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Scenario for near-term implementation of partial capture from blast furnace gases in Swedish steel industry

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Part of the CO2stCap project CO_2stCap

Cutting Cost of CO_2 Capture in Process Industry

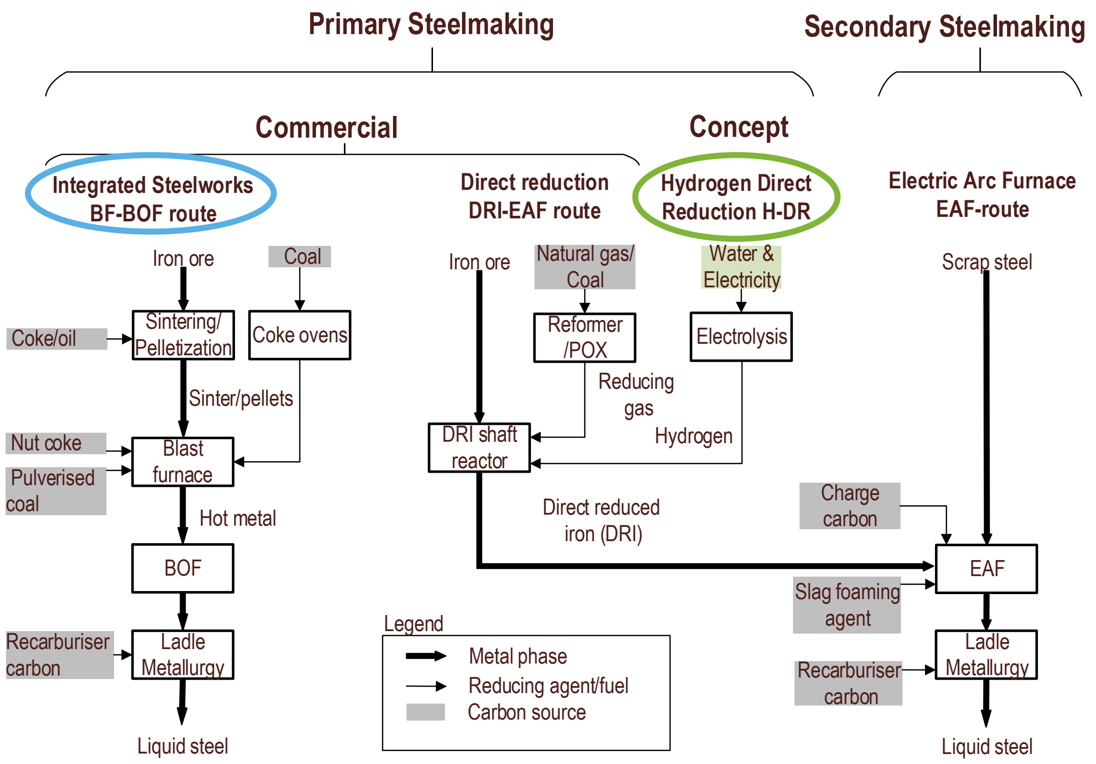
Financial support:
Gassnova (CLIMIT Demo)
The Swedish Energy Agency

Project partners:
SINTEF, Chalmers, USN, RISE, SWERIM, SSAB, Elkem, NORCEM HeidelbergCement Group, A Member of The Linde Group | AGA, Global CCS Institute, ieaghg, GASSNOVA, Swedish Energy Agency

Background: Steelmaking

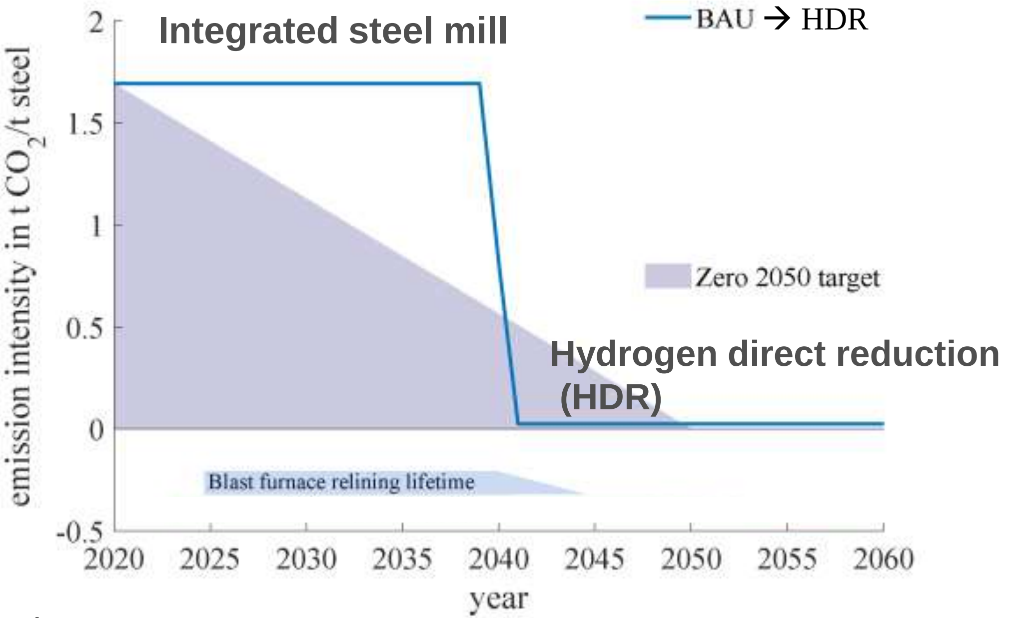
Carbon is used as reducing agent

→ Primary steelmaking has to be decarbonized, while secondary steelmaking is ramped up



How does CCS fit in?

Major steel producers in Europe work with **hydrogen direct reduction (HDR)** to reach close-to-zero CO_2 emissions by Year 2040-2050



How can CCS contribute to early mitigation in the near term and reduce the risks of HDR? What are the techno-economic conditions for this?

