed to the blaze; the disaster was caused by a spark and electrostatic activity in the atmosphere at the time, which ignited the impregnated skin of the airship coated with highly flammable material (iron oxide and powdered aluminium similar to solid rocket fuel). Bain's work has hence helped to shake off the bad reputation of this fuel after 40 years, which is important as events blown up by media have negative impact on the public perception even though it is based on incomplete information. Deutsche Wasserstoff Verband, also announced the conclusion:

"The start of the fire which destroyed the dirigible "Hindenburg" had nothing to do with the hydrogen gas of which great amounts were onboard to provide buoyancy. The reasons were the chemical and electrical properties of the paint of the outer shell in connection with the particular meteorological conditions prevailing in Lakehurst on the day of the accident". (http://www.dwv-info.de).

Used in industrial processes like in fertilizer production to chemically synthesize ammonia, in refineries to remove the sulphur that is contained in crude oil and to convert heavy crude oils into lighter usable fuels[374], industry has produced, stored, transported and used hydrogen safely; and hydrogen is said to be no more dangerous than other flammable fuels, including gasoline and natural gas. Safety concerns are not cause for alarm; they simply are different than those accustomed to with gasoline or natural gas (Hydrogen Safety Fact Sheet). For a new fuel trying to break into the market place, any accidents will slow efforts so making it safe for consumer applications are a primary concern. Education of those differences is the key enabler to making hydrogen a consumer-handled fuel that can be used safely and responsibly.

10.2.1 Modern history of hydrogen energy

In his book, Hoffmann (2002) describes one of the best-known hydrogen advocates of the 1930 and 1940s - Rudolf Erren - expert in the combustion process and a visionary German engineer who had trucks, buses, submarines, trackless torpedoes, and internal combustion engines running on hydrogen. Interest in hydrogen had picked up during the Second World War where fuel supplies were threatened. The technique of "Errenizing" any type of internal combustion process was apparently relatively well known in the 1930 converting engines to run on hydrogen for better fuel consumption and less pollution. Allied victory however brought back cheap oil making the matter less urgent.

Interest picked up in the 1950s due to Francis T. Bacon, a British scientist's development of the first practical hydrogen-air fuel cell. This is where the modern history of the fuel cell begins as it was thereafter that fuel cells began to be integrated info systems as independent power sources. A survey from Fuel Cell Today (2002) estimated that about 4000 fuel cell systems had been built since the 1950s, and up until 1990 a large proportion was used to provide power on NASA spacecrafts. Fuel cells are used in

[374] Hydrogen is used in several other industrial processes

aerospace and explored for military applications due to the low noise profile / ability to provide quiet power and exceeding the energy density of advanced batteries. Hydrogen fuel cells, based upon Bacon's design, have been used to generate on-board electricity, heat and water for astronauts aboard the famous Apollo spacecraft and subsequent space shuttle missions. In the US, the National Aeronautics and Space Administration (NASA), founded in 1958, and NASA's space program have used the most liquid hydrogen worldwide, primarily for rocket propulsion and as a fuel for fuel cells. NASA has used alkaline as well as PEM fuel cells to provide electricity aboard manned spacecrafts. Water produced in the electrochemical process in a fuel cell may be used as drinking water.

The 1970s saw the beginning of the environment as an independent political topic resulting from growth in industrial production, which brought along its waste, air and water pollutants, chemicals, lead and other by-products. However, renewed interest in hydrogen was particularly sparked by the oil crises in the 1970s and the concern for energy security.

In 1974, the first international conference was held to discuss hydrogen energy in Miami, (THEME) and laid the groundwork for setting up the International Association for Hydrogen Energy (1974). Hydrogen researchers' created the informal H_2indenburg Society in 1972 – the 35 anniversary of the Hindenburg disaster – and the group was dedicated to the safe utilization of hydrogen as a fuel. Hoffman (2002) labels the small group of highly idealistic individuals for the initial hydrogen enthusiasts and Hydrogen Romantics. When governments and international organisations started programs and allocated research funds, energy planners and corporations took up the cause; this meant new actors which in turn also put forth less patient expectations in terms of timing, realisation and putting ideas into action. When 'hardware' and a hydrogen economy did not evolve immediately, this spurred a letdown; and when oil prices when down again, interest and urgency in finding a source of domestic energy dwindled.

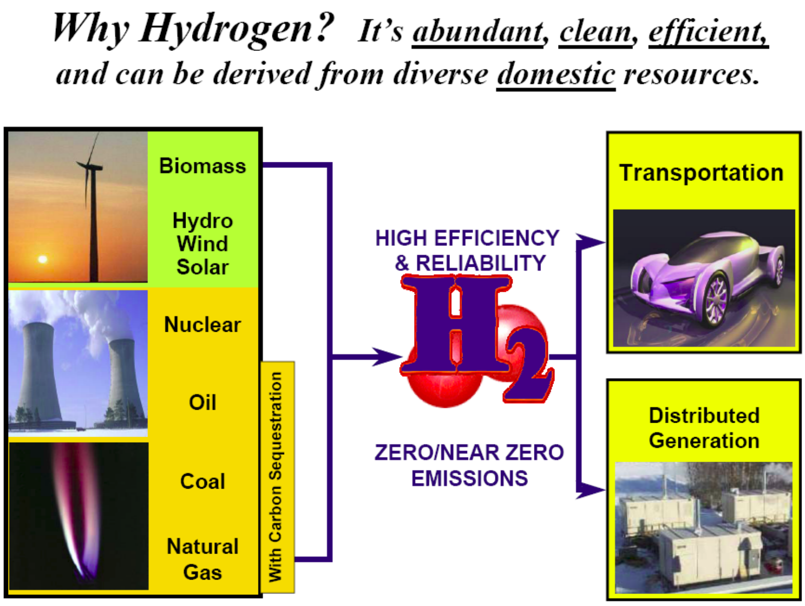
The 1980s has been described as a decade where interest waned, until environmental challenges spurred by global environmental deterioration such as acid rain, ozone layer depletion, and the threat of irreversible climate change, re-entered the energy debate since the late part of the 1980s, The climate conventions in the 1990s and the emissions reduction negotiations in Kyoto (1997) generated a renewed focus on greenhouse gas emitting activities, which in turn established a new rationale for hydrogen as an energy carrier spurring research and development activities. Hydrogen re-emerged as a future energy contender and low carbon energy solution. After 1990, fuel cells have begun to be tested and demonstrated in more mundane application like transportation (buses and automobiles), and in stationary power generators which are tried and demonstrated applications for fuel cells worldwide, as an alternative cooling, heat and power source in buildings or in conjunction with industrial applications for stationary power generation to further energy security and as emergency power to support critical electric loads (Fuel Cells Today).

10.3 Hydrogen vision and value chain

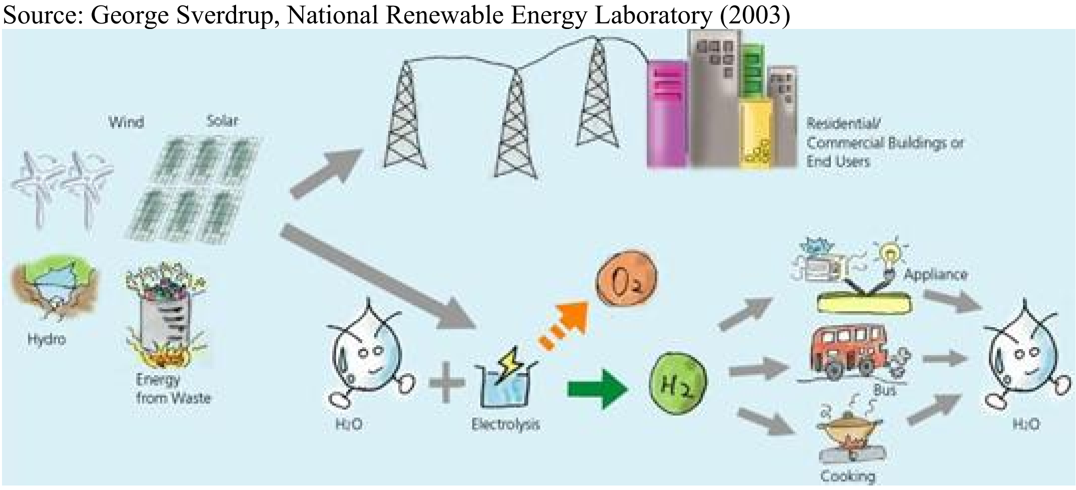
Hydrogen is the most plentiful element or substance in the universe. The hydrogen molecule which consists of two hydrogen atoms (H2) is almost never found by itself in nature. Instead, hydrogen is bound with other elements in compounds such as water (H2O) and hydrocarbons like those in biomass, natural gas, oil and coal. Unlocking hydrogen from these compounds requires the use of energy, generally in the form of heat or electricity. Thus hydrogen does not exist by itself, instead it must be extracted. Unlike oil, coal or gas, hydrogen does not come out of the ground as an energy source. Accordingly, hydrogen is like electricity – *an energy carrier* - that can be used to transport or carry the raw energy contained in fossil fuels, biomass, sunlight, geothermal resources or the wind from one place to another.

The expression: "The Hydrogen Economy" was not phrased by a marketing guru but academic electrochemist John Bockris. Bockris worked as a consultant to General Motors where the term was coined in their discussions. A hydrogen economy is an energy system based upon hydrogen for energy storage, distribution and use. During the oil crisis in the early 1970s concern over secure energy sources grew and government and industry worked together on plans and strategies to implement alternatives including hydrogen into world energy systems. Bockris promoted the idea in his writings in the 1970s by focusing on the relationship between primary resources and hydrogen. His central argument for the hydrogen economy was that either of the likely future energy sources would have to be located a distances from end-users (nuclear near cooling water, solar in the desert). Since transmitting electricity over long distances would be costly, it was argued that it would be cheaper to convert electrical energy into hydrogen and piping it to users and convert it back to electricity at the site of use /fuel cells) or used in combustion to provide mechanical power. His work was driven by his view that fossil fuels would be exhausted and that the future alternatives would be nuclear and renewables, and less by concerns over carbon dioxide emissions that are a central driver today.

Images have helped make the hydrogen economy visible by projecting representations with linkages and hydrogen's fit with societal functions. Below examples of such visualisation are presented.

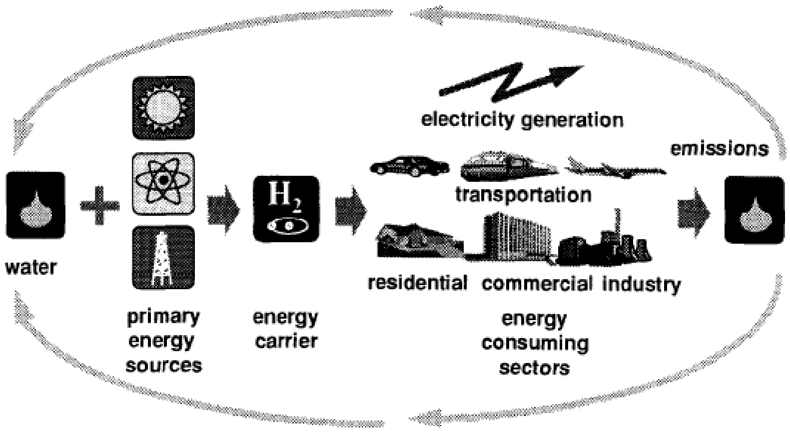


Source: George Sverdrup, National Renewable Energy Laboratory (2003)



Source: Copyright 2007 by Electrical and Mechanical Services Department, http://re.emsd.gov.hk/

Hydrogen energy system: a clean and permanent energy infrastructure for sustainable development



Source: International Journal of Hydrogen Energy, Vol. 23, No. 1, pp. 75, 1998, Elsevier Science ltd. International Association for Hydrogen Energy

The expression "hydrogen economy" carries a way of seeing a future hydrogen economy with a vision of an efficient and environmentally friendly energy system using hydrogen as an energy carrier with no harmful emissions, just water, which in addtition will eliminate external dependence on energy and hence reduce vulnerability to geopolitics. Through hydrogen's reaction with oxygen, H2 releases energy explosively in heat engines or quietly in fuel cells to produce water as its only by-product. The use of hydrogen in an internal combustion engine produces traces of smog-forming nitrogen oxides but fewer total emissions than engines running directly on fossil fuels.

The hydrogen economy is a term for a new way of delivering and using energy describing a future where hydrogen may take the place of fossil fuels like oil, natural gas and coal in our energy systems. Hydrogen is intended to replace diesel and gasoline in the transportation sector eliminating the production of any harmful exhaust emissions from vehicles associated with the internal combustion engine (emissions of nitrogen oxides, carbon monoxide, CO2), and with new methods hydrogen may be used for the production of electricity and heating.

