CARBON CAPTURE – FROM WASTE TO ENERGY

A STYLIZED CASE FROM A PIONEERING INITIATIVE AT KLEMETSRUD, OSLO

Report to the CLIMIT – demo project 618215: Potential for financing and pricing Carbon Capture in Waste-to Energy Installations in cities

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[2] We are also grateful to Mathew Little for excellent text editing.

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However, we wish to underline that BI and IFE are fully responsible for the analysis and conclusions.

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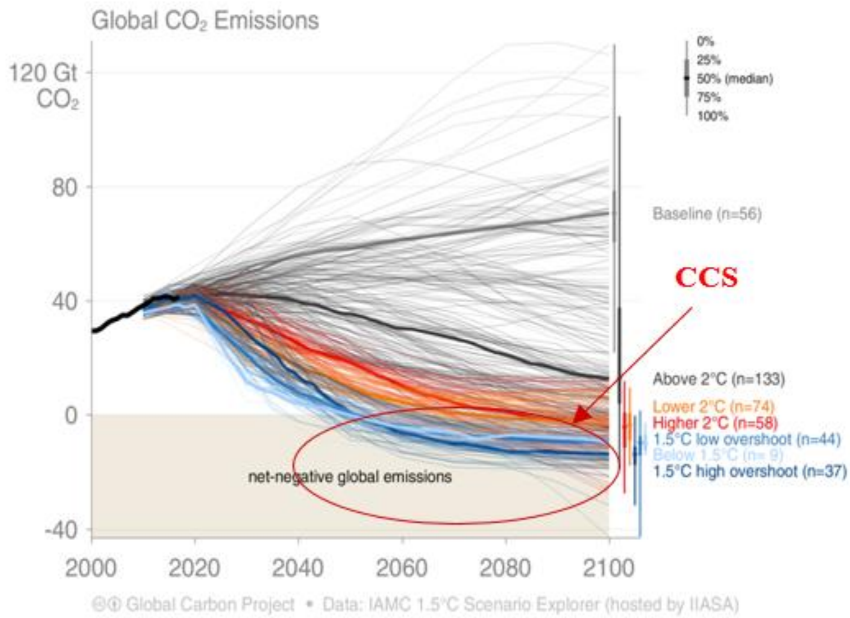
1 THE CONTEXT

Oslo has recently been given the European Environmental Capital award for 2019, following its adoption of an ambitious green strategy of reducing CO_2 emissions by 50% by 2022, and by 95% by 2030. A core premise for Oslo reaching its goals is, however, that the city's waste to energy plant installs carbon capture for sequestration (CCS). With 400,000 tons of CO_2 emissions per year (Fortum 2019), Oslo's Klemetsrud waste to energy plant is the largest single point carbon emitter in the city, and with these emissions it will be impossible for Oslo to reach its CO_2 targets.

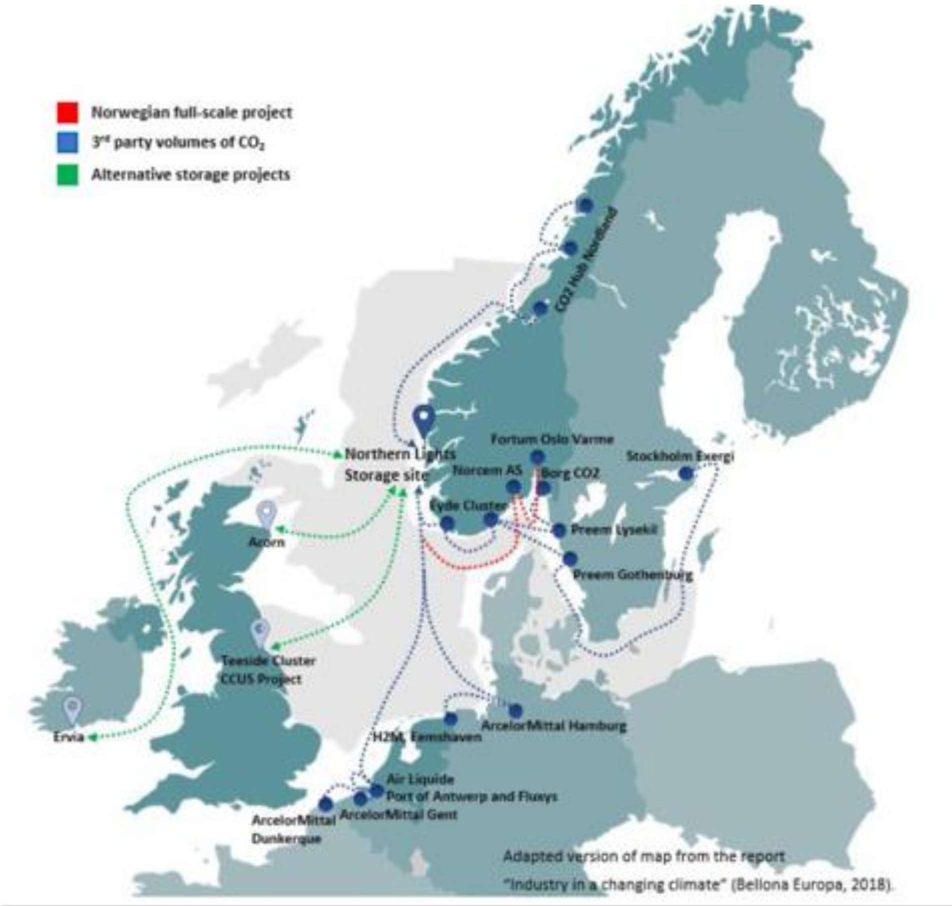
However, carbon capture at Klemetsrud also carries significance in a wider global climate perspective. Global climate models are increasingly reverting to CCS in order to arrive at scenarios that are compatible with the Paris Agreement (Figure 1). This has created new pressure for CCS implementation, and Klemetsrud – if successful – could be an important trigger for CCS in Europe.



Source: Global Carbon Project

Figure 1: Global CO_2 Emissions

Previous attempts at CCS in Europe have experienced serious setbacks. It is enough to mention Vattenfall's Schwarze Pumpe project in Spremberg, northern Germany, where the Swedish company, installed a €70m Carbon Capture project, but ended up venting the CO_2 straight into the atmosphere because of public protest against its storage (Slavin and Joha 2009). In this respect, Oslo, and other cities around the North Sea basin, are in a unique position to link up with the North Sea offshore sector in catering for a complete carbon value chain. A newly launched "Northern Light" project, spearheaded by Equinor, Shell and Total, combines industrial sources of CO_2 from Norway and other counties with safe storage offshore on the Norwegian continental shelf (Figure 2). The project builds on 22 years' operational experience in storing 22 million tons of CO_2 (Sandberg 2019)



(from Sandberg 2019)

Figure 2: the Northern Light Project

It is the combination of ambitious greening at the city level and offshore industrial engagement that gives reason to believe that the Klemetsrud project may have a chance of success. Offshore oil companies like Equinor, Shell and Total – that together front the Northern Light project – have more stakes than most in promoting CCS, both in terms reusing geological deposits after oil extraction, and of adding second life to ships, rigs and other offshore equipment following the coming decline in petroleum resources. Not to mention the vision of gas-to-hydrogen production with carbon sequestration, which could imply a new spring for gas in a carbon-constrained world.

2 STIMULATING TRANSFORMATION

Establishing carbon capture at Klemetsrud involves stimulating transformative technology development to further important societal goals. The implementation of CO_2 capture in the Fortum waste-to-energy (WtE) plant at Klemetsrud will not only enable Oslo Commune to reduce its emissions by about 12%, but also to introduce CCS in this area, prompting systematic implementation and deployment of the technology for Waste to Energy plants.

The Shell Cansolv amine technology that has been selected by Fortum is a patented technology designed and guaranteed for bulk CO_2 removal of up to 99%. Amine scrubbing technology has been previously successfully tested at pilot scale at the Klemetsrud plant with a similar technology to the one provided by Shell Cansolv. A stable CO_2 capture rate of 90% has been obtained[3].

2.1 A LEARNING INVESTMENT

As Carbon Capture (CC) is a technology under rapid evolution, the policy and investment strategy will have to reflect extensive technological evolution as CC moves towards industrial maturity. This is illustrated in Figure 3, where CC moves along the classical *S curve* of technology maturation (upper curve in Figure xxx) which today is a standard reference for technological development (Foster 1986, Sahal 1981, Utterback 1994). The corresponding learning curve (lower curve in Figure 3) reflects efficiency improvements as the technology evolves over time, it is deployed in larger volumes and it benefits from the industrial learning involved (Wene 1999), (Figure 3). As argued by Midttun and Gautesen (2007), the appropriate regulatory tools to drive technology depend on the stage of technology development. They range from early stage R&D policy to technology subsidy policies, niche market policies, and eventually standard competition policy often combined with third party access policy in infrastructure systems, as well as monopoly regulation policy.