Partial capture - a CCS concept

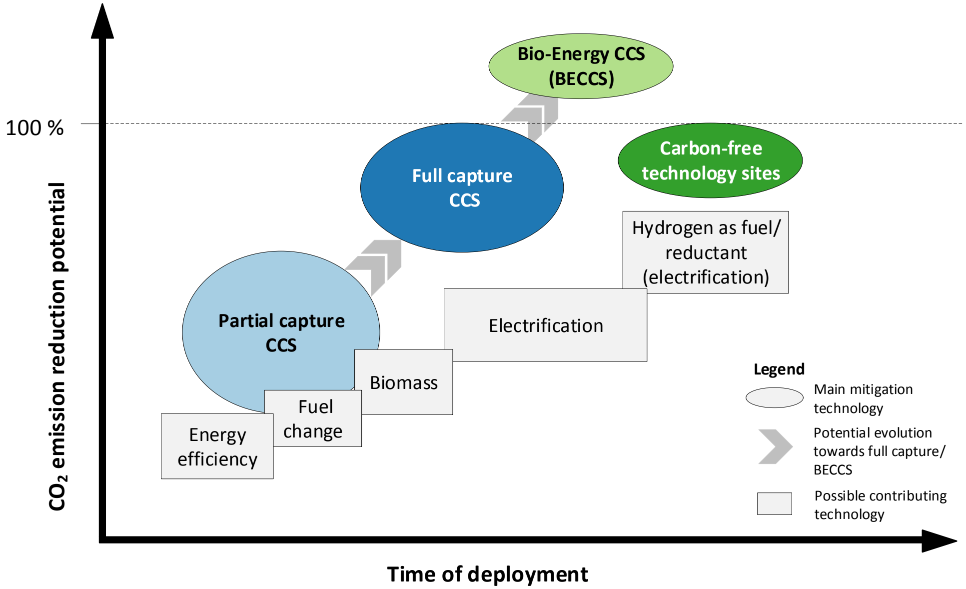
Idea: only a fraction of the accessible CO_2 is captured for storage.

This fraction is determined by

- Economic factors (cost reduction)
- Policy requirements (capture what is required)

<u>Partial capture compared to full capture:</u>

- Lower absolute energy need
- Lower absolute investment cost
- May beat economy of scale (€/t CO_2) for:
    - Plants with multiple stacks
    - Plants with excess/low cost heat
    - Plants that can that can vary their product portfolio flexibly to meet market conditions



Method: Process modeling & costing

Cost estimation

- Aspen In-Plant Cost Estimator
- Detailed installation factors from in-house data base
- ± 40% uncertainty

SINTEF

Dimensions

Cost estimation

Installed cost

CO_2 absorption model in Aspen Plus

- Rate-based mass and heat transfer
- Detailed reaction kinetics
- 30.wt% aqueous MEA solvent
- Opimization after heat demand through manipulation of liquid-to-gas ratio
- Hold up times oriented towards pilots (Tiller, Gløshaugen)

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Excess energy

Process integration

CO_2 lean gas

Steel mill model

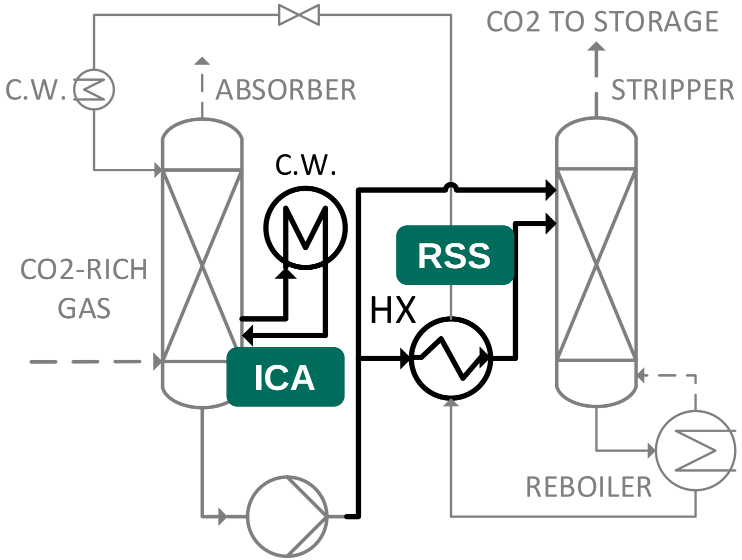
- Mass and energy balances for steel mill process units
- Detailed blast furnace, burden and hot stove calculations

SWERIM

Method: Design choices for partial capture

Entire gas flow into absorber
→ lower L/G ratio
→ separation rate in absorber <90%; lower specific heat demand

Intercooled absorber (ICA) + rich solvent split (RSS) applied as energy efficient, low-CAPEX configurations



Biermann et al. *Partial Carbon Capture by Absorption Cycle for Reduced Specific Capture Cost*. Ind. Eng. Chem. Res. **2018**

Method: Economic parameters

Parameter	Value
Economic plant life time	25 years
Construction time	2 years
Plant availability	**95%**
Rate of return (annuity cost model)	7.5%
Annual maintenance cost	4% of investment cost
Annual labor cost	821 k€/annum
Utilities	
MEA make-up	1867 €/m^3
Cooling water	0.022 €/m^3
Electricity	**0.030 €/kWh**
Steam	**assessed separately**