The idea of hydrogen as the ultimate and limitless fuel is powerful. The promises that are seen in articles on the hydrogen economy are: fossil fuels are running out and we need something to replace them; hydrogen is a clean and energetic fuel, which burns to give pure water; the sources of hydrogen are inexhaustible and secure so no more reliance on the Middle East; fuel cells running on hydrogen will drive electric vehicles quietly and cleanly; hydrogen will end atmospheric pollution caused by fossil fuel combustion; the threat of global climate change will be defeated (Biegler

2005). Hydrogen will also allow for a more distributed energy production system as hydrogen in principle can be produced anywhere that you have electricity and water.
A taste of these promises are seen in the excerpt from an EU report:
"Hydrogen, a clean energy carrier that can be produced from any primary energy source, and fuel cells which are very efficient energy conversion devices, are attracting the attention of public and private authorities. Hydrogen and fuel cells, by enabling the so-called hydrogen economy, hold great promise for meeting our concerns over security of supply and climate change …… hydrogen and electricity together represent one of the most promising ways to realise sustainable energy, whilst fuel cells provide the most efficient conversion device for converting hydrogen, and possibly other fuels, into electricity. Hydrogen and fuel cells open the way to integrated "open energy systems" that simultaneously address all of the major energy and environmental challenges, and have the flexibility to adapt to the diverse and intermittent renewable energy sources that will be available in the Europe of 2030." (EU report: Hydrogen Energy and Fuel Cells – A vision of our future 2003)

Next, I will discuss the hydrogen value chain from production to usage. Widespread production, distribution and use of hydrogen will require many innovations and investments to be made in efficient and environmentally-acceptable production systems, transportation systems, storage systems and usage devices.

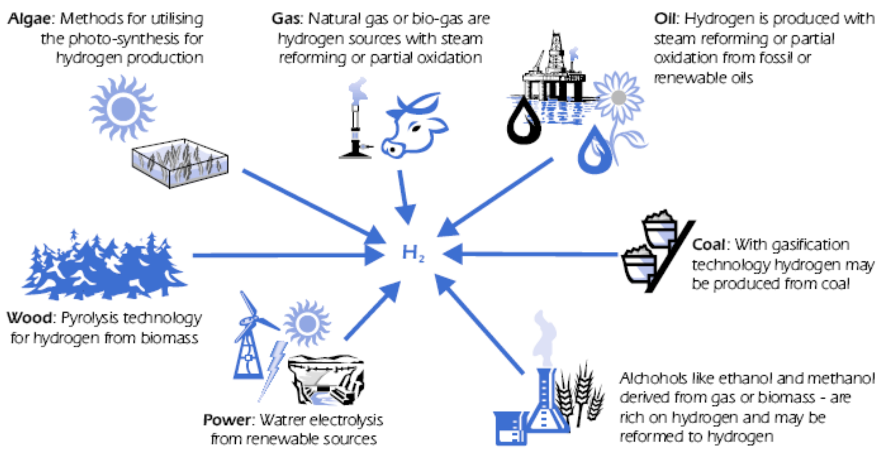
10.3.1 Hydrogen production

One reason why hydrogen economy initiatives enjoy widespread support is that everyone can play the game. There are many possible paths for making hydrogen and it is difficult to know which one will prevail. No energy source is upfront excluded. Hydrogen can be produced from a variety of energy feedstock including fossil fuel resources such as natural gas and coal, as well as renewable resources such as biomass and water with input from renewable energy sources (e.g. sunlight, wind, wave or hydro-power). Hydrogen can be produced at large central facilities or at small plants for local use. Every region of the world has some resource that can be used to make hydrogen. Its flexibility is one of its main advantages as it will allow for more diversification of energy sources.

A variety of process technologies can be used to produce hydrogen including chemical processes (processing natural gas), electrolytic (electrochemically split water into hydrogen and oxygen), photolytic (couples photovoltaic systems with electrolysers to have renewable energy such as solar power produce hydrogen directly) and thermo-chemical (heating and gasification processes for the conversion of biomass and coal).

Each technology is in a different stage of development, and each offers unique opportunities, benefits and challenges. Local availability of feedstock, the maturity of the technology, market applications and demand, policy issues, and costs will all influence the choice and timing of the various options for hydrogen production (IEA 2006). Hydrogen production alternatives are presented in the figure below.

Some feedstock and process alternatives



Source: Hydro.

Since isolated hydrogen does not exist in free form in nature, it has to be made or produced and to make it we have to use energy. Technologies are already available in the marketplace for the production of hydrogen for industrial applications. The first commercial technology dating from the late 1920s was the electrolysis of water to produce pure hydrogen. Electrolysis is a process that splits water into hydrogen and oxygen through the application of electrical energy (see appendix II for more details). It results in no emissions but it is an energy intensive process. Electricity prices and fuel taxes are therefore dominant issues affecting the competitive position of electrolytic hydrogen. Major challenges are to design electrolyser equipment at lower costs with higher energy efficiency and larger turn-down ratios (operating ratio of part load to full load, which is important for more variable production).

In the 1960s, the industrial production of hydrogen shifted slowly towards a fossil-based feedstock which is the main source today. Natural gas (methane, or CH4) is by far the most common source of hydrogen and steam methane reforming (SMR)[375] is by far the most widely used means of

[375] Reforming is a process which, under a given pressure and temperature, breaks whatever is put in down into individual components. The reformer that was planned in the HydroKraft

producing hydrogen on an industrial scale. SMR is a thermal process with natural gas as the feedstock, and is currently the least expensive method of producing hydrogen. It is used in industries to separate hydrogen atoms from carbon atoms in methane (CH_4). Because methane is a fossil fuel, the process of steam reforming results in greenhouse gas emissions and would ideally require methods to capture and store greenhouse gas emissions. On the other hand there is a value in getting started with what is available in order to demonstrate hydrogen potential and concepts and also spur the development of different uses. Hence, the most near term methods for producing hydrogen are steam reforming and electrolysis (water splitting), and hydrogen production in the near term is likely to build on this existing infrastructure and competence. The other methods for hydrogen production are further away from commercialisation and need additional R&D.

As derived from the above, a relevant question is hence to ask what colour is your hydrogen? Because as is the case with hydrogen produced today, the vast majority comes from fossil fuels and processes that turn out the same pollutants that is tried to be avoided. For electrolysis, using electricity from a grid where the electricity is generated using fossil fuels to produce hydrogen, will release global warming inducing emissions, unless carbon capture technology is part of the fossil fuel processes. Accordingly, hydrogen is neither inherently renewable nor inherently clean. *Hydrogen is only as clean as the resources used in its production.*

Original cartoon by Brigit Macomber, Ecology Center,Ann Arbor. Johannes Schwank

In the green vision of a "hydrogen economy", hydrogen is to be produced using renewable resources such as solar, wind and biomass energy; this is the core of a "pure hydrogen economy" and a sustainable energy future. To

---

project was approximately 10 metres in diameter, 15-20 metres high and operated under approximately 40 atmospheres of pressure at approximately 900 degrees Celsius (Larsen and Ruud 2005).

illustrate, there is a perfect cycle where electricity produced with renewable energy is used in electrolysis of water (using electricity to split water molecules to create pure hydrogen and oxygen), and when hydrogen is used in a fuel cell (using an electrochemical process) where hydrogen is recombined with oxygen to create water, heat and power. Hence if hydrogen comes from the electrolysis of water - using electricity from renewable energy sources – then hydrogen adds no greenhouse gases to the environment because when used in fuel cells there are no harmful emissions, the only by-product is water. If the political will is to move to renewable energies, then biomass, solar, wind and ocean energy will be more or less viable according to regional geographic and climatic conditions.

A report from the IEA (2006) concluded that for all hydrogen production processes, there is a need for significant improvement in plant efficiencies, for reduced capital costs and for better reliability and operating flexibility. *In the current and medium term,* water electrolysis and small scale natural gas reformers are available although small scale reformers have only limited proven and commercial availability. With *distributed hydrogen production*, small-scale natural gas steam reformers or small-scale electrolysers would be installed onsite. This is also called forecourt plants as based where hydrogen is needed e.g. at a hydrogen filling station or distributed generation to supply fuel cells in buildings. The benefit would be the reduced need for the transportation of hydrogen fuel through trucking or pipelines, and less need for the construction of a new hydrogen infrastructure, which makes sense in the early stages of a hydrogen economy, when demand is relatively small. Distributed production may also use existing infrastructure, such as natural gas pipelines or water and electric power lines to the site of hydrogen production. Larger water electrolysis plants would be cheaper to build (unit of output) and may command lower electricity prices. However, offsetting that extra cost is the avoided need for transport of hydrogen from central generation facilities to the point of use. For natural gas based, costs are also higher for smaller capacity production and carbon capture and sequestration makes sense only at larger scale. The price for natural gas is also an issue as larger plants can usually command lower prices than smaller ones. The space required for distributed hydrogen production, on-site and close to the point of use, is an additional challenge for hydrogen technology, when compared with conventional trucked-in systems for gasoline / diesel or hydrogen. Minimizing size or footprint matter and developing more compact solutions is an important development priority.

Centralised production requires large market demand as well as the construction of a hydrogen transmission and distribution infrastructure either in liquid form by truck under cryogenic (the use of very low temperature) conditions or pipeline in gaseous form to points of uses. Larger centralised hydrogen production plants have the potential of low unit costs, but are more likely longer term as they need volume and demand. Biomass conversion processes /gasification need improvement in the economics of production processes and the logistics of handling biomass feedstock and the technologies are medium and longer term as none of the technologies have reached a demonstration phase for hydrogen production (IEA 2006) For fossil fuel based hydrogen production the key challenge is to decarbonise the hydrogen production process with CO_2 capture and storage which are not technically and commercially proven and require R&D. Further challenges as to centralised production are hydrogen purification to produce hydrogen suitable for fuel cells and gas separation (to separate hydrogen or CO_2 from gas mixtures). Hence although large-scale industrial hydrogen production from all fossil energy sources can be considered a commercial technology for industrial purposes, it is not yet so for energy utilities (IEA 2006). As it relates to natural gas, an additional question is also whether or not there is enough natural gas to meet the growing demand for gas-fired power plants and supply a hydrogen based transportation system? To sum up production, there are many possible paths for making hydrogen and it is difficult to know which will prevail.

10.3.2 Hydrogen storage

Once produced, hydrogen must be stored. As the lightest of all gases [376] hydrogen has a low energy density and must be either compressed at very high pressures or liquefied at very low temperatures to be stored in any meaningful quantity. Hence important challenges regarding the commercial use of hydrogen as an energy carrier are not only related to its production but also to *storage*. In relation to transport/mobility, fundamental performance issues facing hydrogen vehicles are the related problems of fuel storage and driving range. Hydrogen storage poses a basic physical dilemma: vehicles

[376] Hydrogen is the most abundant substance in the universe and the lightest of all gases. Hydrogen is a chemical element and in its normal gaseous state, hydrogen is colourless, odourless, tasteless, non-toxic and burns invisibly. Hydrogen has an exceptional energy content or high energy density by weight. Per unit of energy contained, it weighs 64% less than gasoline or 61 % less than natural gas. 1 kg of hydrogen has about the same energy as 1 U.S. gallon of gasoline or 4 litres of gasoline, thus, per unit mass, such as per kilogram, nearly triple that of gasoline. Hydrogen has an extremely high energy content or energy density by weight thus weight is not a barrier to the use of hydrogen in any application. But the flip side of lightness is bulk. As the lightest of all gases, hydrogen has a low energy density and must be either compressed at very high pressures or liquefied at very low temperatures to be stored in any meaningful quantity, which presents significant challenges particularly for mobile applications. It is the most voluminous and hence a disadvantage of hydrogen as a fuel is that it has extremely low energy density by volume / energy-to-volume ratio. This means that compressed hydrogen contains far less energy than the same volume of gasoline. That is, hydrogen contains much less energy per litre /gallon than other fuels at the same pressure. At room temperature and pressure, hydrogen takes up three thousand times more space than gasoline containing an equivalent amount of energy.