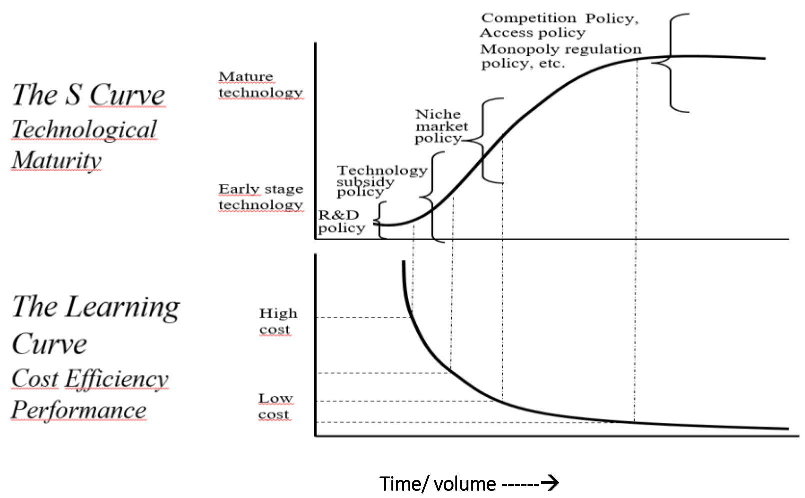


Figure 3: The S curve, the Learning Curve and Regulatory Policy

[3] For further details see Appendix 1 by Julien Meyer

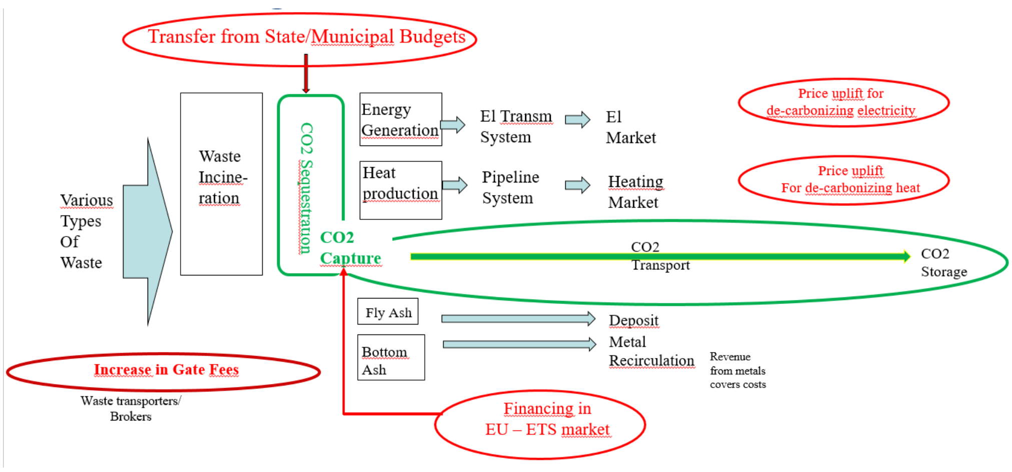
Some of the options for regulatory stimulation of Carbon Capture at early and medium technological maturity include:

1) Financing carbon capture through public budgets, for instance, as investment support.
2) Financing carbon capture through price increases in waste to energy markets by increments in gate fees, heating prices and electricity prices. All according to the 'polluter pays' principle.
3) Financing carbon capture through niche markets such as the EU ETS.
4) Various combinations of the above.

If adequately financially and regulatory supported, there is optimism about advancing carbon capture towards becoming a competitive CO_2 reduction tool. Reflecting expected technological learning, the US Department of Energy (National Energy Technology Laboratory 2013) has already predicted second-generation technologies (defined as those technologies that will be ready for demonstration and deployment from 2025) will reduce capture cost to around 40 US $/ton CO_2 captured. Further cost reductions are anticipated from third-generation technologies, targeted for demonstration in the 2030-35 timeframe and initial deployment in 2035 (National Energy Technology Laboratory 2013)[4].

3 THE BUSINESS ECONOMY OF THE KLEMETSRUD WASTE TO ENERGY PLANT WITH CARBON CAPTURE

For the purpose of financial analysis, the Klemetsrud waste to energy plant can be described as a combination of industrial processes that transform waste into electricity and heat (Figure x) with fly-ash and bottom ash as by-products. The plant derives its income from three main markets: a market for waste with various gate fees, a heating market and an electricity market. CO_2 capture involves the insertion of an additional module with concentrated CO_2 as output – indicated in green (Figure 4). The main access points for financial support – in line with previously listed regulatory options – consist of 1) price increases in the three markets, 2) direct subsidies to cover CC costs, and 3) revenue from the EU ETS market, all shown in red in Figure 4.



[4] For further details see Appendix 1 by Julien Meyer

Figure 4: Klemetsrud plant with CO_2 Sequestration and financing alternatives

Our analysis of the financial aspects of carbon capture at the Klemetsrud plant is based on a standard approach to project economics developed over the last century, taking future revenues, future operation expenses, future capital expenditures, free cash flow, required rate of return, etc. into account (Kruschwitz & Loeffler 2005).

In line with this approach, we have broken down the revenue streams, cost steams and initial investment, as well as the cost of capital, into price and volumes for each of the following segments:

- Capital hurdle rate (cost of capital + risk)
- Production capacity
- Plant life expectancy
- Annual maintenance per production capacity ton
- Market prices electricity and heat
- Market process gate fee for waste, broken down into categories
- Share that becomes bottom ash and associated cost
- Share that becomes fly ash and associated cost
- Cost of carbon capture per ton

The model calculates annual revenues, expenditures and earnings before interests, taxes, depreciations and amortizations (EBITDA). It also includes the cost of capital, before delivering an economic result (that includes the amortization of the plant) with and without the cost of carbon capture. Based on the above, the model will provide the net present value (NPV) and the internal rate of return (IRR).

The analysis is undertaken under different cost-assumptions for the CC plant, respective with today's cost level of 65 Euros per ton; and with a later and more efficient generation of technology that is expected to bring the costs down to 35 Euros per ton. The 65 Euros per ton cost estimate for carbon capture used in our study has been provided by the Klemetsrud staff, and seems credible, although it is in the high range of the spectrum compared to existing studies[5]. Similarly, the anticipated 35 Euros per ton cost for carbon capture technology after a decade or so of industrial learning is also in line with existing estimates in the technical literature.

[5] A review study carried out by Rubin at al. in 2015 [1] assessed the cost of CCS for different applications. The cost of CO_2 avoided has been calculated for supercritical pulverized coal power plants with current post-combustion capture technology, bituminous coals as fuel, and 90% CO_2 capture rate. The study shows cost of CO_2 avoided ranging between 57 and 70 US $/ton CO_2 (2013 US $). Additionally, a study carried out by Foster Wheeler [2] in the framework of the IEA-GHG (IEA Greenhouse Gas R&D Programme) in 2014, for the same application and using the Shell Cansolv amine technology, shows a cost of CO_2 avoided of 68 US $/ton CO_2. Considering the fact that the CO_2 concentration is probably slightly lower in the case of a municipal solid waste incineration plant compared to a coal-fired power plant, and bearing in mind that applying amine technology at the Klemetsrud site will be a 'first of a kind plant', the communicated cost from Klemetsrud staff of about 650 NOK or around 65 Euros per ton of CO_2 for carbon capture is not unreasonable, although it lies at the high end of the spectrum (For further background on costs, see appendix 1 by Julien Meyer).

3.1 ANALYSIS

Using the financial model with data from the Klemetsrud plant, we shall explore financing based on the main regulatory alternatives outlined in the previous section. The model allows us to calculate the financial consequences for the Klemetsrud plant, indicated by the internal rate of return (IRR). At the low end, in line with current municipal practice, we focus on an IRR of 2.45. At the high end, we focus on an IRR of 6.5% – corresponding to normal expectations of companies listed on the Oslo Stock Exchange.

The analysis is presented in the form of tradeoffs between financing the plant through public budgetary allocation (e.g. investment support) and financing through price increases in the waste incineration market (according to the polluter pays principle). We present these tradeoffs under varying costs of carbon capture (today's cost of 65 Euros, and the future cost of 35 Euros); and with and without supplementary financing through the EU emissions trading market. This gives us four sets of assumptions that will frame the following analysis, as indicated in Table 1.

Table1: Four Assumptions

	Without ETS financing	*With ETS financing included*
Today's Cost (65 Euros)	A	B
Future Cost (35 Euros)	C	D

3.1.1 (A) Financing at Today's Cost and without ETS Financing

The (A) alternative is clearly the most expensive. As shown in Table 2, at the two ends of the continuum, an internal rate of return at the municipal level of 2.45 is achievable with support in the range of 51-55 Euros per ton. With an IRR at 6.5 – which is customary at the Oslo Stock Exchange – hereafter called the commercial IRR, the costs would be substantially higher: around 75 Euros per ton.

Alternatively wholly financing the project through a takeout-tariff distributed on the Norwegian incineration market, would entail a price increase of between 7 and 8% at a municipal IRR, and an increase to 10% with a commercial IRR.

As indicated in the table, various mixes are possible, such as 4% price uplift on the incineration market combined with support of around 29 Euros per ton under a municipal IRR, or around 5% and 40 Euros per ton under a commercial IRR.