High availability of key steel units >95%

Average Spotmarket 2013-2016

Bottom-up approach in assessing value of excess heat

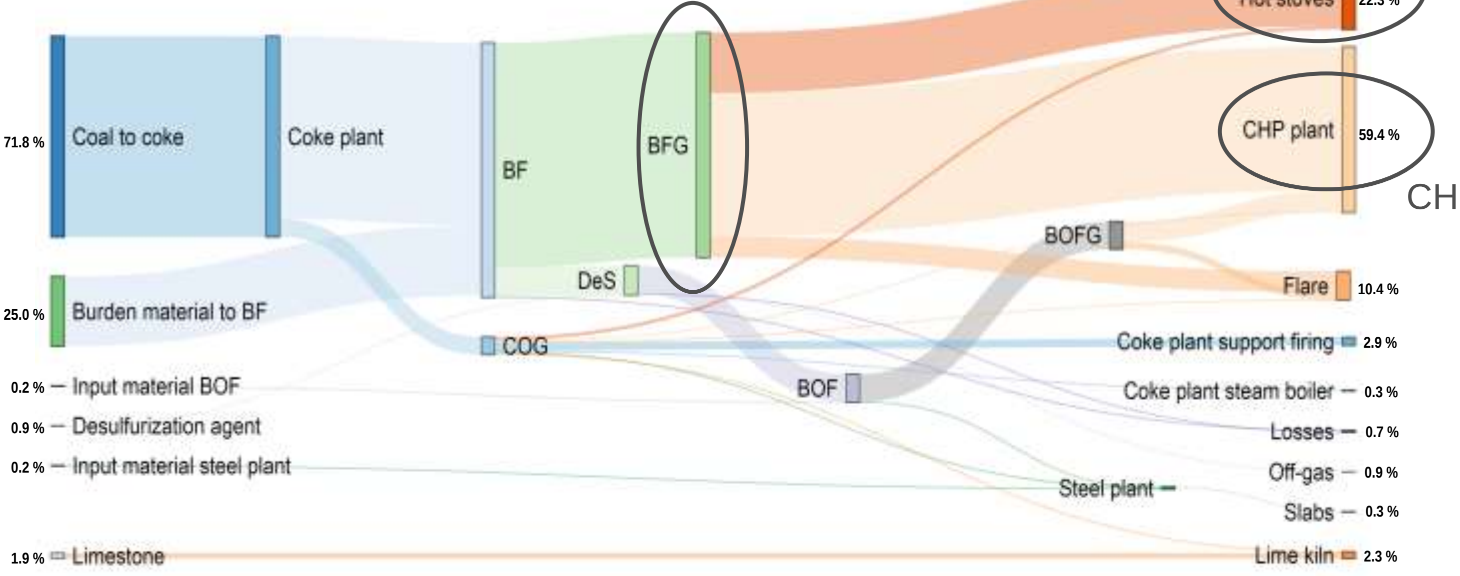
Luleå steel mill - CO_2 sources

~ 2 Mt steel slabs p.a.
~ 3.4 Mt CO_2 p.a.

Blast furnace gas, 25% CO_2, 1.8 bar

Hot stove flue gas
25% CO_2, atm

CHP plant flue gas
30% CO_2, atm

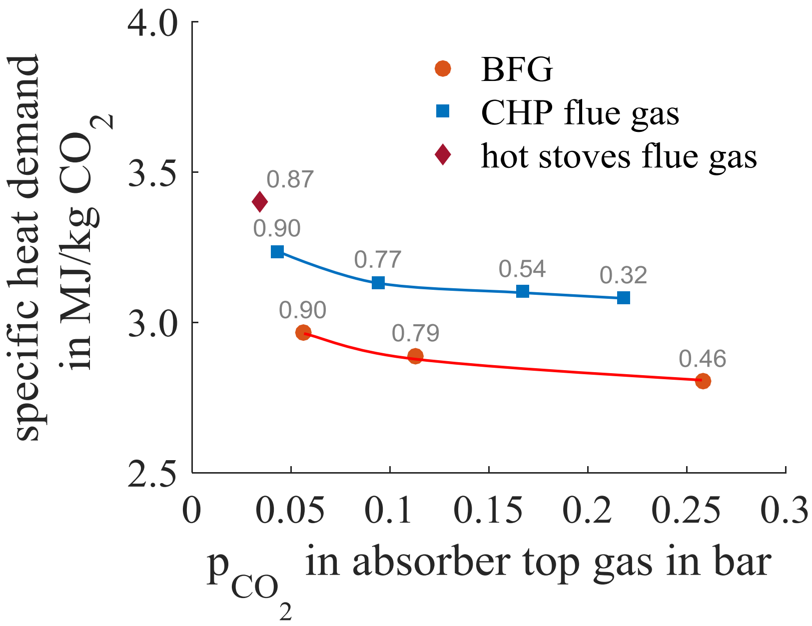


High- or low-level integration?

Capture from blast furnace gas requires less heat compared to capture from atmospheric flue gases

The LHV of blast furnace gas increases with CO_2 capture

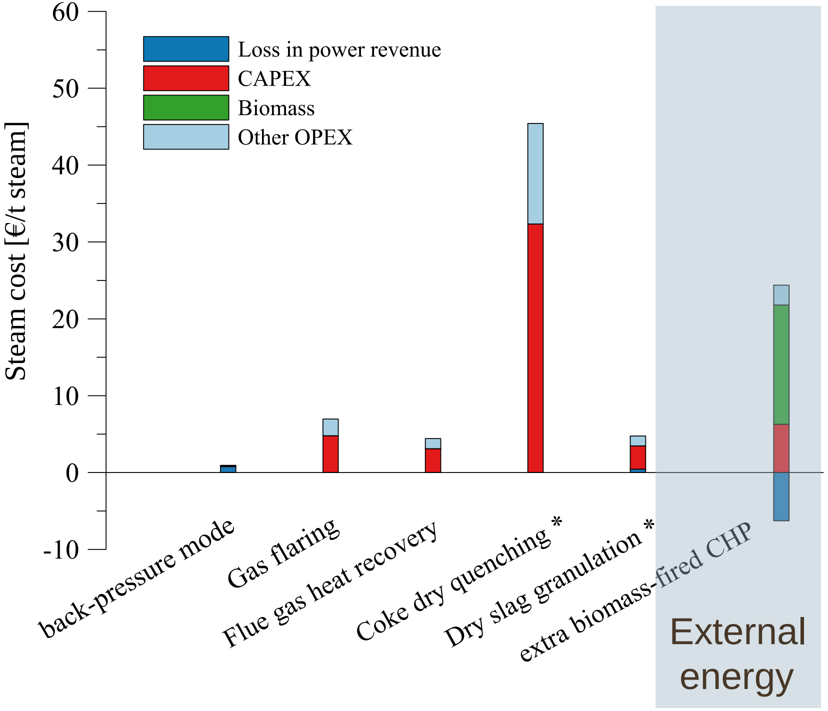
- Gas management on-site can be changed to supply more excess heat to CCS at the expense of electricity production