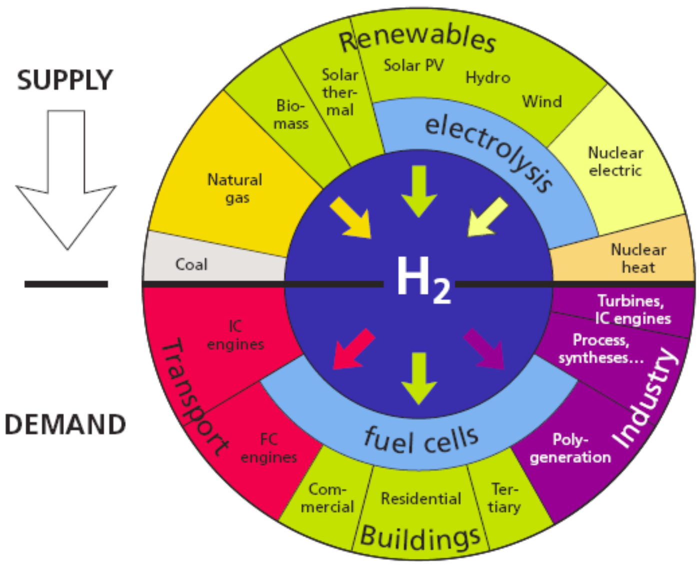
must carry enough hydrogen on board to provide an acceptable driving range between fill-ups, yet must not carry storage tanks that are too large (reducing passenger or cargo room) or waste excessive amounts of energy in compression or liquefaction. In addition, they must be safe (Dutzik 2004).There are scepticism as to whether the storage problem and performance issues can be resolved using current technology. The American Physical Society, said the following in 2004: "no material exists today that can be used to construct a hydrogen fuel tank that can meet the consumer benchmarks [established by the U.S. Department of Energy], a new material must be developed".

The conceived primary forms of hydrogen storage are physical and chemical. *Physical storage includes liquefied hydrogen* kept liquid at a temperature of minus 253°C at the pump and kept that way in the vehicle. The refrigeration demands energy and insulating the tank multiply its size. Liquid hydrogen evaporates daily and researchers are working to find a way to eliminate or utilize this boil-off. BMW is pursuing liquefied storage systems and most recently it was written about the BMW dual-fuel series that it boasts a unique hydrogen vapour recapture system, as well as a fuel tank so well insulated it could keep a block of ice frozen inside for thirteen years (Hydrogen Horizons 2007). *Physical storage also includes compressed hydrogen gas* stored in special tanks at 300-700 bar pressure which is not a technical problem in itself, but the costs for such tanks are not marginal. This is very high pressures compared to storage and operating pressures for other gaseous fuels. Equipment must be especially designed for the high pressures. Research is needed to find materials that are strong enough yet light enough to carry, and cheap enough to mass produce. Most of the prototype hydrogen vehicles presently use compressed gas.

The other primary form – chemical hydrogen storage - is being researched as a promising storage approach. It involves the formation of metal hydride systems that adsorb hydrogen. The tank will be filled with a solid material that soaks up hydrogen like a sponge at fill-up and releases it during drive time. These substances can be kept at room temperature yet you need energy to infuse the solid medium with hydrogen and temperature to get the fuel back out. The storage challenge however also impacts how infrastructure develops. The technological sorting-out process in a way act as a barrier to infrastructure development because infrastructure and stations will less likely develop until storage is solved and standardized and there is a storage technology that dominates the market place. Storage capacity is also linked to *range* that is the consideration to reach a driving range comparable to conventional cars and considered acceptable to users. Presently most hydrogen vehicles are at 200-250 km and 500 km has been the ballpark figure that has been projected as acceptable. To circumvent the storage and infrastructural problems, it has also been considered to have onboard production. This means that the vehicle would be equipped with a small reformer that produces hydrogen on-board from methanol, gasoline, methane. The hydrogen would then be used to power a fuel cell. In the mid 1990s, it was thought that producing hydrogen "on the go" would be an interim step between the hydrogen fuelling infrastructure and the coming of hydrogen powered vehicles. The environmental and energy security benefits of the strategy however would be modest, and nearly all manufactures have abandoned the idea due to technical complexity, which seems not to be compensated by the advantages that no hydrogen infrastructure would be needed. From a technical point of view, the technical storage problems mentioned is not considered insurmountable and there is still large potential to decrease the costs. At any rate, storage and transport of hydrogen place considerable demands on tanks and material, and contribute to higher costs compared to those of conventional fuels, and together with the fuelling stations, they are still of rather tentative than of commercial character.

10.3.3 Applications, uses and markets

Hydrogen can be conceived of as a broad river to which many “primary source” tributaries contribute and at the downstream end, the broad river splits again into multiple “irrigation canals” sustaining many economic activities, including transportation, various industries, domestic uses, and chemical activities such as making fertilizers (Hoffmann 2002, pg. 81).

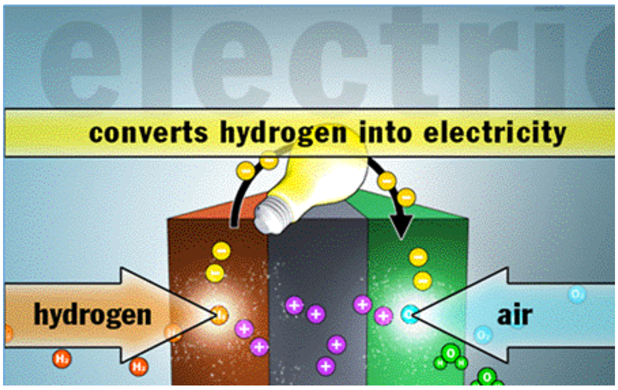


Source: EU Commission (2003)

The wide range of options for sources, converters and applications, shown in the figure, illustrates the flexibility of hydrogen and fuel cell energy systems. The fuel cell is one of several conversion technologies that can be fuelled by hydrogen; and it is the coming of the fuel cell to power the future that has been central in the projections and hopes for a hydrogen economy.

10.3.3.1 The fuel cell

Fuel cells are important as they are an enabling technology for the hydrogen economy. A fuel cell is an electrochemical converter or device that combines hydrogen and oxygen to produce electricity, with water and heat as its by-product. For most purposes, the fuel cell may be thought of as a "black box" that takes in hydrogen and oxygen from separate tanks and puts out only water plus electricity and heat.

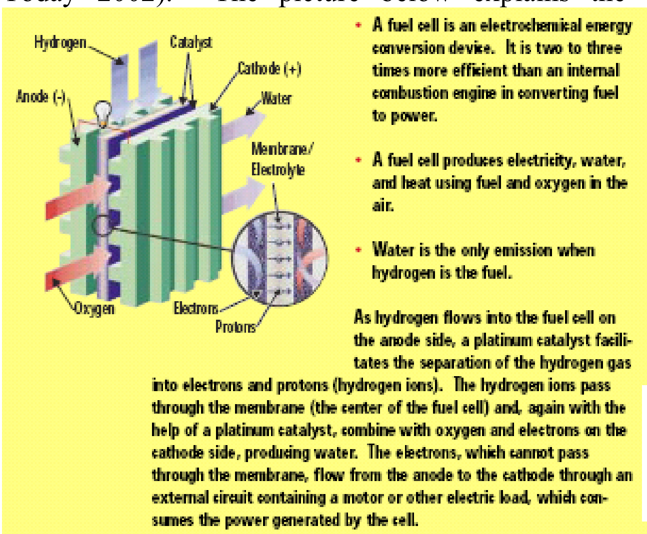


Source: http://www.casfcc.org/

Since the conversion of the fuel to energy takes place via an electrochemical process, not combustion, the process is clean, quiet and highly efficient – two to three times more efficient than fuel burning and a internal combustion engine. Another familiar electrochemical device is the battery, however there the chemicals are stored inside, and it converts those chemicals into electricity too. This means that a battery eventually "goes dead" and you either throw it away or recharge it. The fuel cell does not require recharging, as long as there is a flow of chemicals into the cell, there is production out of the cell. The fuel cell can hence be thought of as a continuously operating battery.

The diverse fuel cell types have different manufacturers behind them and have different levels of maturity. Fuel cells differ in terms of electrolyte used (see Appendix II), components used, size, temperature at which they operate, fuel source, and whether hydrogen is produced within the fuel cell system. The latter means that some of the fuel cells that operate with high temperatures can internally reform various fuels like natural gas or coal gas to generate hydrogen and in turn use it the produce electricity. Accordingly, various types (each named according to the electrolyte that is used in the system[377]) exist. Some are in competition with each other as suited for the same application, and some are mainly suited for stationary applications.

Fuel cells have the potential to serve most sectors of the economy as they may be used in a wide range of products, ranging from very small fuel cells in portable devices, electronics such as mobile phones and laptops, through mobile applications like cars, delivery vehicles, buses and ships, to heat and power generation and space conditioning in stationary applications. The scalability of fuel cells makes them ideal for a wide variety of applications – including laptops (50-100 Watts) and central power generation (1-200 MW). User requirements vary by market segment and specific application[378]. The PEM fuel cell is the most versatile which can be build and range in size from less than one Watt to 300 kW and can power anything from small electronic devices to buses and submarines (Fuel Cell Today 2002). The picture below explains the basics of fuel cells.



Source:
Fuel Cells Green Power, Los Alamos National Laboratory

[377] See http://www.fuelcelleurope.org, http://www.usfcc.com

[378] For example, the Solid Oxide Fuel Cell (SOFC) is the most promising fuel cell for stationary applications, power and CHP (combined heat and power generation) and the system requires a high operating temperature of 500 – 1000^{o} C. The SOFC can utilize a hydrocarbon fuel directly, without reforming, similar to the MCFC Molten Carbonate Fuel Cell (MCFC) also has high operating temperatures 600 – 700^{o} C. High-temperature fuel cells can more easily use a wide range of fuels without using a "fuel reformer", it uses the heat internally to produce hydrogen directly from a variety of fuel (natural gas, ethanol, and methanol). Yet it takes considerable time, (up to eight hours to "warm up") to fully come on line — an attribute that would be unacceptable in transportation and to car drivers. MCFCs are well-suited for large-scale stationary applications (250 kW and above) and are being demonstrated for powering buildings as well as CHP. The Proton Exchange Membrane fuel cell (PEMFC) works at operating temperatures below 100^{o} C and is the type considered most promising and suitable for automotive, small stationary and portable power applications. PEM require very pure hydrogen as fuel, and PEM fuel cells as well as Alkaline fuel cells have been used in NASA's space shuttles. (Bellona 2002).

10.3.3.2 Fuel cell applications

Industrial applications for stationary power generation have been expected to represent the first area of significant market penetration for fuel cell systems. There are more than 250 stationary fuel cell systems generating power for industrial applications around the world providing several benefits. *First*, they provide reliable power, back up power to many service industries and manufacturers, hospitals, data processing centres, and communication providers. In case grid connection fails, this reliability saves lives or is worthwhile economically in terms of ruined products or lost transactions. The marine and military also make use of fuel cell technology. *More generally speaking*, initial uses have been projected to be in markets requiring reliable and secure forms of power (UPS/ uninterruptible power supply) where users are prepared to pay a premium to achieve these benefits, or where the cost of alternatives is already high. Stationary fuel cell systems also generate waste heat that can be captured and used to provide heating, cooling, or to turn steam turbine generators for additional electricity. This ability to utilize both the electricity and the waste heat, known as cogeneration, enhances a fuel cell's efficiency. Stationary fuel cell systems have efficiencies around 40+ percent alone and around 85 percent with heat recovery.

Using hydrogen in for electricity and heating in a distributed energy system is another pillar in the hydrogen vision. This will require residential fuel cell systems sizes appropriate for use in residential applications 3-10 kW to be developed, which may be operated for primary or backup power for the home. They can run independently or in parallel to an existing power grid. A fuel cell power system for a residence could be located in the basement or backyard, taking up about as much space as an ordinary refrigerator, and providing clean, quiet, reliable power. Because fuel cell systems with "fuel reformers" can extract hydrogen for the fuel cell from a variety of conventional sources, countries with existing infrastructures such as natural gas pipelines / distribution systems could be used.

Companies are also working to develop fuel cells for small and *portable power applications* like consumer electronics e.g. laptops fuel cell-powered cell phones where fuel cells would be expected to run about 10 times longer than today's batteries before needing new fuel supplies and where it can be refuelled quickly. For remote/portable power, fuel cells can also be used in applications where you need power for remote sites, or sites where the power grid is not available e.g. construction sites, campgrounds, festival tents as well as for mobile energy in military applications.