Table 2: Financing from climate revenue and/or 'take out tariffs on incineration market'

Price Increase / Subsidy per Ton ↓	<---Internal Rate of Return on Invested Capital --->										
80	7,2 %	8,3 %	9,3 %	10,3 %	11,3 %	12,3 %	13,2 %	14,2 %	15,1 %	16,0 %	17,0 %
72	6,0 %	7,2 %	8,3 %	9,3 %	10,3 %	11,3 %	12,3 %	13,2 %	14,2 %	15,1 %	16,0 %
65	4,7 %	6,0 %	7,2 %	8,3 %	9,3 %	10,3 %	11,3 %	12,3 %	13,2 %	14,2 %	15,1 %
58	3,3 %	4,7 %	6,0 %	7,2 %	8,3 %	9,3 %	10,3 %	11,3 %	12,3 %	13,2 %	14,2 %
51	1,7 %	3,3 %	4,7 %	6,0 %	7,2 %	8,3 %	9,3 %	10,3 %	11,3 %	12,3 %	13,2 %
43	-0,5 %	1,7 %	3,3 %	4,7 %	6,0 %	7,2 %	8,3 %	9,3 %	10,3 %	11,3 %	12,3 %
36	-4,0 %	-0,5 %	1,7 %	3,3 %	4,7 %	6,0 %	7,2 %	8,3 %	9,3 %	10,3 %	11,3 %
29		-4,0 %	-0,5 %	1,7 %	3,3 %	4,7 %	6,0 %	7,2 %	8,3 %	9,3 %	10,3 %
22			-4,0 %	-0,5 %	1,7 %	3,3 %	4,7 %	6,0 %	7,2 %	8,3 %	9,3 %
14				-4,0 %	-0,5 %	1,7 %	3,3 %	4,7 %	6,0 %	7,2 %	8,3 %
7					-4,0 %	-0,5 %	1,7 %	3,3 %	4,7 %	6,0 %	7,2 %
-						-4,0 %	-0,5 %	1,7 %	3,3 %	4,7 %	6,0 %
	-	7	14	22	29	36	43	51	58	65	72
	0 %	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	9 %	10 %

(The precise values for IRR at municipal and commercial levels of respectively 2.45 and 6.5 are not computed in the table. One needs to look at the closest alternatives in the table, and then find the relevant support levels on the x and y axes. The IRR in red indicates negative return, and the yellow indicates the lowest positive values that often would be the closest to municipal IRR, while the closest to commercial IRR is not marked)

3.1.2 (B) Financing at Today's Cost and with ETS Financing Included

As it entails removing CO_2 from the atmosphere, CC could potentially be partly financed through the EU emissions trading scheme, which Norway has also joined. At the present level of around 25 Euros per ton, this would cover a substantial proportion of the CC costs, and reduce the need for supplementary support through public budgets, or price increases in the incineration market. Given the Paris Climate Agreement, there are strong expectations for the emission allowances to rise.

Table 3 indicates that total financing through the incineration market would be reduced to 4% (under 2.45% IRR), alternatively the 29 Euros per ton through the public budget, or some combination of the two. With commercial IRR, the figures would be, respectively, 51 Euros per ton or financing through a 7% price uplift over the total incineration market. In addition various combinations are available, as illustrated in the table.

Table 3: Financing at Today's Cost and with ETS Financing Included

Price Increase / Subsidy per Ton ↓	<---Internal Rate of Return on Invested Capital --->										
80	10,8 %	11,8 %	12,7 %	13,7 %	14,6 %	15.5%	16,6 %	17,4 %	18,3 %	19,2 %	20,1 %
72	9,8 %	10,8 %	11,8 %	12,7 %	13,7 %	14,6 %	15.5%	16,6 %	17,4 %	18,3 %	19,2 %
65	8,8 %	9,8 %	10,8 %	11,8 %	12,7 %	13,7 %	14,6 %	15.5%	16,6 %	17,4 %	18,3 %
58	7,7 %	8,8 %	9,8 %	10,8 %	11,8 %	12,7 %	13,7 %	14,6 %	15.5%	16,6 %	17,4 %
51	6,5 %	7,7 %	8,8 %	9,8 %	10,8 %	11,8 %	12,7 %	13,7 %	14,6 %	15.5%	16,6 %
43	5,3 %	6,5 %	7,7 %	8,8 %	9,8 %	10,8 %	11,8 %	12,7 %	13,7 %	14,6 %	15.5%
36	4,0 %	5,3 %	6,5 %	7,7 %	8,8 %	9,8 %	10,8 %	11,8 %	12,7 %	13,7 %	14,6 %
29	2,5 %	4,0 %	5,3 %	6,5 %	7,7 %	8,8 %	9,8 %	10,8 %	11,8 %	12,7 %	13,7 %
22	0,6 %	2,5 %	4,0 %	5,3 %	6,5 %	7,7 %	8,8 %	9,8 %	10,8 %	11,8 %	12,7 %
14	-2,1 %	0,6 %	2,5 %	4,0 %	5,3 %	6,5 %	7,7 %	8,8 %	9,8 %	10,8 %	11,8 %
7		-2,1 %	0,6 %	2,5 %	4,0 %	5,3 %	6,5 %	7,7 %	8,8 %	9,8 %	10,8 %
-			-2,1 %	0,6 %	2,5 %	4,0 %	5,3 %	6,5 %	7,7 %	8,8 %	9,8 %
	-	7	14	22	29	36	43	51	58	65	72
	0 %	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	9 %	10 %
	Polluter Pays - Taxation on all Waste Burning in Norway Required to finance CC at Klemetsrud: Percent is Implied Share of Norwegian Feed-in Tariffs										

(The precise values for IRR at municipal and commercial levels of respectively 2.45 and 6.5 are not computed in the table. One needs to look at the closest alternatives in the table, and then find the relevant support levels on the x and y axes. The IRR in red indicates negative return, and the yellow indicates the lowest positive values that often would be the closest to municipal IRR, while the closest to commercial IRR is not marked)

3.1.3 (C) Financing Under Future Reduced Cost and without ETS Participation

Following industrial learning that brings the costs down to around 35 Euros, a positive rate of return at municipal expectation levels (2.45) can be achieved with support in the range of 29 Euros per ton under financing exclusively through public transfer.

Alternatively, if wholly financed through a takeout-tariff distributed on the Norwegian incineration market, this would entail a price increase of around 3%. Given a commercial IRR, the rates would be 43 Euros or 6%, respectively. In addition, various combinations are possible, as illustrated in the table

Table 4: Financing Under Future Reduced Cost and without ETS Participation

Price Increase / Subsidy per Ton ↓	<---Internal Rate of Return on Invested Capital --->										
80	11,5 %	12,4 %	13,4 %	14,3 %	15,3 %	16,2 %	17,1 %	18,0 %	18,9 %	19,8 %	20,8 %
72	10,5 %	11,5 %	12,4 %	13,4 %	14,3 %	15,3 %	16,2 %	17,1 %	18,0 %	18,9 %	19,8 %
65	9,5 %	10,5 %	11,5 %	12,4 %	13,4 %	14,3 %	15,3 %	16,2 %	17,1 %	18,0 %	18,9 %
58	8,4 %	9,5 %	10,5 %	11,5 %	12,4 %	13,4 %	14,3 %	15,3 %	16,2 %	17,1 %	18,0 %
51	7,3 %	8,4 %	9,5 %	10,5 %	11,5 %	12,4 %	13,4 %	14,3 %	15,3 %	16,2 %	17,1 %
43	6,2 %	7,3 %	8,4 %	9,5 %	10,5 %	11,5 %	12,4 %	13,4 %	14,3 %	15,3 %	16,2 %
36	4,9 %	6,2 %	7,3 %	8,4 %	9,5 %	10,5 %	11,5 %	12,4 %	13,4 %	14,3 %	15,3 %
29	3,6 %	4,9 %	6,2 %	7,3 %	8,4 %	9,5 %	10,5 %	11,5 %	12,4 %	13,4 %	14,3 %
22	1,9 %	3,6 %	4,9 %	6,2 %	7,3 %	8,4 %	9,5 %	10,5 %	11,5 %	12,4 %	13,4 %
14	-0,1 %	1,9 %	3,6 %	4,9 %	6,2 %	7,3 %	8,4 %	9,5 %	10,5 %	11,5 %	12,4 %
7	-3,3 %	-0,1 %	1,9 %	3,6 %	4,9 %	6,2 %	7,3 %	8,4 %	9,5 %	10,5 %	11,5 %
-				1,9 %	3,6 %	4,9 %	6,2 %	7,3 %	8,4 %	9,5 %	10,5 %
	-	7	14	22	29	36	43	51	58	65	72
	0 %	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	9 %	10 %
	Polluter Pays - Taxation on all Waste Burning in Norway Required to finance CC at Klemetsrud: Percent is Implied Share of Norwegian Feed-in Tariffs										

(The precise values for IRR at municipal and commercial levels of respectively 2.45 and 6.5 are not computed in the table. One needs to look at the closest alternatives in the table, and then find the relevant support levels on the x and y axes. The IRR in red indicates negative return, and the yellow indicates the lowest positive values that often would be the closest to municipal IRR, while the closest to commercial IRR is not marked)

3.1.4 (D) Financing Under Reduced Cost and with ETS Financing

If ETS financing is included in the industrial maturity assumption, no additional financial support – under a 2.45 IRR – will be needed. With a commercial IRR one would still need around 22 Euros and a CO_2 takeout support equivalent to a 3% increase in the total incineration market. As with the previous alternatives, various mixtures are available, as illustrated in Table 5.