Excess heat at an integrated steel mill

Assumption: constant heat load (yearly average)

- 5 sources of excess heat to supply steam of 3 bar investigated
- Bottom-up approach: piping, equipment, OPEX (maintenance, power, cooling) included
- Most are implementable and low-cost compared to steam supply via combustion of external fuel

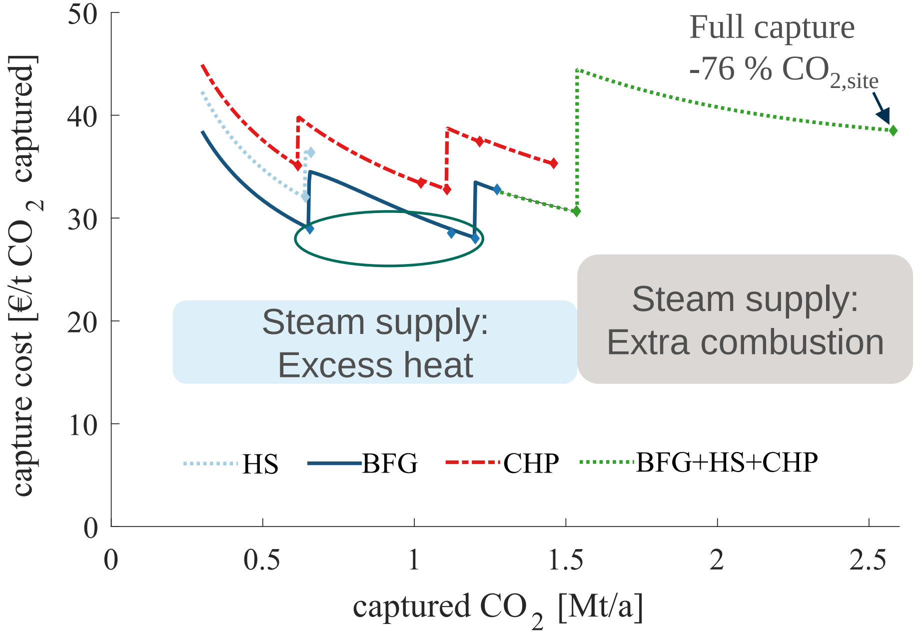


Emissions reductions and capture cost

- Capturing from blast furnace gas is most economic
  → 20%–38% less CO_2 emissions

- Partial capture with excess heat costs less than full capture with external energy

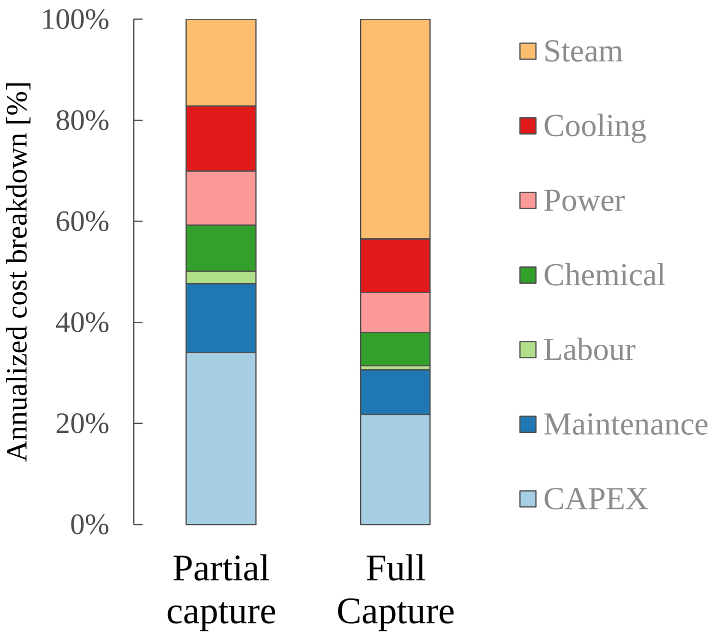
[shows capture cost! no transport and storage cost included]



Cost structure

i) Partial capture with excess heat is dominated by CAPEX;

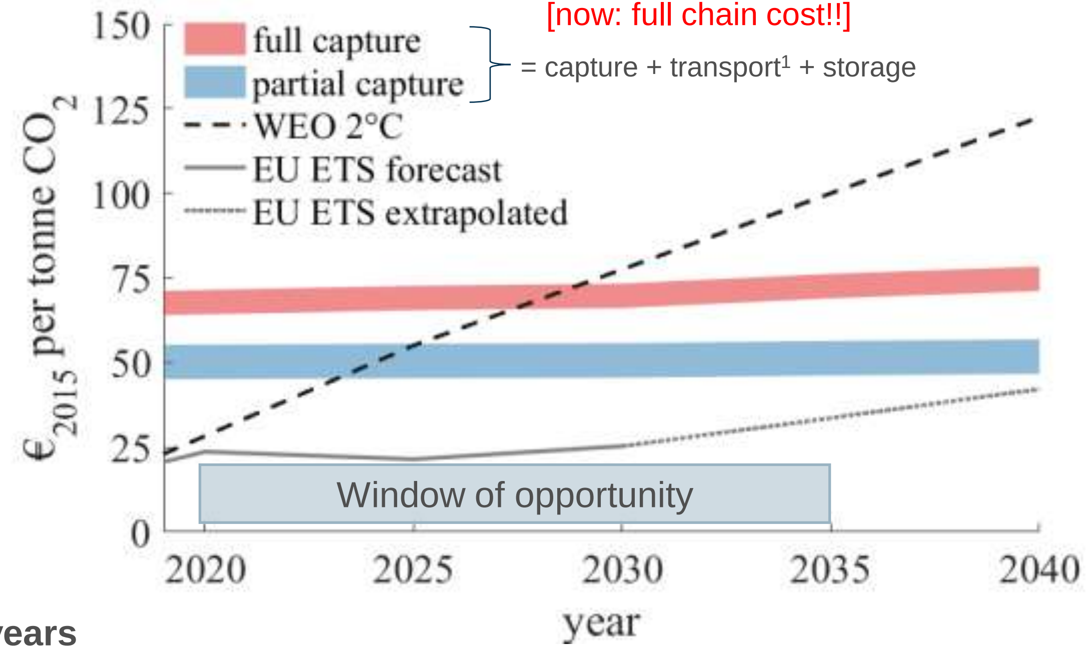
ii) Full capture is dominated by steam cost and is thus more sensitive to changes in energy markets



Partial capture	Full Capture
28 €/t_{CO2}	39 €/t_{CO2}
34 M€ p.a.	99 M€ p.a.

