CCUS – Nordic system perspectives

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The IETS TCP´s International Conference
Energy Future in Industry
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Outline

- Motives for CCUS
- Potential for CCS
- Economic incentives for CCS
Strong growth in renewable energy

![Graph showing strong growth in renewable energy investments from 2004 to 2020. The investments have increased significantly over the years, with peaks in 2008, 2010, 2014, and 2016. The trend is generally upward with some fluctuations.](image-url)
Strong growth in renewable energy – zero reduction in fossil fuel share!
Main motives for CCS

• **The abundant resources of fossil fuels**
  
  — The alternative is to agree on a global phase-out scheme of the fossil fuels, in particular coal

• To achieve **negative emissions** (BECCS) – to compensate for residual emissions in “hard-to-abate” sectors and to contribute to net negative emissions

• A **key mitigation** technology for several of the **basic materials industries** (e.g., cement) to meet stringent emission reductions
Fossil fuels → CO₂ → CCS → CO₂
Fossil fuels → CO₂ → CCS

Biomass → CO₂ → BECCS (Bio-CCS)
CCS – **28** Large *industrial* point sources of CO$_2$ (>500 ktCO$_2$/year)
Applying post combustion (MEA)

**Biogenic** and fossil feedstocks and fuels
CCS – 28 Large industrial point sources of CO$_2$ (>500 ktCO$_2$/year)

- On-site cost for CO$_2$ capture from fossil sources
- On-site cost for CO$_2$ capture from sources of primarily biogenic origin
- System cost for transport and storage

Cumulative amount of CO$_2$ captured (Mt/a) vs. Cost (€)/t CO$_2$
CCS on combined heat and power plants
CCS on Swedish CHP plants in district heating systems
Mainly biogenic (but a significant fossil share in waste incinerators)

- Including truck transport (excl. cost for ship transport and storage)
- Carbon capture potential depends on extent of heat recovery from capture plant

Beiron et al. (2022)
CCS @

28 Large industrial point sources of CO$_2$ (>500 ktCO$_2$/year) + CHP plants of different sizes

Around 35 Mt/year @ cost < 125 €/ton CO$_2$

Swedish total CO$_2$ emissions = 41 Mt/year (GHG emissions 51 Mt/year)

Johnsson et al. (2020), Beiron et al. (2022)
Strong focus in Sweden on CCS as CDR, i.e. on BECCS
Timeline towards zero and negative emissions efforts must be accelerated.

Demonstration, Knowledge building, Implementation, Funding/Policies, Regulations (London protocol, EU-ETS), Permissions…..

"The pathway to a climate positive future" (SOU 2020:4)
Capture targets for biogenic CO₂:
1.8 MtCO₂/y by 2030 & 10 MtCO₂/y by 2045

Capture targets for biogenic CO₂ combined with a cost for emitting fossil CO₂
CCS infrastructure

Capture targets for biogenic CO$_2$ combined with a cost for emitting fossil CO$_2$
Drivers incentivizing CCS:
- EU-ETS
- Emission targets for value chains in firms
- Negative emission credits (issued by the state)
- Climate compensation
• Pricing of CO\textsubscript{2} is crucial
• Fit for 55
  – Almost doubling of yearly decrease in supply of emission allowances (from 2.2\% to 4.3\%)
Increased ambition in the EU ETS

• With current cap reduction pace, 2.2% per year, zero emissions are reached in 2058

• With the new reduction pace, 4.3% per year, emissions will reach zero in 2039
• Pricing of CO₂ is crucial
• Fit for 55
  — Almost doubling of yearly decrease in supply of emission allowances (from 2.2% to 4.3%)
  — The free allocation to industry will be phased out (from 2026 to 2033)
Phase-out of free allocation, starting 2026

Free allocation (Year 2023=100)

Last year of free allowances will be 2033

Creates level playing field between incumbents and zero carbon industries

Lars Zetterberg, IVL
• Pricing of CO₂ is crucial
• Fit for 55
  – Almost doubling of yearly decrease in supply of emission allowances (from 2.2% to 4.3%)
  – The free allocation to industry will be phased out (from 2026 to 2033)
  – Free allowance replaced by the Carbon Border Adjustment Mechanism (CBAM)
Carbon Border Adjustment Mechanism CBAM – final proposal

- **Scope**: some intermediate goods added + hydrogen
- **Revenues**: keep it in Brussels
- **Free allocation**: industry mourns its passing
- **Correct for others’ carbon prices**
- **WTO compatible? Yes**
- **Countries affected**: EU close neighbours more than US/China (gravity model)

**Sectors:**
- ✓ Electricity
- ✓ Steel
- ✓ Cement
- ✓ Some chemicals
- ✓ Aluminium
- ✓ Hydrogen

(no refineries)

From Milan Elkerbout, CEPS, presentation | Washington DC, 2023-03-22
Looking back - a bumpy road
Price increase provides strong business case for industrial decarbonization

Lars Zetterberg, IVL
Emission targets for value chains in firms...
Example - Nordic basic material industry (Cement & Steel)
Cost increase from CCS

Cement industry
Price increase cement
+70%

Steel industry
Price increase steel
+25%
Supply and product value chain analysis
Cement (and steel) to building