Table 5: Financing Under Reduced Cost and with ETS Financing

Price Increase / Subsidy per Ton ↓	<---Internal Rate of Return on Invested Capital --->										
80	14,7 %	15,7 %	16,6 %	17,5 %	18,4 %	19,3 %	20,3 %	21,2 %	22,1 %	23,0 %	23,9 %
72	13,8 %	14,7 %	15,7 %	16,6 %	17,5 %	18,4 %	19,3 %	20,3 %	21,2 %	22,1 %	23,0 %
65	12,9 %	13,8 %	14,7 %	15,7 %	16,6 %	17,5 %	18,4 %	19,3 %	20,3 %	21,2 %	22,1 %
58	11,9 %	12,9 %	13,8 %	14,7 %	15,7 %	16,6 %	17,5 %	18,4 %	19,3 %	20,3 %	21,2 %
51	10,9 %	11,9 %	12,9 %	13,8 %	14,7 %	15,7 %	16,6 %	17,5 %	18,4 %	19,3 %	20,3 %
43	9,9 %	10,9 %	11,9 %	12,9 %	13,8 %	14,7 %	15,7 %	16,6 %	17,5 %	18,4 %	19,3 %
36	8,9 %	9,9 %	10,9 %	11,9 %	12,9 %	13,8 %	14,7 %	15,7 %	16,6 %	17,5 %	18,4 %
29	7,8 %	8,9 %	9,9 %	10,9 %	11,9 %	12,9 %	13,8 %	14,7 %	15,7 %	16,6 %	17,5 %
22	6,7 %	7,8 %	8,9 %	9,9 %	10,9 %	11,9 %	12,9 %	13,8 %	14,7 %	15,7 %	16,6 %
14	5,5 %	6,7 %	7,8 %	8,9 %	9,9 %	10,9 %	11,9 %	12,9 %	13,8 %	14,7 %	15,7 %
7	4,2 %	5,5 %	6,7 %	7,8 %	8,9 %	9,9 %	10,9 %	11,9 %	12,9 %	13,8 %	14,7 %
-	2,7 %	4,2 %	5,5 %	6,7 %	7,8 %	8,9 %	9,9 %	10,9 %	11,9 %	12,9 %	13,8 %
	-	7	14	22	29	36	43	51	58	65	72
	0 %	1 %	2 %	3 %	4 %	5 %	6 %	7 %	8 %	9 %	10 %
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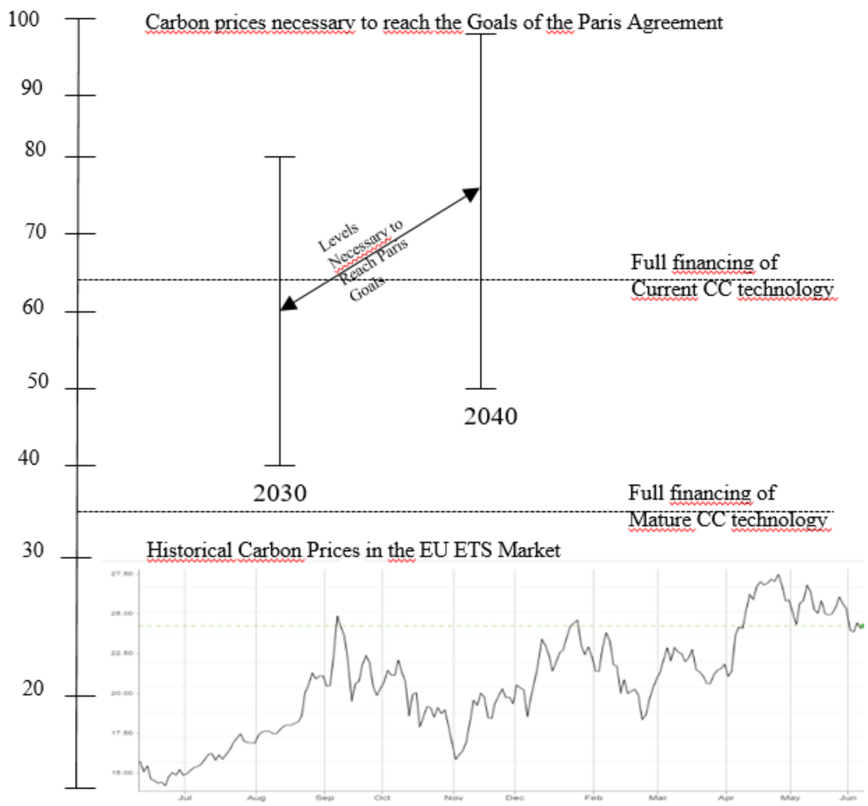
3.1.5 Differentiating Markets

To simplify, we have undertaken the previous analysis with reference only to the waste incineration market, and have calculated the costs of applying the 'polluter pays' principle to that market alone. As the Klemetsrud plant collects close to 50% of its income from the heat and electricity markets, one might argue that the 'polluter pays' principle might be applied to them as well. If this were done, the CC support from the incineration market could be halved, as the heating and electricity markets would provide the other half.

4 DISCUSSION

4.1 POTENTIAL EU ETS FINANCING

Looking ahead, the combination of industrial learning through deployment and increasing pressure towards fulfilling the Paris agreement heightens the chances of fully financing CC through the EU ETS market. With the expectation of a cost for CC falling to around 35 Euros per ton and the present carbon emission allowance of 25 Euros per ton of carbon, this may not be too far away (Figure 5). As indicated in Figure 5, the price per ton compatible with the Paris goals will, according to Carbon Market Watch (2019), have to increase to between 40 and 80 Euros per ton by 2030 and to 50 to 100 Euros by 2040. This implies that even current CC costs would be covered by the expected 2030 carbon price levels.



Sources: Market Insider 2019 and Carbon market watch 2019

Figure 5: Current and Future Carbon Prices under a Paris Climate Policy Perspective

Under such conditions one could imagine a relatively swift transition to commercial viability for CC, and also the gradual covering of storage costs.

4.2 EXPANDING CC TO WASTE TO ENERGY MARKETS IN NORTHERN EUROPE

Municipal waste incineration contains a considerable potential for CC in Northern Europe. With Sweden and Finland weighing in heavily, the Nordic market in 2016 constituted around 22.5 million tons – more than six times the Norwegian market. The countries around the North Sea together incinerate more than 110 million tons[6]. Given the *Northern Light* provision of a complete CCS and transport value chain, the scene could therefore be set for an extensive rollout of CC in the region, one that could drive extensive industrial learning and ensuing cost-reduction.

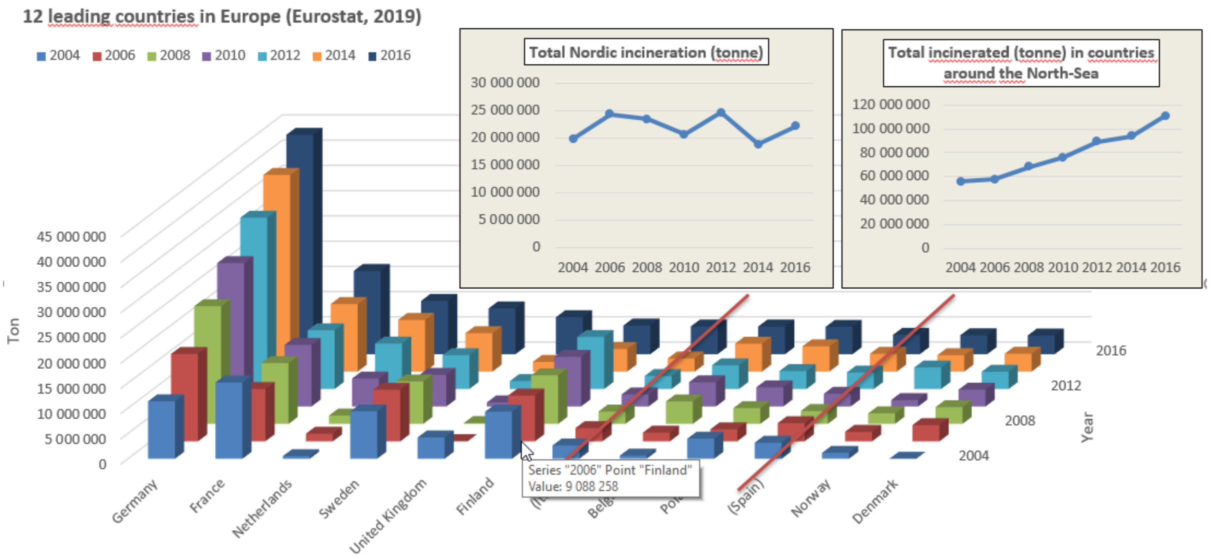


Figure 6: Incinerated Waste to Energy in Selected European Countries

The political signals for CC deployment are ambiguous, however. On the one hand, a landfill ban from 2015 allowing only 10% of waste to be landfilled will be operative as of 2020. Taken alone, this would presumably incentivize incineration and thereby prepare for increased CC. However, the EU Cohesion Fund has announced it will not finance any new combustion facilities, as the EU is prioritizing recycling. Adopted targets as of May 2018 were: 55% recycling rate by 2025, 60% by 2030 and 65% by 2035. Yet, despite a much heralded Circular Economy Ambition, challenges and big differences between EU countries remain. In 2016, ten member states still landfilled over half of their household waste and six of them incinerated 40% or more (EU). There are also limits to how much more of the material that goes into the existing 450 incineration plants each country can recycle. Nevertheless, current trajectory in waste policies unapologetically favours recycling, reuse of materials and direct waste production reduction, not CCS[7].