Near-term implementation

Partial capture with excess heat requires a carbon price of 40-60 €/tonne CO_2



Window of opportunity: coming 5-15 years

Later: economic lifetime of partial capture unit (25yrs) would be too short before policies will require close to 100% emission reduction

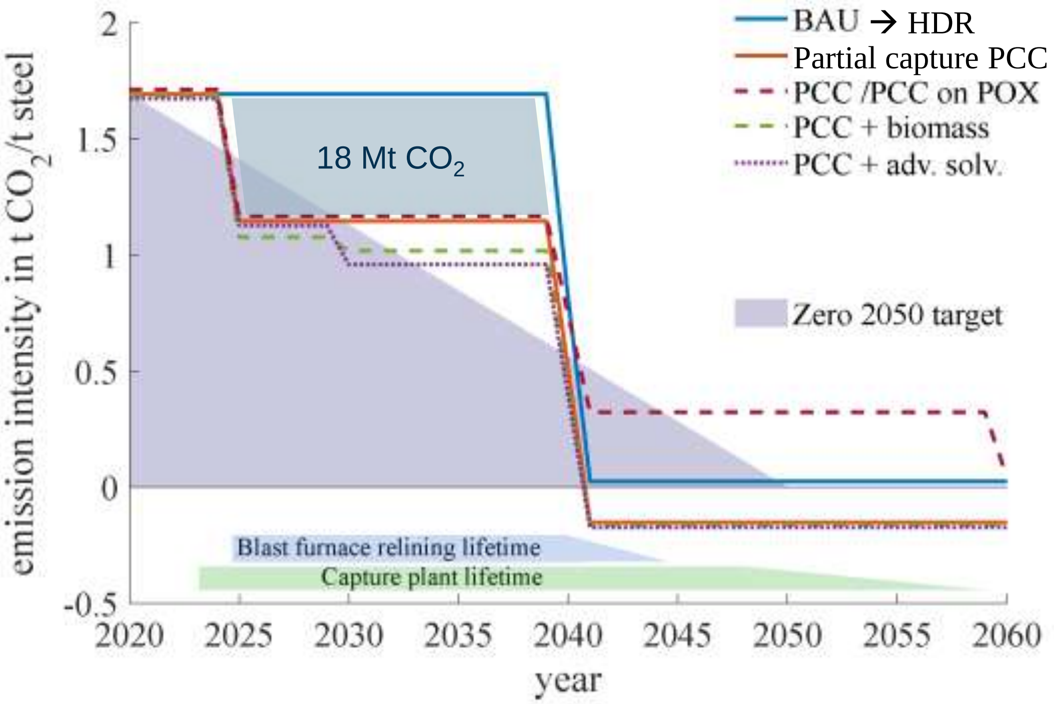
[1]Assuming ship transport to storage

Transition to low-carbon technologies

i. Accumulated emissions are relevant! Partial capture could de-risk late arrival of HDR

ii. CCS infrastructure could be used in HDR concepts
- capture remaining fossil & biogenic emissions
- produce ”blue” hydrogen from fossil fuels

iii. Partial capture could evolve
- co-mitigation with biomass
- solvent improvement



Integrated steel works with 2Mt steel slabs p.a.

Conclusions

- Integrated steel mills: Partial capture powered by excess heat is more cost-efficient than full capture that relies on external energy

- Near-term implementation in 2020s: possible if policies value carbon at 40-60 €/t CO_2

- Window of opportunity for implementation of partial capture, before low-carbon technologies are required to meet CO_2 emission targets!

- Partial capture may allow for synergies with other mitigation options (biomass, electrification, etc.)

- Partial capture could be a step toward the transition to low-carbon technologies, such as hydrogen direct reduction (HDR), to enable the low-carbon economies of the future.

”Some is better than none!”

Thank you!

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Project home page

with publication list

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Project partners:

CO2stCap project

Project duration: 2015-2019
Project manager: Ragnhild Skagestad
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Cutting Cost of CO_2 Capture in Process Industry

Aim: Reduce cost for CO_2 capture from process industry

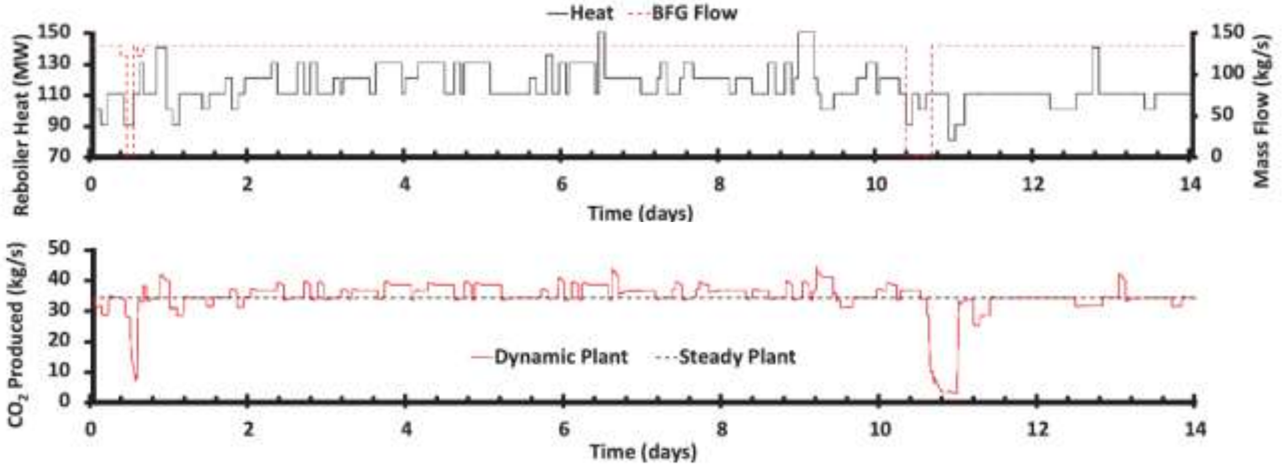
Scope: Steel & iron, cement, pulp & paper and metallurgical production of silicon for solar cells