As it relates to transport applications, automakers worldwide are working to bring fuel cell vehicles to the marketplace. To offer an alternative to the internal combustion engine but still provide the performance that consumers have come to expect e.g. in terms of range and comfort. Fuel cell technology is being demonstrated in a variety of transportation applications:

from scooters and passenger cars, to buses. *Fuel cells are considered attractive in transportation as it will allow two strategies to be pursued at the same time namely enhancing fuel efficiency and reducing vehicle emissions* Aside from being pollution-free, fuel cells are quiet, and can achieve efficiencies that are two- to three-times greater than internal combustion engines. The higher efficiency[379] of fuel cells means that hydrogen cost may be tolerated that are 1,5 – 2,5 times as much as gasoline fuel cost for an equivalent amount of energy delivered (1,5 if comparing with a gas hybrid and 2,5 a typical gasoline car, Ogden 2007). Additional advantages are that the elimination of moving parts in the propulsion system leads to a less complicated mechanical system, less maintenance, and low vibration and noise levels. The case for hydrogen and fuel cells in vehicles are also supported by the fact that they in addition to environmental and energy advantages also provide benefits to the consumer that the electric car has been unable to provide namely the longer driving range and the shorter recharge / refuelling time.

10.3.3.3 Technological progress, fuel cells and other technologies

Fuel cells confirm that it is difficult to predict technological progress. Ogden (2007) points out that by the mid 1990s, the frustration with batteries caused car makers to pursue hydrogen as a better route to an electric car. Fuel cells are the logical extension of the technological pathway automakers are following and will allow a superior consumer product – if fuel cell costs become competitive and if hydrogen fuel can be made widely available at reasonable costs. *Fuel cells are still in relative infancy with challenges in terms of cost, operational reliability, durability and lifetimes of fuel cell system* Costs are on a downward slope and now estimated at a factor of four too high. The suggested mass production of the state of the art fuel cell stack would most likely drop to a a propulsion system cost of $ 6000- 10,000, which would be about $ 125 per kilowatt of engine power, which is about four times as high as the $ 30 per kilowatt cost of a comparable internal combustion engine. Today's fuel cell cars are handmade specialty items that cost about $ 1 million apiece (Ogden 2006b).

[379] Electrical efficiency refers to the ratio of electrical energy produced by a system (such as a fuel cell) compared to the energy supplied (usually chemical energy). By harnessing the fuel's energy via a chemical reaction rather than combustion, a fuel cell can convert 40–65 percent of hydrogen's energy into electricity. Because a fuel cell's energy efficiency is not scale-dependent, stationary fuel cells can be sited locally where the waste heat can be used. The cogeneration of heat and power would bring a fuel cell's energy efficiency close to 90 percent. See http://www.rmi.org

A challenge for hydrogen and fuel cells, and most new technology, is that fuel cells compete with the potential of other technologies[380]. They must prove themselves against alternatives to get emission reductions and to provide the things that consumers need e.g. mobility, sound, light, heat, cooling, and communication. The competition usually does not stand still. Illustrating this by looking to transportation, a wide range of technological pathways is being discussed for the road sector and mobility. There are continuous enhancements in best current technology and there are alternative fuel options / competing technologies with the potential to meet, at least in part, some of the same policy objectives. These include biomass-based fuels[381] that may be mixed in / added to conventional fuels in various percentages and with associated engine modifications. The STOA report prepared by the European Technology Assessment Group from 2007 indicated that in the EU, the technical potential of biofuels is considered to be between 20-30% of EU road transport fuel by 2030. The potential of biofuels is limited by the available acreage and cultivation and preparation also require considerable amounts of energy. Imports from sensitive tropical rain forest areas are questionable and controversial. Overall, biofuels are regarded as a bridging technology which means that it will help overcome the gap between mobility based on fossil fuels and "something else". There are also new propulsion system technologies like electric and hybrid[382] electric vehicles. Widespread use of battery electric[383] vehicles (BEV) is still being developed and dependent on advances in battery technology. For widespread acceptance, additional development is needed to improve the performance, durability, and cost of advanced batteries, such as lithium-ion batteries. Many of the major automakers have shifted focus away from BEVs and toward hybrid electric vehicles - including plug-ins[384]- and fuel

[380] As it concerns the fuel cell, you need a fuel cell that is lightweight and compact enough to fit under the hood of a car but that can still deliver the power and acceleration drivers have come to expects. You also need cost and reliability comparable to that of the gasoline-powered internal combustion engine, which is an exceedingly mature technology, the product of more than a hundred years of development and testing in hundreds of millions of vehicles.
[381] Such as ethanol from cellulosic biomass that is residues from plants, and biodiesel made from various crops and waste animal fats.
[382] Hybrids combine a small combustion engine with an electric motor and battery. Regular hybrid cars do not use any electricity from the grid. Recharging the battery comes from recapturing energy normally wasted during braking / regenerative braking and the engine is used both to propel the vehicle and to recharge the batteries.
[383] Electric vehicles are recharged from the electric grid
[384] A plug-in hybrid electric vehicle (PHEV) is a hybrid vehicle with batteries that can be recharged by connecting a plug to an electric power source. It shares the characteristics of both conventional hybrid electric vehicles and battery electric vehicles, having an internal combustion engine and batteries for power. The car runs on battery power only for the first 10 to 60 miles [16-100 km] with the gasoline engine available for faster acceleration etc. After the battery is nearly fully discharged the car reverts to the gasoline engine to recharge the battery or the battery may be to recharged from the electrical grid.

cell vehicles[385]. Today's hybrid gasoline-electric vehicles like the Toyota Prius, are already much more efficient than traditional internal combustion engine vehicles. The problem is that they are still dependent on fossil resources and that near term improved energy efficiency and fuel economy will have limited effect due to the fact that the number of vehicles is projected to triple by 2050 worldwide. *Hence efficiency needs to be coupled with a decarbonisation of fuels*.

Using natural gas for transportation applications is also an alternative. CNG and LPG[386] are already commercialised and compete with each other and gasoline and diesel engines. It has a cleaner combustion and lower local pollution than conventional fuels. However, with today's vehicle technology, natural gas and LPG does not significantly reduce CO2 emissions; that would require further technology development of the gas engine to the use of these fuels which in turn depends on the car manufacturers willingness to undertake such development. The challenge is that CNG and LPG face similar problems as oil as they are based on fossil feedstock, contributing with green house gas (GHG) emissions, and finite resources with associated imports and security of supply concerns. Demand for natural gas is expected to grow and transport then will compete with the use of natural gas in other applications such as the generation of electricity and heating. A question that emerges however is: why make hydrogen solutions if hydrogen is produced from natural gas, why not just use natural gas vehicles? The answer is that fuel cells are more efficient. A fuel cell using hydrogen as fuel can reach 60 % efficiency. Hydrogen fuel cell cars are two to three times more efficient than conventional cars and light trucks, and the energy efficiency in the gas engine is generally equal to that of gasoline engines. Further, from the point of view of greenhouse gas emissions, hydrogen would be better than natural gas because of no CO_2 emissions when used in the vehicle and CO_2 capture and handling may be required at the site of hydrogen fuel production.

385 The fuel cell produces electricity directly from the reaction of hydrogen and oxygen to power the vehicle. Fuel-cell vehicles are similar to battery-electric vehicles in that they are powered by electricity, but they do not have to be recharged like battery vehicles. Fuel-cell vehicles have onboard storage tanks that could be filled at hydrogen filling stations,

386 Compressed natural gas (CNG) Natural gas primarily consists of methane (CH4) and nearly needs no processing for the use in automobiles. CNG is easiest to handle and can be transported in pipelines. Liquefied (LNG at low temperature – 161^o) need transport in specialised vessels. Liquefied petroleum gas (Autogas / LPG) is an artificial by-product from refining processes or can be extracted from natural gas. There are 4.7 mill natural gas vehicles in operation around the world today; nearly 557,000 in Europe alone; stations are situated in larger cities or industrial areas but not along the highway network. There are 4,3 mill LPG cars however the penetration of the total vehicle fleet of LPG is given the resource itself (a surplus in upstream oil production/ a by product of refining).

Since both CNG and LPG are based on fossil feedstock, they must be considered as a bridging technology that may help pave the way for cleaner gaseous fuels such as hydrogen (STOA report / European Technology Assessment Group from 2007). However, the use of natural gas for transportation applications will require infrastructure investments, laying the groundwork for the future introduction of fuel cell vehicles. Experience with gaseous fuels and infrastructure can facilitate a transition to a future hydrogen transportation system (NREL 2003) which is similar to the conclusion in the STOA report mentioned above. Dunn (2001) also noted that *gases are rising* and points to the shift from one form of energy to another – from solids to liquids to gases. From wood, to coal, to oil, and then natural gas, being cleaner and lighter and burning more efficiently. The transition similarly involves a process of decarbonisation. From wood to coal to oil to natural gas, the ratio of hydrogen (H) to carbon (C) has increased to 4 to 1 in natural gas (CH_4). The world has progressively favoured hydrogen atoms over carbon, and Dunn has indicated that the next logical fuel in this progression would be hydrogen.

While it is difficult to say what fuel will be dominant in the future, it is expected that hybrid technology will be part of the propulsion system and expected to dominate the personal vehicle market already around 2010. Hybrid technology is an important component of most fuel cell concepts and there is potential to further improve the efficiency of conventional fuels. The hybridisation at the same time means "electrification" of drive train technology and thus support a more dominant role of the electric engine in general (STOA 2007).

10.3.3.4 The uncertain time horizon

The time horizon for a possible hydrogen transition can be illustrated by looking at transportation applications. In conjunction with the Kyoto Conference, Framework Convention on Climate Change in 1997, European car producers promised to reduce the amount of CO2 emitted per vehicle from a level of about 200 g/km to 140g/km in 2008 and 120g/km in 2012, which triggered focus on fuel cell cars as more effective propulsion systems than conventional engines. There was a period of hyped expectations in the 1990s where fuel cell commercialization was projected within 5 to 10 years (Physicsweb 1998). Development was on the way with car makers in the 1990s. DaimlerChrysler (then DaimlerBenz), Ford, GM, Honda, Mazda, Nissan, Renault, Toyota and VW all presented hydrogen vehicle prototypes in the 1990s. Canadian Ballard Power Systems working on fuel cell and hydrogen technologies were central in showing the industrial and commercial potential of hydrogen fuel cell technologies by increasing the performance of PEM fuel cells; and Ballard delivered the fuel cell when early mover DaimlerBenz's (DaimlerChrysler merger in 1998) introduced the world's first fuel cell vehicle in 1994. A fuel cell vehicle alliance was also set up with DaimlerBenz, Ballard and Ford Motor Co. in 1997. In the middle of the 1990s there were projections from car manufacturers DaimlerBenz, BMW, General Motors, Honda and Toyota on expected commercialisation and serial production of hydrogen-based vehicles expected from 2003/2004[387]. Around 2000 Toyota and Daimler demented these expectations and started to operate with year 2010 in their projections. Romm (2005, p. 6) referred to a 2002 report concluding that the hydrogen industry was experiencing a backlash to the "just around the corner" hype that had surrounded automotive fuel cells. Revised targets and more sober projections were advanced as it concerns transportation sector applications and vehicles. Honda, Toyota and General Motors announced plans of commercial readiness between 2010 and 2020. This means that at that time they expect to be technically ready to make a mass production decision (Ogden 2007).

A recent statement from Honda points out how Honda envisions future vehicles: «*I would say there's no future for the auto industry without fuel cell cars….. Honda plans to begin leasing a pricey new hydrogen-powered fuel-cell car in Japan and the United States next year…… I expect that fuel cell vehicles will come very close to a mass production in 10 years' time…… Takeo Fukui, the president of Japan's second-largest automaker, said at a conference in Tokyo on the auto industry*»[388]

At the 2007 Los Angeles Auto Show, Honda presented its new Honda FCX Clarity hybrid fuel-cell vehicle which is to be leased to users in California from 2008 and will be the first fuel-cell car to be offered to the general public. At the same time, Honda also announced that it is using the Home Energy Station IV (fourth-generation experimental unit developed with technology partner, Plug Power, Inc.) at its Honda R&D Americas, Inc. facility in Torrance, California. The Home Energy Station is designed to provide fuel for a hydrogen-powered fuel cell vehicle, as well as heat and electricity for an average-size home. Honda's Home Energy Station technology is designed to facilitate the broader adoption of zero-emissions fuel cell vehicles by developing a home refuelling solution which represents one solution to address the need for a refuelling infrastructure for hydrogen fuel cell vehicles[389]. Hence announcements illustrate that the idea that a car can run on hydrogen with water as the only tailpipe emission is not only a vision but also in the process of becoming a reality. It also points to a visionary coupling between stationary applications and mobility.

[387] http://www.hyweb.de/index-e.html

[388] Wed, 24 Oct 2007 http://motoring.iafrica.com/newsbriefs/659443.htm.