The Nordic countries face far less public opposition to waste incineration than other EU/EES members. Sweden – which imports more than 14000 tons of Norwegian waste – has a bigger incineration facility park already in place than Norway does[8]. The Swedes' relatively higher interest in CCS is evidenced on the governmental level, yet talk of a Swedish incineration fee indicates a negative impact on CCS potential in their waste sector. Norwegian waste incineration and CCS may, in turn, benefit from a resulting higher Swedish gate fee. Open landfills are prohibited in the Nordics, but closed ones – such as 'mountain holes' and sea landfills – aren't.

[6] Critique has been raised about the accuracy of Eurostat waste data.
[7] For further details see Appendix 2 by Margrethe Storaas
[8] For further details see Appendix 3 by Magne Lia

4.3 Wider Policy Challenges

The policy challenges for CCS in Europe go beyond waste policy. Since the initial optimism leading up to the CCS Directive in 2009, CCS has made scant progress in Europe. This has in part been due to lack of public acceptance for carbon storage, which has not been deemed safe. ETS prices have also been low after the economic setback following the 2007-2008 financial crisis.

In part, CCS also appears to have suffered from competition from renewable energy such as solar & wind that have been viewed as better options. This competition is still noticeable, particularly in the European Parliament, where many see a competition between CCS and renewables for funding.

Nevertheless, there has been some positive development for CCS. The ETS 2021-2030 Directive 2018/410 ensures changes that are believed to restore trust in ETS, and establishes the Innovation Fund financing 60% of project startup costs, with e.g. “Northern Lights” first in line in its application process starting early 2020. In relation to the extensive *2050 Energy Roadmap* process, a text was adopted in a Plenary Session on 14 March 2019 where, for the first time, the European Parliament acknowledges the IPCC’s stance on CCS and supports two EC scenarios that include CCS. Yet, the text reiterates the ‘last resort’ principle and still demands EU prioritizes direct cuts[9].

4.4 Summing Up

To conclude, the “Northern Light” project will, if implemented, create an opportunity for carbon sequestration. North Sea deposits have already been certified, and are currently deployed for ‘gas sweetening’. The engagement by the offshore petroleum industry in carbon sequestration and CO_2 transport, together with industrial and municipal actors engaging in carbon capture, would create an impressive CCS industrial ecosystem with promising potential for innovation and industrial learning. This system could conceivably service large parts of Northern Europe.

The likely further increase in CO_2 prices in the EU ETS market is about to reach levels such that the next generation of carbon capture plants can be wholly financed. In fact, as we have seen, implementation of the Paris climate agreement would likely necessitate emissions pricing at levels that could cover current carbon capture.

Nevertheless, motivating CC politically has been an uphill battle, both because of scepticism towards waste-burning in general – following dioxin scandals – but also because CC is seen as competing with renewables for favourable investment conditions. The ‘last resort’ clause indicates that the EU might need to be further climate-pressed before giving in to carbon capture and sequestration. Many things therefore point to strong initiatives having to come from North Sea front runners. Offshore oil economies like Norway and Scotland have more at stake in promoting CCS than others, both in terms of the reuse of geological deposits after oil extraction, and of adding a second life to ships, rigs and other offshore equipment following the coming decline in petroleum resources. And this is without mentioning the vision of gas-to-hydrogen production with carbon sequestration, which could imply a new gas bonanza in a carbon-constrained world.

[9] For further details on policy see Appendix 2 by Margrethe Voll Storaas

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6 APPENDIXES

6.1 TECHNICAL NOTE - JULIEN MEYER , IFE

CO_2 capture in municipal solid waste (MSW) incineration plants – Oslo's case for the Fortum Klemetsrud waste-to-energy plant

Why CO2 capture in MSW incineration plants?

Today, about 1.3 billion tons of MSW is produced annually. This number is expected to increase up to about 2.2 billion tons of MSW per year in 2025. On average, 1 ton of MSW generates about 1.14 tons of CO_2. Landfilling of MSW generates significantly more CO_2 than incineration. Due to the expected large increase of MSW generation in the coming years and also because strict regulations are about to be applied for landfilling, MSW incineration is likely to be the first choice for treating MSW. In Europe, there are about 450 incineration plants in operation producing electricity and heat for homes and businesses, and this number is likely to multiply. In Europe only, MSW incineration generates about 90 million tons of CO_2 in the atmosphere each year. Therefore, capturing CO_2 – followed by transport and permanent geological storage – from incineration plants has great potential for contributing to the massive reduction of CO_2 emissions required to reach the +1.5°C IPCC scenario. In addition, about 60% of the carbon contained in MSW is biogenic. This means that capturing CO_2 from MSW incineration and sequestrating the CO_2 permanently in geological reservoirs in a BECCS concept (Bio-Energy with CCS) will be carbon negative and represent an efficient measure to reduce CO_2 emissions over the long term.

The implementation of CO_2 capture and CCS in the Fortum waste-to-energy plant at Klemetsrud will not only enable Oslo Commune to reduce its emissions by about 12%, but also to introduce CCS in this area, stimulating for a systematic implementation and deployment of the technology for WtE plants.

CO2 capture technology envisaged for the Fortum WtE Klemetsrud plant

The CO_2 capture technology envisaged for the Fortum WtE Klemetsrud plant is the so-called amine scrubbing technology. This process has been used for decades and is a standard chemical process in the oil and gas industry for removing CO_2 and sulphur dioxide (SO_2) from natural gas (also known as natural gas sweetening or acid gas removal) and for removing sulphur from refinery tail gas streams. It is also employed in the petrochemical sector in the manufacture of fertilizers and petrochemicals such as methanol and ethylene.

A number of amine scrubbing processes are available worldwide and they share the same general design. The major units of an amine scrubbing process are:

- Flue gas blower to facilitate flow of the power plant flue gas to the capture plant;
- Vessel or column for contacting flue gas with the amine solution and removing the CO_2;
- Vessel or column for regenerating the amine solution and releasing the CO_2;

- CO_2 dehydration unit;
- CO_2 compression unit.

Depending on the application and specific proprietary amine scrubbing processes, additional unit operations, such as flue gas cooling, flue gas sulphur removal, and amine purification/reclamation, may be included. Distinguishing features between various processes offered by technology vendors include the use of specialized solvents and mixtures exhibiting performance parameters such as low heat of reaction, fast absorption rate, high capacity for CO_2 and resistance to thermal degradation. Various cost reduction opportunities offered include improved solvent regeneration, higher energy efficiency, and specialized proprietary equipment.

The Shell Cansolv amine technology has been selected by Fortum.

This patented technology is designed and guaranteed for bulk CO_2 removal of up to 99%. The CO_2 capture rate fixed at the Fortum plant is 90%. The key process steps are:

1. The feed gas is quenched and saturated in a circulated water pre-scrubber.

2. Gas contacts the lean amine solution in a counter-current mass-transfer packed absorption column.

3. CO_2 is absorbed and the treated gas exits to atmosphere.

4. CO_2-rich amine from the absorption column is pumped through a lean–rich amine heat exchanger and then on to the regeneration column.

5. Rising, low-pressure saturated steam in the column regenerates the lean amine solution. CO_2 is recovered as a pure, water-saturated product.

6. Lean amine is pumped from the stripper reboiler to the absorption column for reuse in capturing CO_2.

7. The CO_2 is directed to by-product management systems.

The Shell Cansolv amine technology has been demonstrated at full scale at the Boundary Dam coal-fired power station in Canada and has been operational since 2014. The similarity of the flue gases in terms of CO_2 concentration (10-15 vol%) for coal-fired power plants and MSW incinerators makes the technology transferrable to the Fortum WtE plant. Additionally, the flue gas from the Klemetsrud plant is already treated for NOx, SOx, heavy metals and dioxins, which is a clear advantage.