Idea: Apply partial CO_2 capture, i.e. capture the most cost-effective share of CO_2 [€/t CO_2]

How:
- Utilize excess heat/energy on site
- Apply mature capture technologies (amine absorption) with energy efficient design
- Consider only some stacks on site
- Consider changes in market conditions over time

Dynamic partial capture from BFG

Hourly changes can be coped with well



→ **Capture performance similar to steady-state if:**
the unit is designed to manage the entire span of experienced loads in heat and gas flow;

Publications

What designs of partial CO_2 capture are cost efficient for process industry?

Biermann et al. *Partial Carbon Capture by Absorption Cycle for Reduced Specific Capture Cost*. Ind. Eng. Chem. Res. **2018**

How do energy need and capture rates relate for CCS in integrated steel mills ?

Sundqvist et al. *Evaluation of Low and High Level Integration Options for Carbon Capture at an Integrated Iron and Steel Mill.* Int. J. Greenh. Gas Control **2018**.

Is a near-term implementation of partial capture economically feasible? Under what conditions?

Biermann et al. Excess-*Heat Driven Carbon Capture at an Integrated Steel Mill – Considerations for Capture Cost Optimization*. Submitted for Publication. **2019**.

How can partial capture function in synergy with and transition to other mitigation options for steel?

Biermann, M. *Partial carbon capture – an opportunity to decarbonize primary steelmaking.* Licentiate thesis. **2019**.

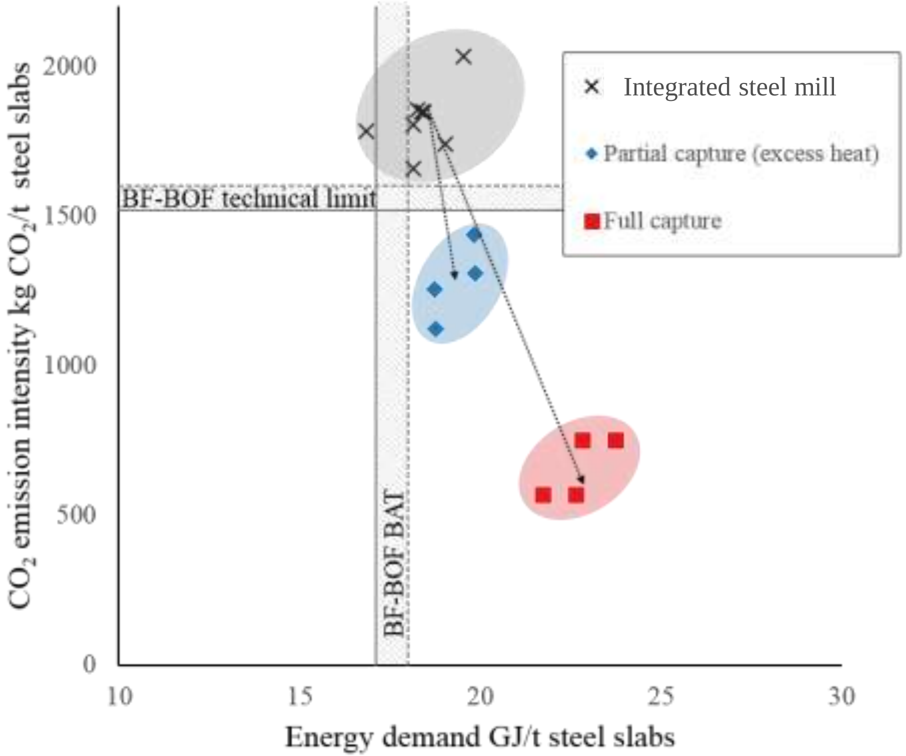
Co-mitigation of CCS with biomass in integrated steelworks – can we go carbon negative?

Biermann et al. *Evaluation of Steel Mills as Carbon Sinks*. In *International Conference on Negative Emissions*; Chalmers University of Technology: Gothenburg, **2018.**

Carbon versus energy intensity?

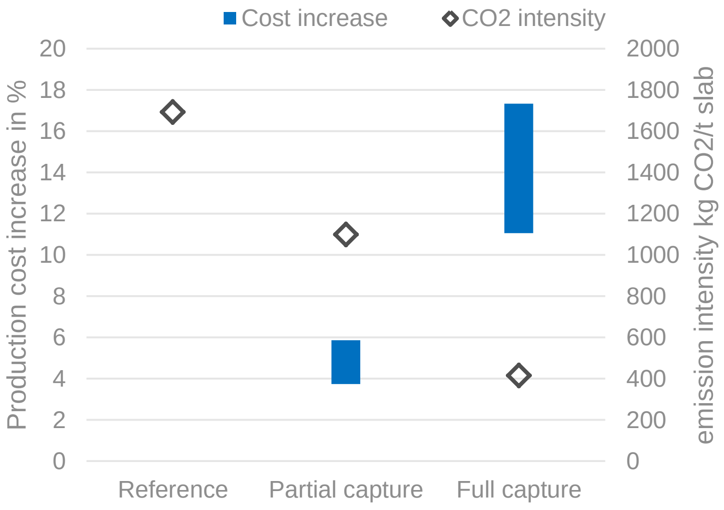
Partial capture with excess heat
can reduce CO_2 intensity of primary steel …

…without affecting significantly the energy demand!



Steel product: CO_2 vs product cost?

Production cost for steel slabs increase 2 – 17% for investigated cases



Mechanisms required to pass on production cost?