[389] http://www.hyweb.de/News/gazette.html#HondaUnveilsFCXClarity071115
http://www.autospider.org/index.php/2007/11/16/2007-los-angeles-auto-show-honda-home-energy-station-hes/

Fuel cells are the enabling technology for a hydrogen energy-based economy. However, the coming of fuel cell systems is an advantage (efficiency, range for automobiles) but not a requirement for the use of hydrogen as an energy carrier. While waiting on the fuel cell vehicle, there have also been a return to the predominant thinking prior to the mid 1990s namely burning hydrogen in modified internal combustion engines (ICE) as an alternative to gasoline in ordinary internal combustion engines. Quantum's hydrogen hybrid is used in hydrogen demonstration projects around the world. Ford is developing hydrogen combustion engines as a bridging technology, and BMW launched its first series production of H2 ICE vehicles in November 2006 that is bivalent, which means that they can be driven by H2 as well as by conventional gasoline. This is an advantage in terms of flexibility and may increase demand for hydrogen as a fuel for cars; especially in the light of the fact that the emergence of a significant network of H2 fuelling stations is not yet clearly visible. The BMW solution may provide an elegant and pragmatic bridge between the petrol past and the hydrogen future. The ability to run on clean burning hydrogen for 125 miles, and then seamlessly switch to traditional gasoline for an additional 300+ miles of range, provides unmatched flexibility for long distance driving and intermittent hydrogen fuelling infrastructure. Hence hydrogen fuelled combustion engines are considered as instrumental in the build-up of hydrogen demand and to speed up the long-term trend towards fuel-cell propulsion hydrogen vehicles and the service station infrastructure they require.

In a way there has been a full circle here. It was the conviction of hydrogen supporters from the 1970s through the early 1990s that hydrogen should be used in modified internal combustion engines as an alternative to gasoline in ordinary ICEs (Hoffman 2002). However, in the 1990s, fuel cells became widely recognised as vanguard technology that could launch hydrogen energy to become an environmentally benign and renewable component of the world’s energy mix for stationary and transportation applications. With the commercialisation date on fuel cells being pushed out in time, there has been a renewed focus on hydrogen fuelled combustion engines facilitating a corridor and transition.

10.3.4 Infrastructure

"Talk to anyone in the fledgling industry for a few minutes, and inevitably they'll bring up the old barnyard cliché about chickens and eggs. What comes first? The pumps? Pipelines? Fuel storage? The cars? They remain prohibitively expensive, because so few are made and because fuel cells are still a work in progress" Santa Barbara Press 2008)

Infrastructural development is an unsolved puzzle. No infrastructure for a hydrogen based energy system exists; it needs to be build to support stationary as well as mobile applications. This will take time and money, and there is a "chicken-egg" type problem; that is a market for fuel cells requires that hydrogen is available and a market for hydrogen requires that fuel cells are available. There is no incentive to develop H2 delivery infrastructure until there is substantial demand from H2 users. There is no incentive to produce H2 technology (e.g. fuel cells for stationary el and heat production or cars) until there is adequate H2 delivery infrastructure. To illustrate, producers of hydrogen are waiting for car companies to put fuel-cell-powered vehicles or hybrids (e.g. using el or with hydrogen burned in an internal combustion engine) on the road. On the other hand, car manufacturers are waiting for a system of distribution that is hydrogen filling stations from hydrogen producers, but who wants to put an infrastructure in place when there is currently limited demand / use? The development of a hydrogen infrastructure with critical mass and availability at the retail level is a key challenge. How and who should establish the necessary infrastructure?

There are many possible paths for making and delivering hydrogen, and it is difficult to know which will prevail. The choice of hydrogen infrastructure (production, distribution, storage) is still premature as technical issues with major impact on the infrastructural choice, such as hydrogen storage and fuel cell concepts, are still being worked out. Any construction of hydrogen supply is linked to uncertainty about market volume, demand and utilisation of capacity in the built up phase. Only thinking in terms of today's existing natural gas and petroleum distribution systems may not be good models to mimic for hydrogen distribution at early stages of hydrogen use because the cost would be untenably large and risking that the whole hydrogen transition is stillborn.

To serve both stationary and mobile users, a hydrogen based energy system is likely to rely on small as well as large hydrogen production facilities, access a variety of energy feedstocks, incorporate CO2 capture and sequestration and be geographically diverse depending on local resources. In other words, the development of a hydrogen production infrastructure may evolve along several pathways; the question is to handle the logistical challenge of making hydrogen available, how to get started? The nature of the infrastructure will be determined by where the hydrogen is produced but also by the form that hydrogen is e.g. stored aboard the vehicle (discussed under Hydrogen production). A distributed production infrastructure located at the point of use will require smaller capital investments and minimal transport and delivery infrastructure. In contrast, a centralized production infrastructure with large industrial production sites would achieve the economic benefits of scale and mass production but would require a delivery infrastructure to the hydrogen to points of use e.g. with tankers delivering liquid hydrogen, hydrogen gas pipelines or trailer trucks.

Distributed generation offers a way to overcome the chicken-and-egg problem. Instead of having to deploy a massive H2 infrastructure fully developed at the start, H2 can be made available at a smaller scale, on-site where the hydrogen is needed and gradually ramped up; synchronising uses and the build up of infrastructure. Initially, hydrogen is likely to be produced using existing energy systems based on different conventional primary energy carriers and sources. However, to realise the environmental promise of the hydrogen economy, zero-carbon energy sources like renewables will have to become the most important source for the production of hydrogen, and this will require larger quantities and a more centralised production of hydrogen closer to e.g. giant wind farms, solar plants or biomass gasification power plants from where delivery will have to be made. In many respects, hydrogen is more like electricity than gasoline, and because hydrogen is more costly to store and transport than gasoline, hydrogen will most likely be produced in multiple locations with each generation site serving a regional market. Once a certain level of demand is reached in a region e.g. in a large city, Ogden indicates that a regional centralized plant with pipeline delivery is likely to offer the lowest cost (2006b).

At this stage, demonstration projects are testing different forms of production, e.g. in Europe, the CUTE project and follow up HyFLEET:CUTE are projects testing hydrogen under real life conditions. Testing vehicles and different supply pathways for hydrogen like electrolysis, natural gas steam reforming, and hydrogen trucked. Other suggestions to break the chicken and egg stalemate is to link the transportation sector's need for hydrogen fuelling with the use of stationary fuel cells in businesses located in buildings that could produce and store a stream of hydrogen for the early hydrogen powered cars.

To catalyse hydrogen development, the EU project NATURALHY is also exploring the use of existing infrastructure, the natural gas system to distribute mixtures of natural gas and hydrogen to connect hydrogen producers to hydrogen end users. This would help break the chicken and egg problem; but it requires research as the physical and chemical properties of hydrogen differ significantly from those of natural gas so a system designed for natural gas cannot be used without appropriate modifications for hydrogen. Adding hydrogen will also change the gas properties and, as a consequence, the related risks may change. Separating hydrogen from the distributed hydrogen/natural gas stream for end-use applications also requires investigation.

Needless to say government support during a low volume transition state is needed. Further, the development of renewable energy sources and carbon capture and sequestration are also efforts that should be pursued and supported.

10.4 Sceptics

There are ample sceptics to the notion of the hydrogen economy that question hydrogen as the cure-all solution to global warming, air pollution, fossil fuels dependence and environmental problems, and that hydrogen is wishful thinking and a much-sought magic bullet.

> "So in closing, I would suggest that to effectively communicate about hydrogen we do not need more hydrogen advocates and we certainly do not need more hydrogen cynics. What we need are more hydrogen realists, because that really, is what a credible sceptic is. We need the people who understand the complexities of the problems and are working diligently towards the solutions" (Eggert 2005)

One source of opposition comes from those most concerned about environmental and energy threats and a core concern is that efforts put into hydrogen undermine efforts to reduce greenhouse gas emissions. The key question is: where do you get the energy to create the hydrogen? A pollution-free source for the production of hydrogen is the only sensible thing to pursue. From the perspective of global warming and emissions, it makes little sense to produce hydrogen through energy–intensive processes using greenhouse gas emitting fossil fuels as the energy input. Hydrogen supply can only ever be as secure as the supplies of energy needed to make it. Saying that hydrogen is abundant is misleading and to make any sense as a saviour of the planet, the hydrogen economy must work as either a renewable energy economy or nuclear economy wherefore its prospects depend on the prospect that renewable (solar, wind, tide, biomass etc) or nuclear energy will be able to replace the energy we now get from fossil fuels (Biegler 2005). Linking hydrogen to hazardous nuclear power brings out a different set of concerns. A main point is that the environmental case for developing hydrogen and fuel cells is flawed without large-scale renewable energy production, a position which may be moderated if fossil-based production involves carbon capture and sequestration.

Another concern is that a focus on hydrogen stalls or crowds out initiatives that are more near-term i.e. energy efficiency and investment in renewable energy opportunities. When will hydrogen become practically available and affordable for everyday use? Many think hydrogen is an important alternative for the future but not the near future so why is it being offered as an alternative to immediate action to reduce green house gas emissions? (Lash 2003, Romm 2005).

Addressing this concern, Ogden[390] responds that if energy efficiency and climate change are compelling matters, then the debate should be over the size of the budget. The speed of any transition will depend on the importance that policy-makers place on climate change and hydrogen efforts should not be seen as holding up market-ready hybrid technology and undermining near-term climate-change action. The hurdle to hydrogen is the building up of demand to make it feasible. A hydrogen transition will be a marathon, not a sprint. Hydrogen should be pursued as a component in a long-term energy strategy and hydrogen policy is synergistic with - and must complement and build on near-term policies aimed at energy efficiency, greenhouse gas reduction and enhanced renewable energy investments. Hydrogen vehicles will not happen without those policies in place. Indeed, hybrid vehicles are an essential step on the technological transition to fuel cells and hydrogen. Further, if not hydrogen, then what? No other long-term option, with the possible exception of battery powered electric vehicles, approaches the breadth and magnitude of hydrogen's public good benefits (Ogden et al. 2004, 2006a 2006b). A similar view has been advanced in Norway by the chairman of the Norwegian Hydrogen Council, researcher Steffen Møller-Holst (Klassekampen 24.1.07) who in the context of the transportation sector indicates that electric, bio-fuelled cars and hydrogen-based cars initially with modified internal combustion engines and then with fuel cells are all needed to get emissions down. Basically, the central message is that in future energy systems several initiatives must be embraced and pursued in parallel.

Romm (2005) is a strong advocate of taking a long-term and conservative perspective on hydrogen energy in transportation because overhyping the potential of e.g. hydrogen fuel cell vehicles will not bring them to the market sooner. The pilot projects in hydrogen should seek to answer the key questions about storage, infrastructure, and safety more than speed the number of fuel cell vehicles. Mean while, near term solutions should be embraced and introduced now to achieve petroleum savings and emissions reductions in the near term e.g. through energy efficiency, renewable energy, increased electrification and hybridisation of IC engined, liquid fuelled vehicles. Romm's concern is that money spent on hydrogen is money that could have been spent on near term solutions.

[390] Joan Ogden is one of the world's premier systems analyst for hydrogen energy, who started as nuclear fusion physicists and left this to work with hydrogen since 1985 (Hoffmann 2002)

In Europe, one of hydrogen's most outspoken critics is German researcher, Ulf Bossel, calling it "the hydrogen illusion….and that the recent surge of interest in a 'hydrogen economy' is reflecting visions rather than reality" (Bossel et al. 2003). Bossel was also active in a Norwegian newspaper in January 2007, after the Norwegian Action Plan on Hydrogen was presented by the Hydrogen Council in December 2006. "Drop the plans" was his central message (Klassekampen 22.1.2007). Hydrogen will never be profitable or sensible as it competes with its own energy source. Bossel is concerned with energy use and energy loss in the steps from the production of hydrogen to the use in an engine or fuel cell where hydrogen is converted back into electricity. Where does the energy come from to make and distribute hydrogen? Generation and compression of hydrogen as well as extraction of electricity at the destination are associated with losses. Bossel argues that energy must be distributed and used with highest efficiency and is pro-electricity with the battery as the preferred energy carrier minimizing losses in the chain from the electricity grid and use in e.g. an electric car with a battery charged with electricity from renewable energy sources. "Renewable electricity is better distributed by electrons than by hydrogen." (EurActiv.com 2006).