A study carried out by Foster Wheeler [2] in the framework of the IEA-GHG (IEA Greenhouse Gas R&D Programme) in 2014, for a coal-fired power plant using the Shell Cansolv amine technology for CO_2 capture reports a net electrical efficiency loss of 8.9%, LHV-based (35.2% with CO_2 capture compared to 44.1% without CO_2 capture).

Amine scrubbing technology has been previously successfully tested at pilot scale on-site at the Klemetsrud plant with a similar technology as the one provided by Shell Cansolv, and a stable CO_2 capture rate of 90% has been obtained.

Price of CO_2 capture at the Fortum WtE Klemetsrud plant

A review study carried out by Rubin at al. in 2015 [1] assessed the cost of CCS for different applications. The cost of CO_2 capture has been calculated for supercritical pulverized coal power plants with current post-combustion capture technology, bituminous coals as fuel, and 90% CO_2 capture rate. The study shows cost of CO_2 capture ranging between 36 and 53 US $/ton CO_2 captured (2013 US $). Additionally, a study carried out by Foster Wheeler [2] in the framework of the IEA-GHG (IEA Greenhouse Gas R&D Programme) in 2014, for the same application and using the Shell Cansolv amine technology (822 MW net output), shows a cost of CO_2 capture of 53 US $/ton CO2 captured, i.e. about 458 NOK/ ton CO_2 captured using today's exchange rate. Considering the fact that the CO_2 concentration is probably slightly lower in the case of a MSW incineration plant compared to a coal-fired power plant, that the MSW plant is smaller in size, and that applying amine technology at the Klemetsrud site will be a "first of a kind plant", the communicated cost of about 650 NOK/ ton CO_2 captured seems reliable.

Learning curves and cost reduction for CO_2 capture

The US Department of Energy estimates the current capture cost for the nth plant of CCS deployment for coal-based combustion systems to be about 60 US $/ton CO_2 captured, including CO_2 compression. For second-generation technologies (defined as those technologies that will be ready for demonstration and deployment from 2025) the US DOE has targeted a goal of reducing capture cost to around 40 US $/ton CO_2 captured. Further cost reductions are anticipated from third-generation technologies, targeted for demonstration between 2030 and 2035 and for initial deployment in 2035 [3].

For power plants and combined heat and power plants, the pathway to lower cost of electricity (and lower cost of CO_2 capture) involves a combination of advances in power generation technology (to increase their overall efficiency without large increases in cost), coupled with advances in CO_2 capture technologies (especially a reduction in their energy requirements, which currently account for a major portion of overall capture costs).

In post-combustion retrofitting cases, it is mainly only advances in CO_2 capture technologies that account for cost reduction. In the case of amine technology, this implies the development of new solvents than require less regeneration energy, new cheaper component designs, and lower solvent consumption, affecting both capital and operating costs.

In addition to sustained R&D, learning from experience and strong policy drivers that create market for CCS technology, will be pathways to cost reductions.

Both the US DOE and EPRI (Electric Power Research Institute) have carried out studies that typically employ a 'bottom-up' engineering analysis of a proposed flowsheet or process design whose cost is then estimated. Their projections foresee reductions of roughly 20% in both the overall plant heat rate and unit capital cost for coal-fired power plants, resulting in a reduction of LCOE (Levelized Cost of Electricity) of roughly 20%, corresponding to about a 50% reduction of the cost of CO_2 avoided [4].

An alternative method of estimating the future cost of power plants with CCS is a 'top-down' approach based on the use of experience (learning) curves. Here, cost reductions are related to increases in the cumulative installed capacity or cumulative production of a technology [6]. Based on historical learning rates for various power plant components, Rubin et al. [5] estimated LCOE reductions relative to current technology of roughly 15% for combustion-based plants with CCS.

Broadly speaking, then, the outlook for CCS cost reductions from top-down models is quite similar to projections from bottom-up studies for current commercial or near-commercial technologies. A key difference in the two methods, however, is the importance of experience at the commercial level. Thus, as noted by Rubin et al. [7]:

> Achieving significant cost reductions will require not only a vigorous and sustained level of R&D, but also a substantial level of commercial deployment. That, in turn, will require a significant market for CO_2 capture technologies that can only be established by government actions. At present such a market does not exist.

For early plants (few plants in number), production technology and financial risk reduction will be most important for driving the costs of CO_2 capture down. When the market is established, meaning that the value chain is established, and thus when many vendors compete, the margin reduction should play a more important role.

Finally, development in the last decade of emerging CO_2 capture technologies like calcium looping, solid sorbent adsorption PSA systems, and membrane systems, shows promising results for potential CO_2 capture cost reduction. A review study carried out by Abanades and al. [8] indicates cost of CO_2 avoidance of 27-41, 30-46 and 32-54 US $/ton CO2 avoided for calcium looping, solid sorbent adsorption PSA systems, and membrane systems respectively. The credibility of such cost estimates remains however questionable since these processes are at lower technology readiness levels (TRL 5-7) than amine technology and performance goals have yet to be realized.

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6.2 POLICY NOTE BY MARGRETHE VOLL STORAAS – BI

Waste and carbon policies in the EU

Since 2015 especially, overall waste policy in the EU has tightened its noose on incineration, pushing its member countries' waste management strictly towards increased recycling. Despite steps taken to ensure the EU's Circular Economy Ambition, such as rapidly increasing recycling rates, significant differences between EU countries remain. In 2016, ten member states still landfilled over 50% of their household waste and six of them incinerated 40% or more. Nonetheless, current trajectory in waste policies unapologetically favors recycling, reuse of materials, and direct waste production reduction, not CCS on waste incineration. As a result, we may witness a cold-shower experience in Europe when a strict landfill ban comes into force in 2020, regional funding for new incineration plants is withheld, yet local recycling potential reaches its maximum (and there is nowhere to put waste product materials). This development may create a demonstrable need for CCS that exceeds public and political skepticism on incineration, but only after a build-up pressure over time. As a prolonged process, attitudinal change on the European continent will most likely not be present to benefit Klemetsrud in its start-up phase. Overall, it is highly unlikely that EU waste policies will incentivize increased incineration and the use of CCS on waste facilities any time soon. Instead, the EU would have to exert pressure indirectly through carbon policies.

Today, large-scale deployment of CCS is absent in the face of increased inclination towards more radical climate action. This combination have yielded a political discourse that somewhat traps the EU in a stalemate relating to CCS' image problem. On the one side, we find the European Commission (EC) in clear-cut support, along with for example the IPCC, IEA, Bellona and ZEP, or 'Zero-Emissions Technology and Innovation Platform', an influential stakeholders' union. These provide for repeated statements of CCS' indispensability as an un-delayed addition to other direct cut measures.

On the other hand, several Ministers in the European Parliament (MEPs), system-critical environmental NGO's, and renewable industry actors continue to raise zero-sum-concerns over CCS' impacts on the Circular Ambition. They view carbon capture and sequestration as a Business As Usual techno-fix to climate change, at the expense of direct emission cuts, and prefer 'natural' Carbon Dioxide Removal (CDR) techniques such as forest and soil carbon sinks, afforestation (planting trees), and Direct Air Capture (DAC).

Despite the European Commission's best efforts, CDR and negative emissions technology (NET) are therefore still rather immature concepts, politically speaking. The first international conference ever held on the subject occurred in Sweden, May 2018. One of the main problems within the political discourse on CCS in the case of waste incineration is that the EU has shown little to no ability to differentiate between sequestration of carbon from biocrops and land use, or forests, and carbon from CO2 already in cycle. This is the unique case with waste: at the Klemetsrud co-incineration plant for instance, 55% of the total amount of carbon is biogenic. This is due to waste from the construction industry, households, and other sources that are partly biological. Until these outputs become 100% waste-free, biogenic carbon will continue to constitute large parts of the total waste for the foreseeable future. CCS at Klemetsrud is therefore a case of BECCS: Bio-energy carbon capture.

Capturing biogenic CO2 for storage in the geosphere would mean to remove it from the natural carbon cycle in the biosphere, where consumers have already put the carbon dioxins into cycle. Subsequently, the carbon budget benefits from negative emissions would result as a bi-product of the waste management process and 'old' biogenic carbon– not from waste production and 'new' CO2*. Earlier this year, the inability to separate between the two reached a zenith when actors from six member countries filed a lawsuit against the EU. Here, the plaintiffs claim that the Union's categorization of biomass as 'renewable fuel' will increase deforestation. Companies will chop down trees to meet their obligations on renewable energy, and not count this as an increase in emissions from the reduction of natural carbon sinks. Opposing views on the lawsuit maintain that land use management is a separate matter. In the case of Klemetsrud, biomass includes biogenic CO2 from waste, on which CCS ensures negative emissions, not positive. Now a pending case, the verdict might be useful to inform stakeholders on BECCS as burning of biomass, and its interaction effects with **different* carbon cycles.