→ a price of 50 €/t CO_2 leads to an increase in retail price for a mid-sized European passenger car of <0.5%

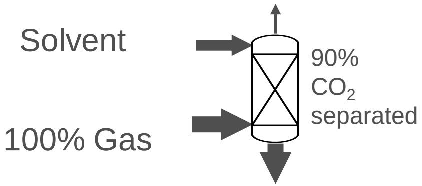
Rootzén, J.; Johnsson, F. *Paying the Full Price of Steel – Perspectives on the Cost of Reducing Carbon Dioxide Emissions from the Steel Industry*. Energy Policy **2016**

Reference production cost:
280 – 450 €/t slab

Source: IEAGHG. *Iron and Steel CCS Study (Techno-Economics Integrated Steel Mill)*; 2013/04, July, 2013.

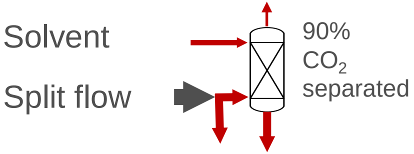
Design of partial capture

Full capture



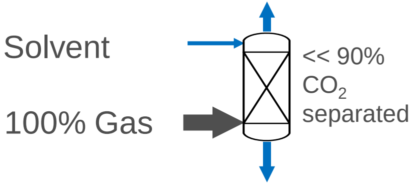
Two principle paths for partial capture design:

Split Stream Path (SSP)

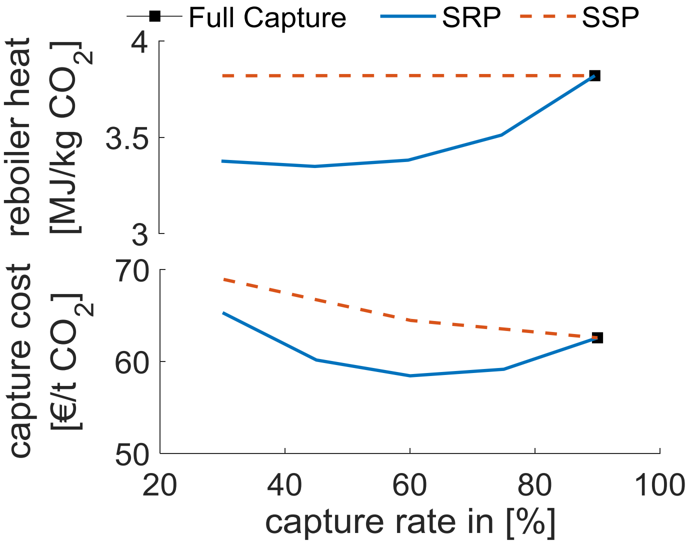


++ Lower specific CAPEX

Separation Rate Path (SRP)



++ Flexibility: variations and increase capture later on



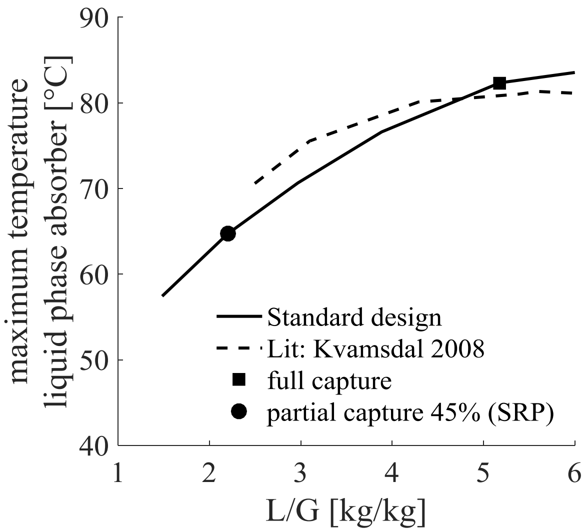
→ The choice of design path affects heat demand and specific cost

Design of partial capture

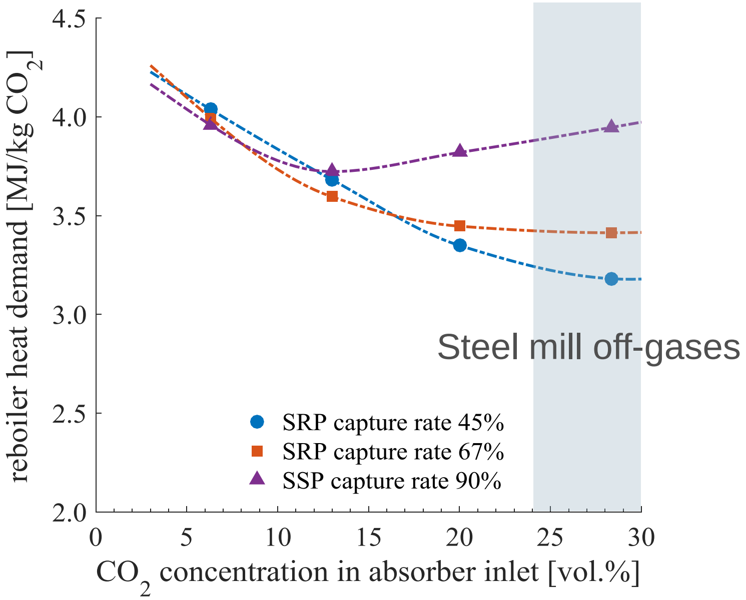
Impact of changing separation rate depends on CO_2 concentration