The issue raised by Bossel is: why bother producing hydrogen at all if you have already got renewable electricity from the sun and wind? The question is, why generate electricity twice, first to produce electricity for the process of electrolytic hydrogen and then again to produce electricity and heat in a fuel cell? One answer is that electricity can be stored only in batteries, which are cumbersome to transport and slow to recharge, while hydrogen can be stored at lower cost and transported in various ways (Rifkin 2003). Mainly because hydrogen like gasoline packs a lot of energy into a small space. And unlike the sun or wind, it can be consumed where and when it is needed. The ability to derive and store hydrogen transforms on- and off energy sources like the sun and the wind into dependable bulwarks of the power systems.

In the US, Harvard and Oxford-educated physicist Amory Lovins with the Rocky Mountain Institute wrote a document called: Twenty Hydrogen Myths (2003, updated in 2005) to deal with what he refers to as *"the great deal of conflicting, confusing and ill-informed commentary on hydrogen"*. He addresses the 20 myths one by one. Myth 2 is that making hydrogen is prohibitively inefficient. Lovins responds that in competitive electricity markets, it may make good economic sense to use hydrogen as an electricity storage medium. True, the overall round-trip efficiency of using electricity to split water, making hydrogen, storing it, and then converting it back into electricity in a fuel cell is relatively low at about 45% (considering electrolyzer - and fuelcell losses) plus any byproduct heat recaptured from both units for space-conditioning or water heating. But this can still be worthwhile because it uses power from an efficient baseload plant (perhaps even a combined-cycle plant converting 50-60% of its fuel to electricity) to displace a very inefficient peaking power plant (a simple-cycle gas turbine or engine-generator, often only 15-20% efficient). This peak-shaving value is reflected in the marketplace. When the cost of peak power for the top 50-150 hours a year is $600-900/MWh, typically 30-40 times the cost of baseload power (~$20/ MWh), the economics of storage become quite interesting. Distributed generation provides not only energy and peak capacity, but also ancillary services and deferral of grid upgrades. Hydrogen storage can also save power-plant fuel by permitting more flexible operation of the utility system with fuller utilization of intermittent sources like wind. Once all the distributed benefits are accounted for, using hydrogen for peak storage may be worthwhile, particularly in cities with transmission constraints (such as Los Angeles, San Francisco, Chicago, New York City, and Long Island). Such applications may be able to justify capital costs upwards of $4,000/kW. Another attractive use of large-scale hydrogen storage would be in places like New Zealand or Brazil, whose hydroelectric systems have too little storage (12 weeks in NZ) to provide resilience against drought - but whose snowmelt or rainy seasons provide cheap surplus hydropower that could be stored as hydrogen.

Also fronting hydrogen as an energy carrier, recent work in the European Hydrogen and Fuel Cell Technology Platform (2006) discuss the functional synergies between hydrogen and renewable energy sources (RES), which is to be understood as the capacity that the combination of RES infrastructures with hydrogen systems can generate in terms of addressing new applications, facilitating integration in the energy infrastructures and improving demand-offer management. By assembling the technologies both paths can be leveraged and hydrogen is hence envisioned as an enabler of renewable energy technologies and is also advanced as working well with hybrid-vehicle technologies and with batteries and plug-ins to extend the limited range of batteries in electric vehicles. To have a highly effective and efficient renewable-hydrogen system, the hydrogen should be used at choice times. At the time when renewable resources are available (e.g., the sun IS shining), and electricity is needed, the electricity should be used directly. To meet an even higher electricity demand, energy can be supplied directly from renewables sources as well as from the hydrogen stores. As demand decreases, extra electricity from renewables can be converted and stored as hydrogen. This entire portfolio of options is what makes renewable-hydrogen systems effective in providing flexible, reliable energy in whichever form is needed most. There are few other options today for electricity storage at a large scale. Batteries are not practical and too costly and pumped water systems and compressed air energy storage systems are only implementable in limited geographical areas.

What may be extracted here is that technical and economic comparison between the alternative strategies, carriers and storage methods are relevant when various applications are discussed. In some applications hydrogen should be used in others it should not. Another maybe more personal frustration when trying to make my way through the jungle of hydrogen claims, is that when the scientific community of engineers, physicists and electrochemists do not agree; how are social scientists, politicians and the public in general supposed to derive at any kind of sound opinion on the pros and cons of diverse energy alternatives and futures? Without a background is chemistry, physics, engineering; it is difficult to evaluate the validity of the claims made for and against hydrogen as an energy carrier. Nevertheless, from the top of my non-engineering head, it seems strange to discredit hydrogen on the basis that it has to be produced. As we speak, or as I write, nonconventional petroleum (oil or tar sands, heavy oil, oil shale, coal) are alternatives exploited where the processing of these sources to yield "oil" require large amounts of other forms of energy such as natural gas and electricity.

10.5 Uncertainty

The uncertainty, in which hydrogen as an energy carrier is intertwined relate to the long time frame and the interrelatedness of technological developments, societal changes, parallel efforts that make it unrealistic to predict a final outcome. Humans live in time in a particular way, we construct goals that refer to presently nonexistent future states and then seek to bring them about. Goals for the future are based on our experience, current situation and performance. Various actors are involved in hydrogen development with their respective visions, intentions and plans that in turn change over time as development is undertaken and as they encounter and work with other actors and organisation with their respective intentions and plans. If a pathway to hydrogen is accomplished, it will be an effect of this intermingling of visions, intentions, action and it will build upon the efforts of many.

Although not empirically pertaining to hydrogen energy, Hekkert et al. (2007) developed a typology on the nature and sources of uncertainties that face and influence actors involved in innovation decisions.

1. Technological uncertainty: uncertainty about the characteristics of the new technology (such as costs or performance), uncertainty about the relation between the new technology and the infrastructure in which the technology is embedded (uncertainty to what extent adaptations to the infrastructure are needed) and uncertainty about the possibility of choosing alternative (future) technological options.

2. Resource uncertainty: relates to uncertainty about the amount and availability of raw material, human and financial resources needed for the innovation. Resource uncertainty both resides at the level of the individual firm, as well as at the level of the innovation system.

3. Competitive uncertainty: Whereas technological uncertainty includes uncertainty about competing technological options, competitive uncertainty relates to uncertainty about the behaviour of (potential or actual) competitors and the effects of this behaviour.

4. Supplier uncertainty: Uncertainty about the actions of suppliers amounts to uncertainty about timing, quality and price of the delivery.

5. Consumer uncertainty: relates to uncertainty about consumers preferences with respect to the new technology, uncertainty about consumers' characteristics e.g. requirements and energy demand of consumers and, in general, uncertainty about the long-term development of the demand over time.

6. Political uncertainty: Political uncertainty comprises uncertainty about governmental behaviour, regimes and policies. Uncertainty can emerge about current policy (e.g. uncertainty about the interpretation or effect of policy, or uncertainty due to a lack of regulation) or about future changes in policy.

From the discussion of hydrogen in this chapter, these sources of uncertainty widely pertain to hydrogen energy and development activities. Considering the entire hydrogen cycle and assessing the prospects of hydrogen as a future energy carrier, Bendixen (2004) indicated that there were basically three main types of technological barriers to a rapid, economic, widespread deployment and use of hydrogen:

1. Energy efficiency of the complete hydrogen cycle (production, distribution and use);
2. Fuel cell costs, operational reliability and lifetimes;
3. Efficiency, safety and reliability of hydrogen storage media for mobile systems; in that order of importance.

The road to a society where hydrogen as an energy carrier is used is a long one. Technical characteristics have not been captured or stabilised; there is an ongoing technological sorting-out process with technology validation and accordingly there is no settled technological order that allows the overall costs to be attached. Infrastructures do not develop overnight, are costly, there is uncertainty as to the extent of adaptations needed to infrastructure and overall little is known about the production and delivery model that will prevail. There is the challenge of producing competitively priced hydrogen including production and distribution costs. There is an issue of the timing and coordination of investments.

Technological breakthroughs are needed to get costs down. As was / is the case with the electric vehicle that 'waited' for a battery (one that would overcome the short range and long recharge time) so too is the hydrogen economy with hydrogen as the energy carrier dependent on technical development in many areas and many industries. Like other novel technology, there are challenges in developing fuel cells and demonstrations are needed to increase performance and to lower costs. Will fuel cells reach their potential and be moved from the lab to the marketplace? When will breakthroughs occur and will another technology come along that reduces the need for the development of hydrogen technology – in other words what is the competition doing?

There is ongoing market preparation to get into the identified applications. Even if fuel cells had the best possible performance, there would still be the challenge of developing hydrogen markets and into the applications identified. The point is that market preparation is a central task, since there is no automatic demand. Getting fuel cells and hydrogen into the identified applications are not clear-cut and takes time. New technology needs time to be established and the question is how to do this?

Demand is also eventually embedded in politicians and consumers who need to be acquainted with a new energy carrier. Hydrogen needs to gain public acceptance and focus also needs to be maintained among politicians for support. Communication and demonstrations are needed to raise awareness and knowledge about hydrogen. Will there be concrete support policies and public / private partnerships to share the costs of hydrogen development, and to support the development of applications and markets in a low-volume transition stage? Will there be political commitment in terms of greenhouse gas emissions' reduction? Will there be renewed concern over security of supply?

A lot is unknown and in the making at the same time and also involves a process of sorting out diverse roles of organisations, companies, research and governments. The path to hydrogen is uncertain and may be a reason not to explore or undertake development in the area; it may also trigger actors to explore a new technology to learn more. Just as perceptions of opportunities and uncertainties are different from organisation to organisation so is the response and how actors deal with uncertainties organisation specific and may only be known by studying practice.

10.6 Summing up hydrogen in the making

The idea of a hydrogen economy as an instant panacea for both energy security and environmental problems is intriguing. Putting into action is an arduous path, and political and private company interest has fluctuated. Already in the 1970s, there were observations in Europe that any new energy system required decades maybe even a century before it could achieve a significant share of the energy system (Hoffman 2002). Cheap oil and gasoline has time and again put hydrogen progress and interest to a halt. With the ever increasing focus on climate change and global warming, there is a surge in interest in cleaner energy technologies combined with national security concerns to replace insecure foreign oil with secure new domestic energy sources. Whether or not a transition in energy systems will be undertaken and how long it will take seems to be a matter of choice, not fate. Maybe hydrogen energy is an old idea whose time has come.

In innovation studies researchers have been interested in describing patterns in development over time, finding that the rate of major innovation for both products and processes follows a general pattern over time. That product and process innovations share an important relationship, namely that the rate of product innovation in an industry or product class is highest during its formative years during which a great deal of experimentation with product design and operational characteristics takes place among competitors. There is technical variation that characterise an era of ferment as it is referred to in evolutionary models. Each competitor hopes to capture the allegiance of users or markets to their respective designs, and there is product variety, products or technologies are non-standard and unique. In a later stage of industry development, product innovation slows down and the rate of major process innovations speeds up. This is so because product variety gives way to standard designs, a dominant design as a synthesis of a number of proven concepts that have either proven themselves in the market place as the best form of satisfying user needs, or designs that have been dictated by accepted standards, by legal or regulatory constraints. Hence as the form of product / technology becomes settled, process innovation takes over and innovations are principally incremental; investments in production technology will be higher and there will be more emphasis on process efficiency the basis for competition begins to shift to product price, efficiency and economies of scale in production. A central contribution is here that the focus in innovative activities shifts with the stage of industry development and that the type of innovation depends on the phase of development (Utterback & Abernathy 1975, Abernathy and Clark 1985, Tushman and Anderson 1986).

How does this relate and what can be said about hydrogen? Maybe it can help say something about where hydrogen is today. It is fair to conclude that hydrogen is in an explorative phase of development with multiple building blocks but no architectural master plan. There is no dominant design but various technological options, potential system combinations are being explored and compete for development, performance improvements, cost reductions and development of applications and markets. As indicated by Lovins (2002):

«In the long run, hydrogen will most likely be made from water, using renewable electricity or possibly just sunlight. Or it may be extracted from oil and perhaps even coal (with carbon sequestration ALK insert) without releasing the carbon into the air. All these options are evolving rapidly and will compete vigorously»

The quote from Lovins relate to alternative production options but in addition e.g. in transportation, there is the challenge building - and the nature of infrastructure which in turn will be determined by where hydrogen is produced and in what form it is stored onboard of the hydrogen vehicle. There is the challenge of thinking out transition or bridging strategies e.g. using combustion engines and exploring on-board reforming options to enable fuel cell vehicles to use existing fuel infrastructures which again depend on the vehicle design strategies of vehicle manufacturers.

There is uncertainty as to how hydrogen will perform as an energy carrier and if moving outside the circle of already converted hydrogen energy advocates and naysayers, there is little knowledge about what hydrogen energy is, its possible uses and the hurdles needed to be overcome. Governments, private companies, and experts have different views and expectations regarding the prospects for hydrogen energy and fuel cells. There is a complex array of technologies and processes for hydrogen production, storage, transportation, distribution, different types of fuel cells, and other end use technologies. There is also a range of competing technologies with the potential to meet, at least in part, some of the same policy objectives.