Instead of recognizing the NET effect from BECCS in particular, EU carbon policy formulation pays heed to zero-sum-concerns that have proven hard to confute in the promotion of technological CDR. This is the belief that any CCS efforts will happen at the expense of direct emission cuts, not as an addition. Were the EU to facilitate and financially reward removal of biogenic carbon, the fear is that this, in turn, would incentivize increased use of fossil fuels in a too-flexible carbon budget, and therefore offset countries' reductions in carbon emissions in general. The lack of a reward mechanism contributes to severely restrain industrial development. This plays into another objection also detrimental to the much-needed political mobilization for CCS, namely the lack of trust in the technological and economic feasibility of full-scale CCS projects. The economic model in our report refutes this objection in the case of a complete carbon value chain in Northern Europe.

In opposition to sceptic Ministers of the EU Parliament (MEPs) and dark green environmental organizations, many influential policy actors such as IPCC, IEA, the EU Commission, Bellona, and more are working effortlessly to increase political awareness of the need for (BE)CCS, with unabated scientific evidence on their side. On March 14, 2019, it seemed that their efforts had paid off somewhat. For the first time, the EU Parliament adopted a text that acknowledges IPCC's stance on CCS and supports two EU Commission scenarios that include CCS. Yet, the announcement still makes sure to give weight to the 'last option'-principle when it comes to CCS, and urges prioritization of direct emission cuts and increased use of renewables.

Notably, the political stalemating has economic consequences for the industry. Where funding sources such as the Innovation Fund decrease start-up costs associated with new CCS facilities, the EU needs to put in place a positive gain reason related to operation (as opposed to a cost avoidance pain reason), for CCS projects to happen. However, due to the significant resistance within the EU Parliament especially, as well as the slow rate of changing the EU Emission Trading System (ETS), it is quite unlikely that a positive gain mechanism will materialize in the near future. The Klemetsrud case will likely provide for a much-needed trust-inducing demonstration, but cannot be expected to gain from any regional-political development until CDR alternatives such as afforestation and DAC are sufficiently disproved as commensurable solutions. This process has only just begun, all the while it is fueled by several influential actors. In light of the 14 March Plenary Session, it is more probable now than before that EU carbon policies will steer in the direction of CCS, as the discussion evolves and pioneer projects emerge. One indicator for this process is the outcome of ongoing research funds negotiations relating to the £100 billion 'Horizon Europe' program, which will succeed 'Horizon 2020'.

Another point for optimism is the successful restructuring of the ETS through directive 2018/410, which will likely aid in restoring trust in the European carbon market now hampered by a severe surplus of carbon quota units. This reorganization improves the ETS' functionality as an institutional framework through which future economic incentives for BECCS in the waste management industry can be channeled. However, the extensive making of the directive lasted from 2014-2019, which speaks to the time it takes to institutionalize changes to the ETS. As of today, the political will needed to begin this process at all is lacking in Europe: EU carbon policies are still heavily directed towards direct emission cuts, heated conceptual disagreement has reached the courtrooms, and awarding biogenic carbon as that from incineration plants is far from the agenda in the current political climate. A successful differentiation in political fora between for instance "dirty incineration" (without CCS) and "clean (or green)" incineration (with carbon capture technology) could provide for an outlet for European skepticism towards waste combustion facilities in general, all the while create an alternative discourse on BECCS which places waste incineration within the natural life cycle of bio-energy.

Carbon policies in the Nordic countries

In the EU agreement 'Effort Sharing Regulation', Norway has agreed to EU emissions reduction efforts of 40% also in non-ETS sectors from 2021, which include waste. Norwegian Governmental Energy and Climate departments both express a desire to do this partly through CCS. Our interviews have shown little political reservation towards furthering plans of CCS at Klemetsrud, neither on State nor municipal level. In a global Policy Index on supportive policies for CCS, Norway scores "best in class" together with the US, the UK, Canada, China and Japan (Sweden and Denmark on the other hand score relatively low).

Instead, observed national reservations toward the Klemetsrud project are mainly economic in nature, which is likely the reason for the project's delay. Initially, the full-scale project was scheduled for realization in 2020 but was postponed to 2023, due to double-checking financial viability. Notably, Klemetsrud's emissions are accounted for in municipal carbon budgets directly, equal to 14-20% of Oslo's total emissions. This explains why Oslo municipality is visibly more impatient to launch the Klemetsrud CCS project than the Oil and Energy department, as the State can cut emissions elsewhere. Equinor displays a higher risk-willingness as well, yet for reasons beyond Klemetsrud specifically, such as the hydrogen business case as it relates to England, Russia and the mainland continent. On state level, Norway has generally proven less capable than its neighbors of reducing overall greenhouse gas emissions, and has recently received criticism for the national increase of such by 0.4% from 2017 to 2018. This can partly be attributed to a fossil energy dependency avoided in Sweden, Finland and Denmark, under a conservative government ideologically guided by economic liberalism and dealing with the energy transition through market mechanisms. Nordic Green Parties are discussing a carbon fee for common distribution, but so far it exists only as an initial concept ("KAP: Karbonavgift til Fordeling").

Nonetheless, according to the Global CCS Institute, Norway scores especially high on political maturity for CCS. It also holds a higher incentive for carbon dioxide removal than other (also Nordic) countries, due to both a current fossil energy dependency, increasing emission rates, private and municipal-level pressure for the Norwegian full-scale CCS project, in addition to Norway's technological advantage in providing for the entire CCS value chain. It is therefore unlikely that the Klemetsrud project will be further delayed. Although additional national and/or regional carbon policies supporting CCS such as positive gains for negative emissions are not in sight as of now, the Nordic state leaders explicitly included CCS in their "Declaration on Nordic Carbon Neutrality", signed January 2019. This positive circle of trust, where governmental support and public acceptance motivate industrial investments, is only hampered by ongoing incineration fee discussions in Sweden. The Nordics' political benefits come as an addition to a regional technological advantage in large-scale CCS infrastructure and cooperation, all in all painting a much brighter picture than the political prospects for (BE)CCS on the European continent.

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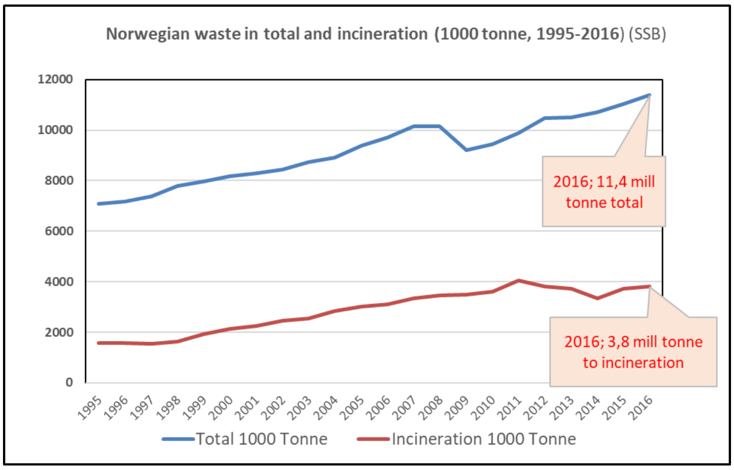
6.3 Note on waste markets by Magne Lia - BI

6.3.1 Total Norwegian waste and incineration (1000 tons (1995-2016))

Explanation of the axis: Y: 1000 tons waste, X: Years

Total waste curve (blue): The main reasons for the waste increase is population growth combined with increased consumption (World Bank Report, 2019). The total waste generation is increasing despite decreased waste generation pr. capita. The 2008-2009 waste generation fall reflects the decrease in production and consumption volumes.

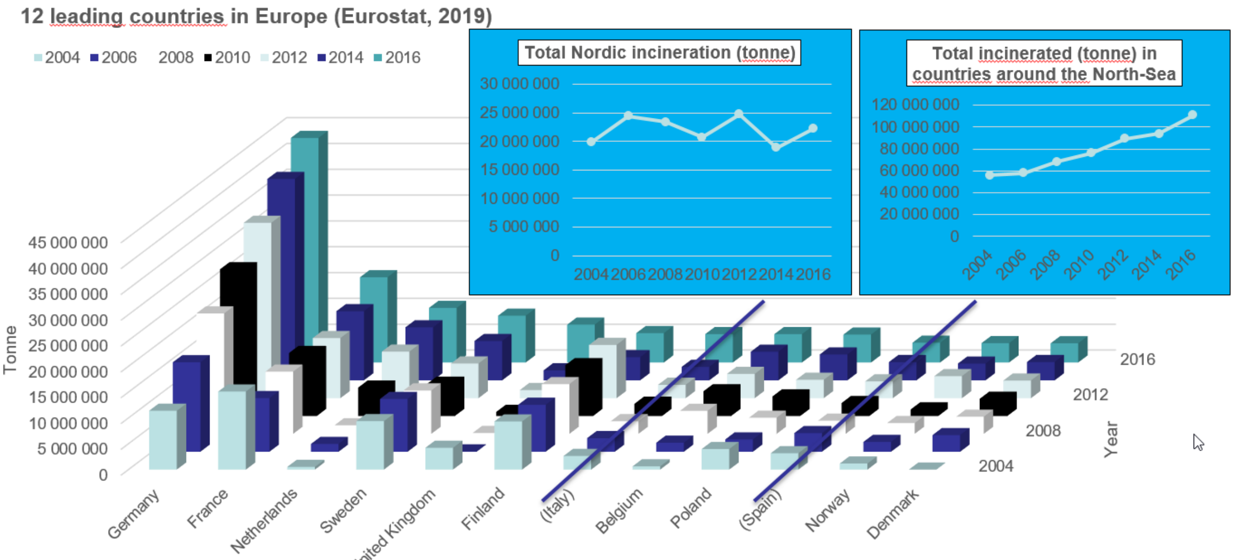


Source: SSB (2019)

Incineration curve (orange):
Incineration has been practiced in Norway since the 1960s, but saw an increase after the implementation of landfill-reducing policies in the late 1990s. These policies led to a demand for more incineration and the market grew until around 2011.