CLinker PRODUCTION

CEMENT PRODUCTION

White clinker

Grey clinker

Blended cements

White cements

CONCRETE MANUFACTURING

RCM

CEM I

CEM II

RMC

PCE

PCP

Civil engineering

Transport infrastructure

Hydraulic works

Other

Non-residential buildings

Public

Commercial

Other

Residential buildings

Multi-dwelling houses

Single detached houses

Other

Civil engineering

Transport infrastructure

Hydraulic works

Other

Non-residential buildings

Public

Commercial

Other

Residential buildings

Multi-dwelling houses

Single detached houses

Other
Supply and product value chain analysis
Steel to car

IRON & STEEL MAKING
HOT STRIP MILL
PLATE MILL
COLD ROLLING
FABRICATION

By-products

Steel slab
Hot rolled coil/sheet
Cold rolled coil/sheet
Coated coil/sheet
Heavy plate
Fabrication scrap

Vehicles
Cars
Trucks
Other transport

Industrial equipment
Machinery
Electrical

Construction
Infrastructure
Buildings

Metal goods
Packaging
Appliances
Other

Machinery
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<table>
<thead>
<tr>
<th>Cement industry</th>
<th>Steel industry</th>
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<tbody>
<tr>
<td>Price increase cement</td>
<td>Price increase steel</td>
</tr>
<tr>
<td>+70%</td>
<td>+25%</td>
</tr>
<tr>
<td>Price increase building</td>
<td>Price increase car</td>
</tr>
<tr>
<td>Less than +0.5%</td>
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</tr>
</tbody>
</table>
Cost increase from CCS
- cement to high-speed railway & fluff pulp to diaper

Emanuelsson and Johnsson (2022)
Cost increase from CCS
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Emanuelsson and Johnsson (2022)
Negative emission credits (issued by the state)
Great potential for BECCS in the Nordics

Swedish Government will launch a reversed auctioning system for carbon negatives, i.e. Governmental guarantees for purchasing BECCS outcomes

Good to initiate BECCS!

But, not obvious that BECCS always provides the highest climate benefit

Biomass is a limited resource – a waste fraction today may not be a waste fraction tomorrow
If development in line with climate targets – value of renewable fuels will increase

Berndes et al., Forests and the climate – Manage for maximum wood production or leave forests as a carbon sink? KSLA, No 6, 157, 2018
Climate compensation
Targets for net zero emissions ⇒ increased interest in climate compensation

Sweden's climate policy framework

Published 11 March 2021

In 2017, Sweden’s Riksdag decided by a large political majority to introduce a climate policy framework with a climate act for Sweden. This framework is the most important climate reform in Sweden's history and sets out implementation of the Paris Agreement in Sweden. By 2045, Sweden is to have zero net emissions of greenhouse gases into the atmosphere.

Climate compensation by means of negative emissions...
Direct Air Capture - DAC

BECCS – Bio Energy CCS

Biochar/Soil carbon

Enhanced weathering

Afforestation

Reforestation

https://www.mn.uio.no/geo/english/research/projects/1.5C-BECCSy/


https://energyeducation.ca/encyclopedia/Afforestation

https://pubs.acs.org/doi/10.1021/acsest.6b05942

Ovanstående uppvisar väldigt olika kostnader. Man skulle kunna säga att desto lägre permanensrisk desto högre kostnader (afforestation/reforestation har lägst kostnad men högst permanensrisk), Direct Air Capture - DAC

BECCS – Bio Energy CCS

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Net = Negative Emission Technology
Risks with climate compensation – even if certified

 Revealed: more than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows

Investigation into Verra carbon standard finds most are ‘phantom credits’ and may worsen global heating

- ‘Nowhere else to go’: Alto Mayo, Peru, at centre of conservation row
- Greenwashing or a net zero necessity? Scientists on carbon offsetting
- Carbon offsets flawed but we are in a climate emergency

Based on a new analysis at least 90% of Verra’s rainforest carbon credits do not represent real emission reductions

Each credit is equal to one metric tonne of CO2 equivalent

94.9m carbon credits claimed

5.5m real emissions reductions

Guardian graphic. Source: The Guardian analysis based on a significant percentage of the projects as looked by West et al studies and Verra registry (accessed in August 2022). All figures are estimates. West et al 2023 is a pre-print. Note: Verra’s claims versus analysis of independent scientific studies
Summary

• Main motive for CCS is the abundant fossil fuel reserves
• The Nordics have favorable conditions for CCS and BECCS
• Strong enough climate policy must be in place – EU “Fit for 55” is promising
• Industry also drives – targets on Scope 1, 2 & 3 emissions
Suggestions for further work in IETS TCP

• The role of CCS and CCUS - systems analysis on efficient use of green carbon atoms in industry
  • Considering limitations of renewable energy supply
• To find robust policy measures - deliver intended objectives under uncertainty

Some publications

• Rootzén, J., Johnsson, F. Managing the costs of CO2 abatement in the cement industry (2017) Climate Policy, 17 (6), pp. 781-800.
• Johnsson, F., Normann, F., Svensson, E. Marginal Abatement Cost Curve of Industrial CO2 Capture and Storage – A Swedish Case Study (2020) Frontiers in Energy Research, 8, art. no. 175, DOI: 10.3389/fenrg.2020.00175
• Emanuelsson A., Johnsson, F., The cost of CCS – a product chain analysis of the cement and pulp industries,16th International Conference on Greenhouse Gas Control Technologies, GHGT-16
• Fuss, S., Johnsson, F. The BECCS Implementation Gap—A Swedish Case Study (2021) Frontiers in Energy Research, 8, art. no. 553400 DOI: 10.3389/fenrg.2020.553400
• Berndes et al., Forests and the climate – Manage for maximum wood production or leave forests as a carbon sink? KSLA, No 6, 157, 2018