Separation Rate Path

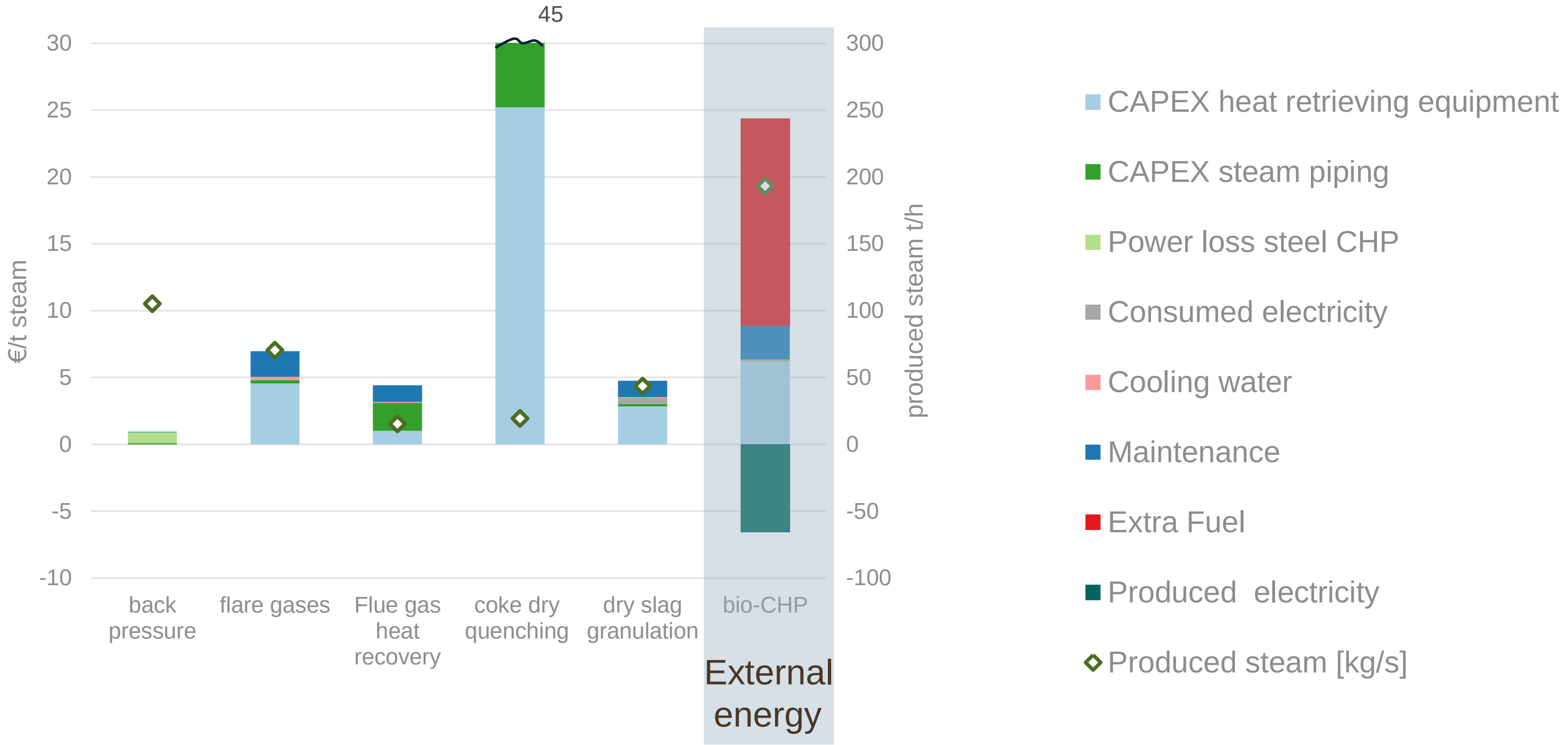
lower L/G → maximum T in liquid phase lowered



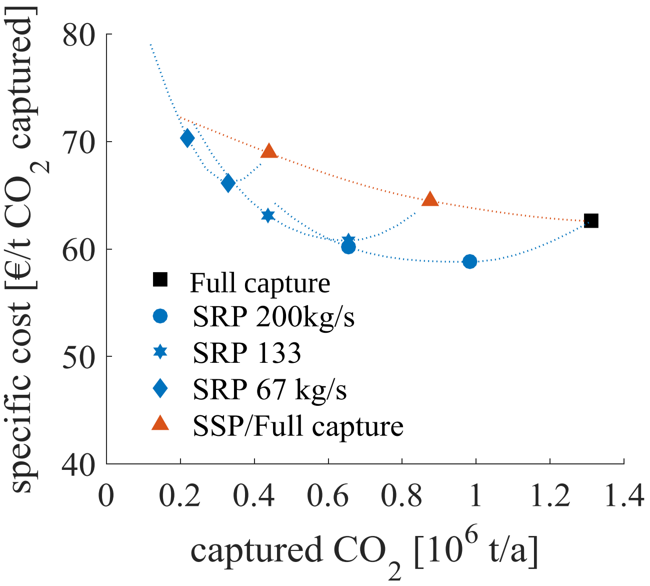
relevant for high CO_2 concentrations!

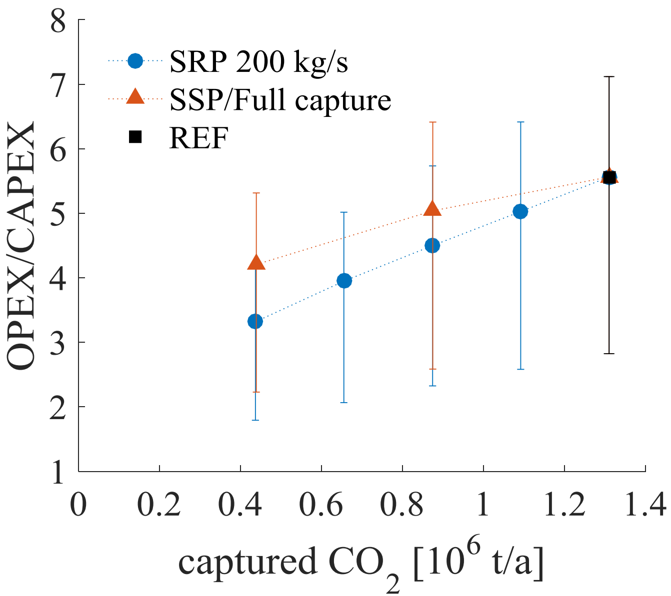


Cost of steam – example: integrated steel mill



Impact of scale and steam price on capture cost





CO_2 concentration: 20 vol%; 200 kg/s
Steam price 16 €/t; Electricity: 55 €/MWh

Error bars: steam price span of 2-25 €/t steam

Sensitivity analysis: steel case

Partial capture:
BFG, 28€/t CO_2

Full capture:
BFG + HS + CHP, 39 €/t CO_2