Prior to the 2008 financial crisis, Sweden invested heavily in incineration plants, leaving them with a capacity surplus when their waste generation fell. They therefore started importing Norwegian waste to achieve high enough capacity utilization for the plants to be profitable. Since then, Norwegian investment in incineration plants has decreased, and the amount of incinerated waste has stabilized at around 3.8 mill. tons annually.

6.3.2 Leading WtE countries surrounding the North Sea



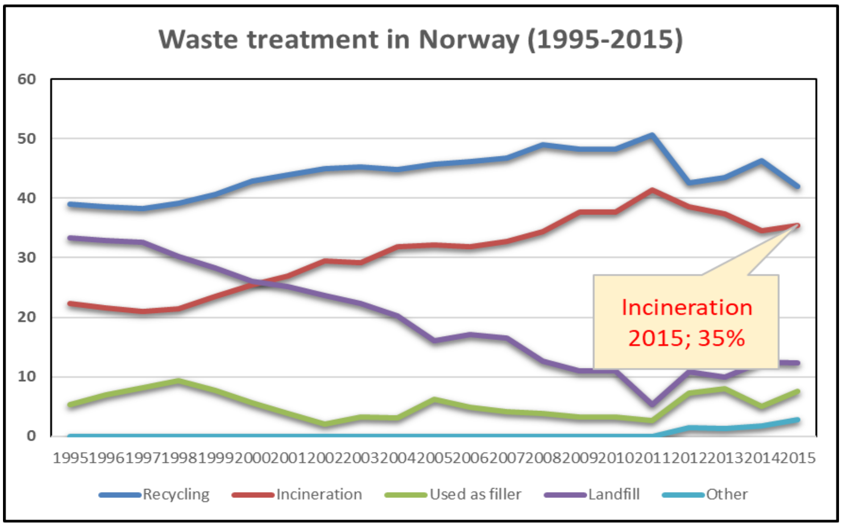
Critique has been raised about the accuracy of Eurostat Waste data

Source: Eurostat, 2019

Many of the leading European WtE countries are located around the North Sea. Germany is the sovereign leader with ca. 43.5 mill tons waste incinerated in 2016 and growing. The German incineration therefore represents a big opportunity for CCS from incineration. By comparison, Norway is in 11th place with ca. 3.8 mill tons incinerated.

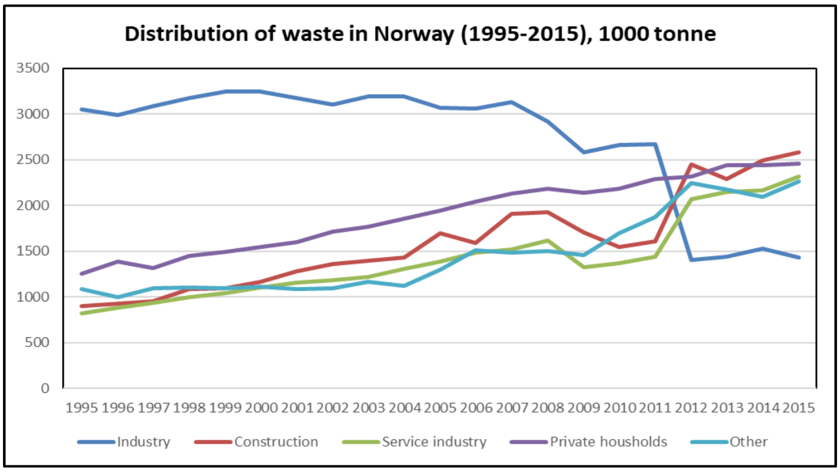
6.3.3 Norwegian Waste treatment

Explanation of the axis: Y: Percentage of the total treatment methods, X: Years



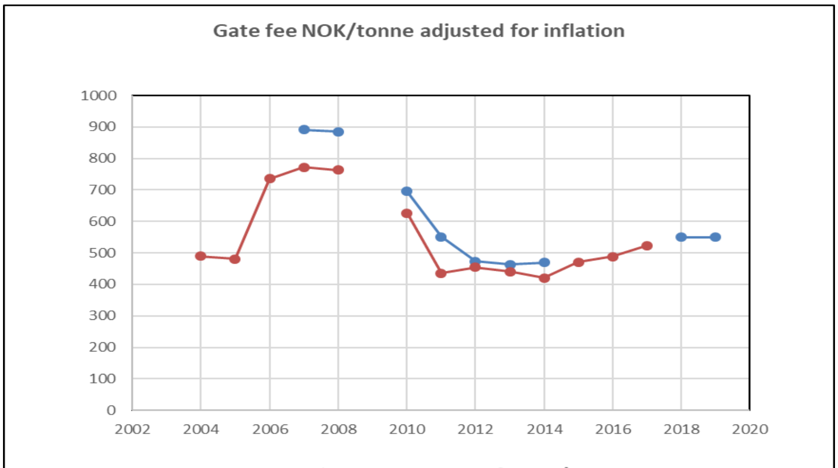
Landfill-reducing policies since the late 1990s led to growth in incineration as a treatment method. While recycling is the most preferred method, the waste managers are not able to recycle and reuse all the waste (Stuen, 2019).

6.3.4 Norwegian Waste distribution



Strong decrease in industrial waste generation in the aftermath of the financial crisis. Stable private household waste generation, while construction and the service industry trends are more volatile.

6.3.5 Gate fees and incineration tax



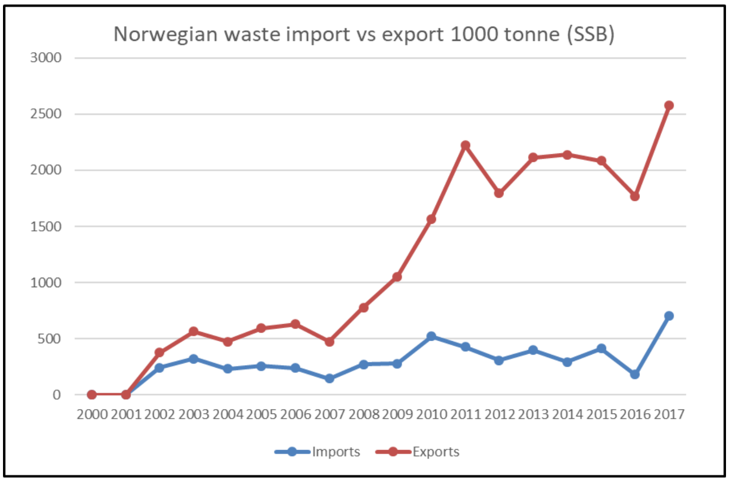
Source: Mepex Consulting, Profu, Avfall Sverige

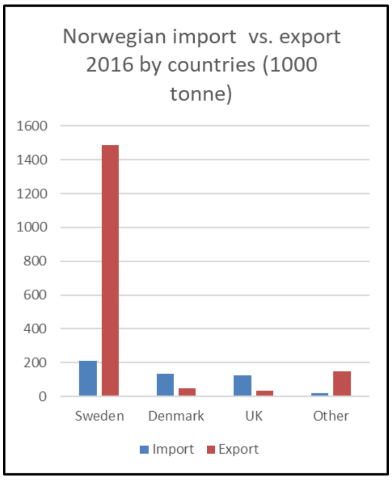
Details of the contract agreements differ between the suppliers of the waste. Municipal waste is included on public tenders with a duration of 3-5 years, with extension options. In the market for industry-waste, there are price negotiations and adjustments annually. The right price for municipal solid waste is important in order to retain competitive advantage in the market for industrial waste.

Norwegian incinerators have adjusted their gate fees to their Swedish competitors after the increasing export trend post 2008/2009. Incineration tax in Norway 1999-2009 (ca. 100 NOK/tonne), and in Sweden 2006-2009 (ca. 100-150 SEK), combined with increasing waste generation and landfill-regulating policies, had a strong impact on the gate fee in the 2000s.

Sweden is considering a new incineration fee for 2020 (Regeringen, 2017). This may affect Klemetsrud's CC-case, raising the question of whether they can increase their gate fee to finance CC and still be competitive.

1. Norwegian balance of waste trade





Source: Norwegian Environment Agency, 2019

Explanation of the axis: left figure: Y: 1000 tons of waste, X: Years, right figure: Y: 1000 tons of waste, X: Countries

6.4 References:

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