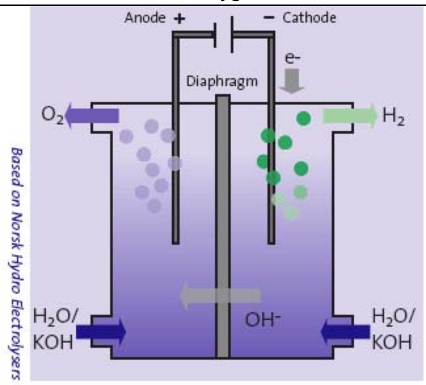
The research that have found that the rate of major innovation for both products and processes follows a general pattern over time may point to where hydrogen as an energy carrier is today; but say very little about where development is going, how and if it will proceed. It is too early to say if hydrogen will become the energy carrier that advocates want it to become. There is nothing inevitable about hydrogen, no natural momentum and it may stop before it ever moves from research and development projects, business development and to a business case.

To sum up from this appendix's review, it is seen that this is a development path with great uncertainty as to its realisation. Although research and development efforts and policies are in the making that relates to cleaner fuels in transportation and cleaner energy supplies in general; there is great indeterminacy and no automatic linkage that hydrogen will be the answer and that a hydrogen energy-based economy will be the ensuing reality and end result. *The key issue therefore becomes: how the hydrogen energy mobilisation is going to happen? And for the purposes of my research, the broad and general interest that has driven my project has been how the organisation studied has organised and navigated in relation to this open-ended and uncertain setting of hydrogen energy.*

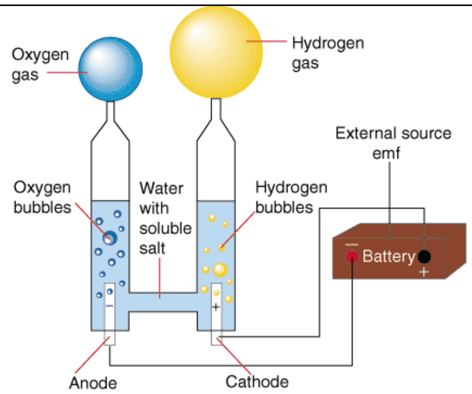
11 Appendix II factsheet electrolysis

A water molecule is formed by two elements: two positive Hydrogen ions and one negative Oxygen ion (ions are electrically charged atoms). The water molecule is held together by the electromagnetic attraction between these ions. When electricity is introduced to water through two electrodes, a cathode (negative) and an anode (positive), these ions are attracted to the opposite charged electrode. Therefore the positively charged hydrogen ions will collect on the cathode and the negatively charged oxygen will collect on the anode. When these ions come into contact with their respective electrodes they either gain or lose electrons depending on there ionic charge. (In this case the hydrogen gains electrons and the oxygen loses them) In doing so these ions balance their charges, and become real, electrically balanced, bona fide atoms (or in the case of the hydrogen, a molecule).

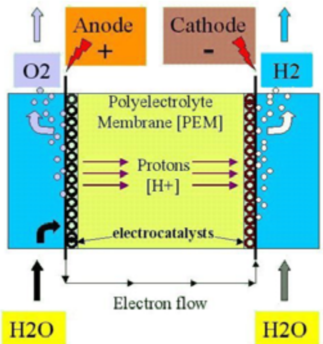
Three types of industrial electrolysis units are being produced today. *Two* involve an aqueous solution of potassium hydroxide (KOH), used as the electrolyte, because of its high conductivity, and are referred to as *alkaline electrolysers.* These units can be either unipolar or bipolar. The unipolar electrolyzer resembles a tank and has electrodes connected in parallel. A membrane is placed between the cathode and anode, which separate the hydrogen and oxygen as the gasses are produced, but allows the transfer of ions. The bipolar design resembles a filter press. Electrolysis cells are connected in series, and hydrogen is produced on one side of the cell, oxygen on the other.



Schematic of Water Electrolysis



The third type of electrolysis unit is a Solid Polymer Electrolyte (SPE) electrolyzer. These systems are also referred to as PEM and PEM is derived from the electrolyte used which is a proton-conducting polymer foil. PEM stands for Proton Exchange Membrane or Polymer Electrolyte Membrane. The electrolyte is a solid ion conducting membrane as opposed to the aqueous solution in the alkaline electrolysers. The membrane allows the H+ ion to transfer from the anode side of the membrane to the cathode side, where it forms hydrogen. The membrane also serves to separate the hydrogen and oxygen gasses, as oxygen is produced at the anode on one side of the membrane and hydrogen is produced on the opposite side of the membrane.. Both sides of the membrane are coated with a thin layer of catalyst material. These two layers form the electrolyser's negative and positive electrode.



12 Appendix III HPE path

12.1 HPE development

In the HPE path, the technology is based on alkaline electrolysis technology. The development dimensions are multiple. The technology seeks to enhance security with a new lye circulation system making it more secure in terms of leakages. It is with a new electrode assembly to decrease losses referred to as a zero gap design between the electrodes to increase energy efficiency. A compact design shall allow cost savings in gas compression, gas storage and gas handling.

The new development also relates to a process for switching off the electrolyser in which the reliable inerting of the electrolyser is possible with a minimum amount of inert gas, and it shall be possible to switch off the electrolyser without decompressing it[391]. German patent rights were filed for December 2002 and granted November 2003[392]; and intellectual property was sought through an international patent application filed with WIPO[393] in December 2003. The title: pressure electrolyzer and method for switching off a pressure electrolyzer and inventors Rolf Brand (general manager of GHW) and Oddmund Wallevik who works with Norsk Hydro's Research Centre in Porsgrunn.

Extract from the background of the invention in the patent application:

"A vital safety factor in pressure electrolysers of the type specified lies in their capacity to be inerted quickly, reliably and fully i.e. in the removal of the hydrogen from the pressure reservoir and from the hydrogen seperator, such that the residual hydrogen content is well below the lower explosion limit of 4 % by volume….. The object of the invention is to create a pressure electrolyser and a process for switching off a pressure electrolyser in which the reliable inerting of the electrolyser is possible with a minimum amount of inert gas. In particular, but not exclusively, it should be possible to switch off the electrolyser without decompressing it….. Traditionally, large quantities of inert gas, typically nitrogen, are held ready for inerting, it being used to rinse the hydrogen out of the hydrogen separator when the electrolyser is switched off e.g. in the event of an emergency shut down. To

---

[391] Decompressing the electrolyser at speed typically causes damage to the seals and structural components of the cells and means that the subsequent restarting of the unpressurised plant is associated with considerable energy expenditure.

[392] http://www.wipo.int/pctdb/images4/PATENTSCOPE/36/7b/f1/007bf1.pdf

[393] Filed with Die Weltorganisation für geistiges Eigentum (http://de.wikipedia.org/wiki/Englische_Sprache Engl. *World Intellectual Property Organization*, WIPO) 10.December, 2003 by GWH and published July 1. 2004. WO 2004/055242. In the US patent was issued October 23, 2007. In Canada the national patent entry date was 2005-06-13, CA 02509940, http://patents.ic.gc.ca

this end the pressure in the electrolyser may either be maintained or reduced to ambient (atmospheric) pressure in the course of rinsing with the inert gas. In any event, due to the mixing of the gases, a multiple of the gas volume of the hydrogen separator must be held ready in the form of inert gas. Since, due to the evolution of hydrogen or oxygen in hidden caverns, decompressing the elctrolyser at speed typically causes damage to the seals and structural components of the cells and means that the subsequent restarting of the unpressurised plant is associated with considerable energy expenditure. The electrolyser should, where possible, only be decompressed in three genuinely unavoidable emergency scenarios: an electrolyte leak, a product gas leak or critical impurity in the product gas. In all other cases pressure should be maintained when the electrolyser is switched off."

Source: For more technical details on the invention see http://www.wipo.int Intl. Pub. No. 2004/055242

13 Appendix IV PEM path

13.1 PEM development background

PEM development was a Hydro internal project initiated in 2001. Technology development was handled by the Research Centre in Porsgrunn. PEM electrolysis[394] uses a solid polymer electrolyte membrane as the electrolyte also denoted Proton Exchange Membrane (PEM). Large scale production of hydrogen by electrolysis is dominated by the alkaline electrolysis technology. Electrolysers using solid polymer electrolyte become too expensive due to the high material costs, e.g. noble metal catalysts and polymer membrane. However, in a long term perspective where hydrogen may become the main energy carrier and where large scale production of hydrogen takes place from renewable energy sources, the energy efficiency of the electrolyser will become essential. The solid polymer electrolyte electrolyser has been proven as the most promising system with respect to high energy efficiency and high current density[395], yet

[394] The PEM electrolyser is the twin brother of the PEM fuel cell as they do the opposite of each other; electrolyser (from H20 to H2 and O) and fuel cell (recombines hydrogen and oxygen gases to produce water and an electric current).

[395] Current density is a measure of the density of flow of a conserved charge. Usually the charge is the electric charge, in which case the associated current density is the electric current per unit area of cross section. http://en.wikipedia.org/wiki/Current_density. In PEM development, the energy efficiency and the current density of the system is determined by the noble metal catalysts, which constitute the critical part of the electrodes (Rasten 2001).

research has been important to bring down material costs of such systems (Rasten 2001).

Proton Exchange Membrane (PEM) has gained a large interest due to the absence of a hazardous electrolyte and is for this reason more suitable in energy production and applications that are in close proximity to people e.g. users or owners of equipment. PEM does not have the safety challenges that are linked to the alkaline electrolysers that use a lye circulation system, where you have to have processes and equipment to handle the caustic and corrosive fluid and where there is a risk of leakages posing a risk to life and health (see fact sheet). As there is no lye circulation, PEM opened up for closer proximity to the public and new uses where the operator is not a "chemist".

As a matter of fact the use of PEM electrolysis has its origin very close to people, namely in space shuttles where the risk of lye leakages would have disastrous consequences. Water electrolysis using polymer membrane as the electrolyte was first developed by General Electric Company in 1966 for space applications with NASA as the key sponsor. The General Electric concept was sold in the beginning of the 1990s, and PEM units have been sold to space and military applications like submarines (to produce oxygen); a market with a high willingness to pay and little consideration of costs. This was the point of departure for commercial development and made up existing PEM knowledge and experience. PEM development was entangled with this market segment, and hydrogen as an energy carrier by comparison, is at the other end of the scale where investment - and production costs are extremely important.

The PEM development efforts were based on the competence of mainly one researcher, Egil Rasten[396] who finished his PhD thesis in 2001. The development potential of NTNU research results and the continuation of such development in Rasten's doctoral project were projected and made known to NHEL as early as the spring of 1997, when a research team from NTNU (2 professors, 2 researchers and Rasten) visited NHEL at Notodden in the spring of 1997. Rasten's PhD thesis and project, was to be financed by NFR but the research team was hoping to get NHEL to be interested in the project. The research team from NTNU presented recent research results[397]

[396] PhD from 1997 to 2001 at NTNU with The Department of Materials Science and Engineering. PhD thesis: Electrocatalysis in water electrolysis with solid polymer electrolyte. Development and optimization of the electrodes in a water electrolysis system using a polymer membrane as electrolyte have been carried out in this work. A cell voltage of 1.59 V (energy consumption of about 3.8 kWh/Nm3 H2) has been obtained at practical operation conditions of the electrolysis cell (10 kA ·m−2, 90 ◦C) using a total noble metal loading of less than 2.4 mg·cm−2 and a Nafion ® -115 membrane. It is further shown that a cell voltage of less than 1.5 V is possible at the same conditions by combination of the best electrodes obtained in this work.

[397] Steffen Møller-Holst was part of a meeting with NHEL's Christoffer Kloed in the spring of 1997 and presented test results that showed great potential for increasing the hydrogen

and new project ideas. But at that point of time NHEL was not willing to participate and commit support to the project.

The lack of commitment and interest in the development of a PEM technology project, an entirely different electrolyser technology involving to NHEL hitherto different, less understood, and costly materials (noble metals), may be understandable when considering that NHEL was still trying to secure its position in the Hydro organisation; as it was shuffled around in the Hydro organisation during the 1990s, and its fate unknown as electrolysis was seen more as a non-core activity. 1997 was still a time where hydrogen did not have a secure position as strategically important nor as an energy related business venture to be pursued by Hydro Energy (the Energy Division in Norsk Hydro ASA). The integration of NHEL into Hydro Energy did not occur until the decision to establish the Hydrogen Unit in 2001.

There was also a challenge in detecting researchers' competence, knowing the extent and implications of research and lab test results and their significance and potential for industry. Sometimes a wait and see attitude is adopted and sometimes what seems to be industry reluctance and a "dragging your feet pace", may be because the timing was not right or the technology's potential was poorly understood. PEM development in Hydro was subsequently taken on at a point in time when the crisscrossing of pioneer activities at NHEL, research initiatives in Hydro and the mobilisation of hydrogen as a strategic business area came together in the establishment of the Hydrogen Unit in 2001, and with NHEL activity conceived as a relevant to Oil and Energy activity. The hydrogen research and projects that had been undertaken contributed with information based on which it was possible to consider the potential value residing with Rasten's competence.

13.2 PEM development path

Rasten worked on his PhD project in PEM electrolysis development from 1997 – 2001. As mentioned before, the commercial development of PEM electrolyser technology had hitherto been entangled in an entirely different market context where cost was not a dominant requirement. From day one, the focus of Rasten's doctoral work was to focus on hydrogen as an energy carrier and the objective was to bring down the high material costs of the

production volume at a given unit size. This was part of Møller-Holst's work as a senior researcher with Nordic Energy Research in 1996 /1997 which included a stay in Germany with laboratory work and test runs on PEM-based electrolysis. His work looked into regenerative fuel cells. That is technology that is reversible and can be run in electrolysis mode, splitting water to produce hydrogen, and then producing energy in the fuel cell by recombining electricity with h2.

electrolysis system; to work on energy efficiency and the current density of the system, which in turn are determined by the noble metal catalysts that constitute the critical part of the electrodes[398]. During his doctoral work, there was no formal point of contact or regular interaction to nurture an attention and interest in the project from NHEL. Still, Rasten was actively communicating about the potential of the technology in the milieu at NTNU, as he puts it: "I raced around with a small model that showed what this technology could do". What Rasten accomplished did not go unnoticed among his fellow researchers. Former colleague Møller-Holst[399] attributed all the honour and break-through potential to the skilfulness of Rasten.

«During his PhD work Rasten achieved performance and efficiency at world class levels. He used existing results, looked at previous procedures for making PEM technology, looked at weaknesses, ways to improve, changed recipes, used literature and his understanding surpassed the knowledge of advisors and colleagues. Had he been an average doctoral candidate, he would not have managed to accomplish what he did. Rasten is far from average and he took this further than anyone and got world class results. He should be honoured for his results and technology development which is the foundation of the PEM electrolysis development taking place in Hydro»

Rasten indicated that at the time he started his doctoral project, the promise or propositions on the capacity and performance potential of PEM technology was described in the academic world. However, projections in academia outlined the high cost of noble metals as well as the membrane as the major cost barrier and the crucial challenge. PEM potential was in a way known theoretically and experimented with by organisations in Japan, Germany and the US. So there were available information and publications, feasibility studies on hydrogen as an energy carrier with PEM electrolysis as the hydrogen producing technology. Rasten pointed out that he has not managed to be the first in doing any particular thing, but he managed to do it better and achieved the best results in the world on energy efficiency and production efficiency that is producing the highest volume of hydrogen per unit area with the lowest energy input possible.

After completing his doctoral work, it may seem that the transition to Hydro and NHEL - a world leader in electrolysis - was something meant to happen yet it could very well have turned out differently. Landing his position in Hydro's did not follow the recipe of a carefully timed and

[398] The main key to bring down the high material costs of the electrolyser was to further develop and improve the noble metal catalysts, which facilitate: lower amounts of noble metals, higher energy efficiency, higher specific production capacity, longer life time (Rasten 2001:8).

[399]Researcher Steffen Møller-Holst now works with SINTEF and is the chairman of the Norwegian Hydrogen Council.

planned company resourcing strategy. Actually, Rasten as a resource was close to slipping away to benefit another country and NHEL's chief competitor in water electrolysis. At the end of his PhD work, Rasten had achieved world class results in his lab tests and at an anniversary celebration at the Department of Materials Technology and Electrochemistry; Rasten had a mini exhibition with his results. One guest turned out to be central in raising the researcher's confidence about the importance of his results. In Rasten's words:

«One of the visitors at the faculty's anniversary was Hydro's water electrolysis guru from the 1950s – Knut Andreassen - who developed Norsk Hydro's catalytic coating He could see that these were good test results and he said to me that Hydro ought to be interested in this»

This conversation led Rasten to believe that he might be able to work in Norway after all and he contacted NHEL once more. Rasten wanted to continue working with PEM technology and the achievements from his doctoral work, and at the time he was in negotiations with Canadian Hydrogenics (Hydro's largest competitor in water electrolysis). As he recalled, he had a Friday deadline to sign and return an employment contract with Hydrogenics. He called NHEL on Thursday, spoke to managing director Christopher Kloed on Friday, whom with support from Bauman Hofstad (working with the director corporate of research, Sund) offered Rasten a job on Monday. Rasten was hired via NHEL and transferred to Hydro's Research Centre in Porsgrunn to continue his work with PEM development. Kloed recalled that there was scepticism towards hiring Rasten without clear plans and budgets and only further down the line there was a wider recognition that the development started was sensible. But at the time (2001), it was a matter of seeing a researcher with a unique and valuable competence, getting hold of Rasten and to jointly make the plans.

Once hired, Rasten has been the main brain and the central resource in the development of Hydro's PEM water electrolysis concept and has taken it from lab scale to industrial scale from 2001 through 2007, and in parallel with technology development, the production process has also been developed. The challenge was to convert Rasten's results into a commercial undertaking in an industrial organisation accustomed with research in multiple disciplines yet to which this was an unknown technological area. Rasten had from the onset of his doctoral work been concerned with the commercial direction and used techniques that would be transferable to a commercial process. To illustrate, he had chosen lab methods that he knew would be possible to scale into production, and where he knew technology existed for subsequent production. During his doctoral work, a small electrolyser cell was put together, yet identical and representative of the electrolysis process in a larger cell. This was used for all measurement purposes and development of electrodes.

Coming into the Hydro organisation; the first year was used in the area of communication and demonstration; demonstrating and proving that his results were indeed believable, real and replicable. "I have done many presentations inside Hydro to explain what I am working on and to make people understand the importance of my results"[400]. During 2002 a small laboratory was established and during the first 6 months, a single cell with a 5 cm2 cell area was put together and the world's best laboratory electrolysis performance results were demonstrated in terms of energy efficiency and production density that is producing the most hydrogen with the least possible energy. For long term testing, a small electrolyser with a 10 cell series with a 50 cm2 cell area (producing 0,2 Nm3 H2/hour, small commercial scale) was put together and tested during the year and proved a better performance than typical commercial PEM electrolysers.

The challenge was to prepare for a commercial phase with a process for industrial production. The first couple of years, concept development and research and development challenges were worked on to transform this into commercial technology. Dimension for development, improvements and R&D challenges were summarized as follows (Rasten 2004): active and stable catalysts; PEM electrode production technology - effective mass production and high performance electrodes; corrosion protection of titanium; stack design - manage gas and water transport, heat balance, effective stacking, simplicity, cost; and system integration - stack, control system, safety.

After Rasten took his results to Hydro, development could have been taken in multiple directions to commercialise the technology. Multiple technical paths could have been chosen e.g. in terms of methods and materials use, and the chosen path influenced the continued process and efforts to develop commercial technology solutions. Choosing a path was a balance between interfaces of elements e.g. materials, possibilities for cost reduction, performance requirements, durability, and mass production while maintaining the desired performance characteristics.

The chosen path concerned elements that were carefully kept business secrets but Rasten exemplified by mentioning the electrolyser electrodes that they manufacture, which include the membrane and the catalytic powder coating applied to the membrane to catalyze the electrolysis reaction. Scaling up catalyst production was a tremendous challenge to which there was no immediate solution. In his doctoral work, Rasten was in the vicinity of producing milligrams at a time, however the method and catalyst produced, went dead when trying to scale it to the production of several hundred grams for larger systems. Part of PEM technology

[400] Based on interview with Egil Rasten 21.9.2005

development was to produce the catalyst applied to the membrane, and the development of the Hydro concept was unique. A method was developed to produce the catalyst on a large scale without compromising efficiency and performance (e.g. produce 1 kg or 1 tonne of the catalyst without compromising performance). This method became intrinsically linked to Hydro's technological history and expertise in electrolysis, aluminium and magnesium; as Rasten puts it: "Norsk Hydro is probably the only place in the world where this way of producing the catalyst could be conceived".

Hence bridging historical competences, Norsk Hydro's pool of human competences and the infrastructure at the Research centre was vital. The devil was in the detail and the way e.g. membrane and catalytic coating was developed is one area where PEM technology producers differ. Materials choices influenced the ability to mass produce, possibilities to reduce costs, durability and lifetime, and the eventual technology reflected the interface between such requirements. Rasten further indicated that a significant finding in the project was that albeit the academic focus was with the costs of the membrane and noble metals (and hence the focus on energy efficiency and production per unit area of the electrode); Rasten found that when taking the technology to a commercial scale, the costs of the noble metals and membranes were of less proportion in the total system and cost structure. Compared with conventional technology, the PEM technology system was 'simpler' in the sense that it needed to handle only water, while alkaline technology in addition needed process equipment and a system to handle 80 degree lye that is a caustic and corrosive liquid.

As the lead researcher, Rasten was part of the whole process going from ideas, building, testing, scaling and develop a production process. After the initial year, he started to build cell stacks; stepwise more cells together and larger and larger cells, larger production, pressure and to entire process systems; and to building prototypes. In 2003 and 2004 subcontractors were established for all non-core technology. Infrastructure for production and testing of small PEM electrolysers was established and expanded (effective mass production, high performance of electrodes; a material test lab for small single PEM cells for catalyst- and corrosion research and in-situ electrochemical techniques; and a test lab for PEM electrolysers of commercial scale). In parallel with PEM composition and cell stack development, the production process was developed that would allow production to be scaled[401].

In 2004 and 2005 a strategy for commercialisation was worked out, the prototype was tested and developed further, and a commercialisation

[401] To demonstrate scalability, a larger electrolyser was built (a 1000 cm2 cell area, 10 cells in series with production and 4.2 Nm3 H2 / hour (22/9/2005); and in 2004 a prototype was put together to demonstrate pressurised electrolysis with 50 cells in series, 500 cm2 cell area, at 30 bars pressure producing 10 Nm3 H2 / hour.

path was pursued by linking the prototype with the NHEL organisation and NHEL people responsible for electrolysis sales (PEM as well as alkaline technology). NHEL at this point started to leave its mark on the technology in the sense that NHEL was to develop parts of the process system and the system around the electrolyser. NHEL started to shape the technology by making technical demands, cost demands, size requirements for it to fit into their commercial concept. Since 2004, NHEL progressively came into the process and started to define the product and make demands to the technology package hitherto developed by the Research Centre. NHEL started to shape the technology to their customer segments in a way that the research team would be unable to do singlehandedly due to their distance from the actual application contexts and demands from user. Hence initially, the Research Centre was granted space to innovate and to develop the PEM technology concept and performance results with the project observed by NHEL from the sideline until a technology package was ready, which NHEL could subsequently shape. Further, although NHEL was to be the supplier of electrolyser technology, production capacity for the cell stacks for the initial sales was planned at the Research Centre laboratory. In the beginning, the cell stacks were to be produced at the Research Centre, while the process equipment was to be produced at NHEL, Notodden, and in which the cell stack would be assembled.

The plan was to initiate sales in 2006 with capacity of 10 NM^3/hr for applications with smaller hydrogen production requirements. The initial market was envisioned as demonstration projects where PEM electrolysis would be implemented to serve emerging fuel and energy markets, where PEM was suitable for the smaller capacity ranges of hydrogen generation and suitable in areas in closer proximity to people (e.g. users or owners of equipment) as PEM technology did not require placement in specifically defined hazardous areas. However, PEM technology was also expected to be attractive for already existing industry markets and capture sales in industrial applications e.g. the PEM brochure from 2006 mentioned the technology as a perfect choice for generator cooling.

After the commercial launch in Hannover 2006, however technical problems created a setback that made it necessary to stall sales and to prolong the testing phase. In 2007, the manager of hydrogen in Hydro’s New Energy unit indicated[402] that two completely new and compact electrolysers were “soon ready for the market”. That is both the HPE/GHW and PEM technologies were expected to be ready for sale from 2008.

[402]http://www.forskningsradet.no.*Snart klar for markedet*, RENERGI news nr. 3, 2007