

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

Presenter: Maximilian Biermann, PhD student, Chalmers
max.biermann@chalmers.se

Collaborators Fredrik Normann, Chalmers
Filip Johnsson, Chalmers
Mikael Larsson, Swerim
David Bellqvist, SSAB
Ragnhild Skagestad, SINTEF
Hassan Ali, USN

Part of the CO₂stCap project

CO₂stCap

[Cutting Cost of CO₂ Capture in Process Industry](#)

Financial support:

Gassnova (CLIMIT Demo)
The Swedish Energy Agency

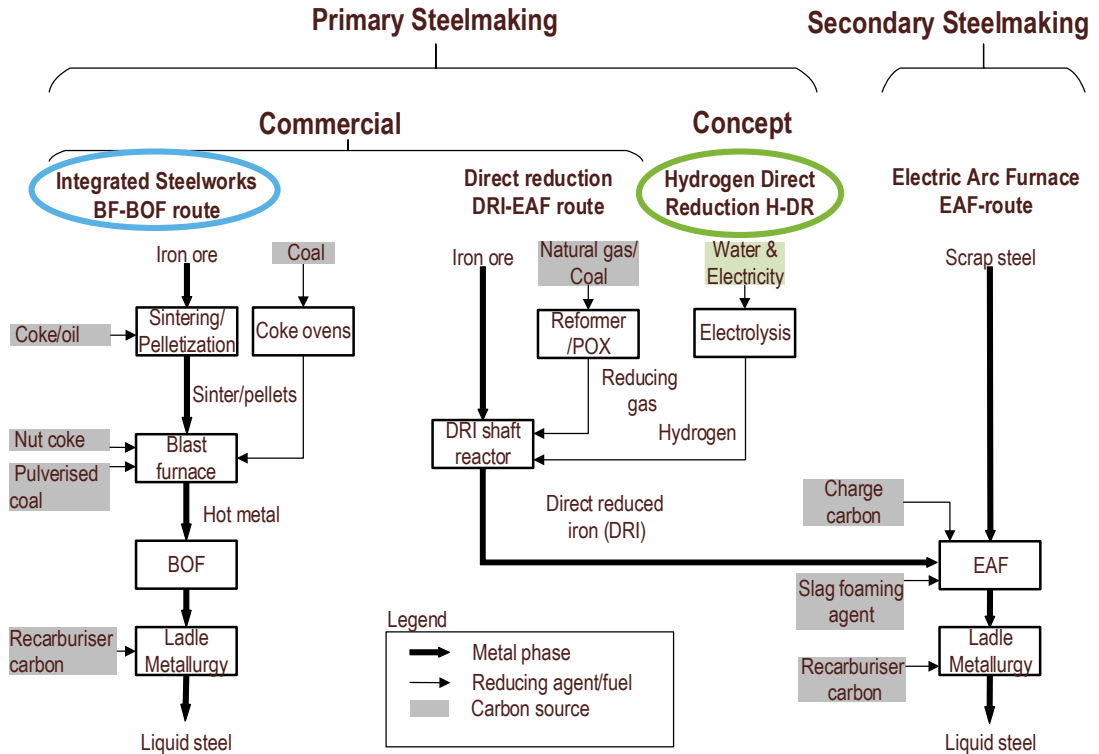
Project partners:



Background: Steelmaking

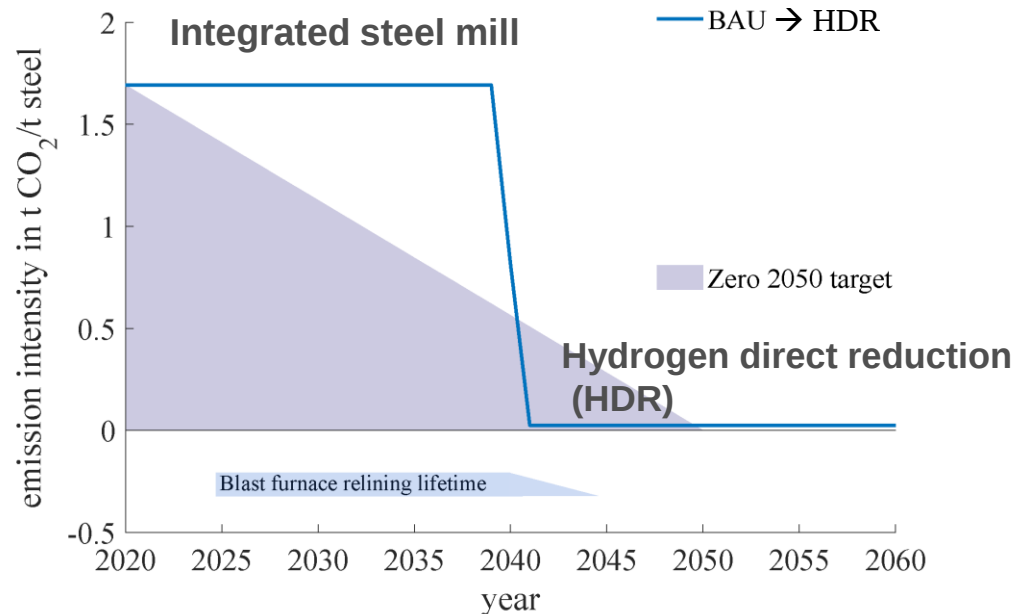
Carbon is used as reducing agent

→ 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 CO₂ 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

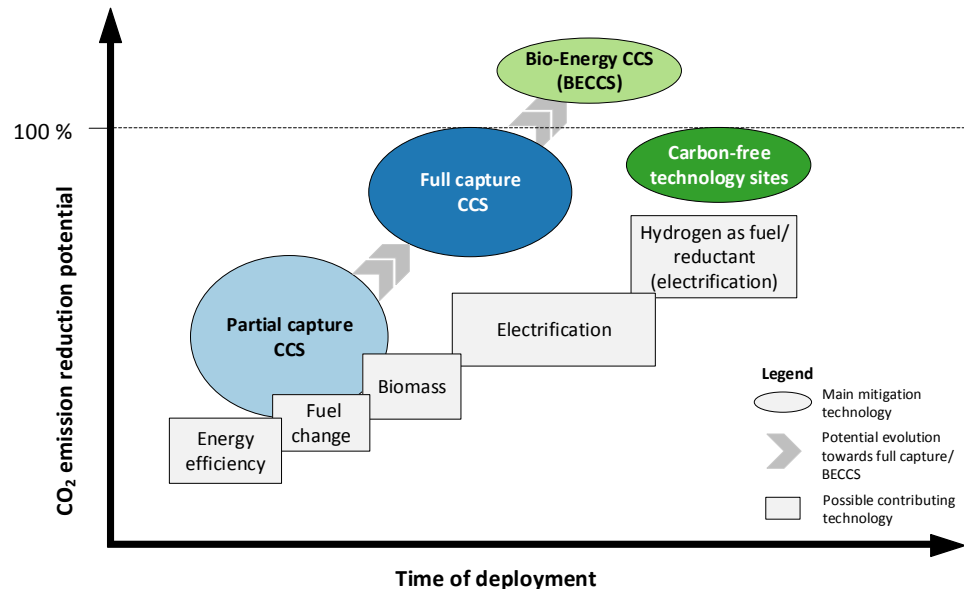
Idea: only a fraction of the accessible CO₂ is captured for storage.

This fraction is determined by

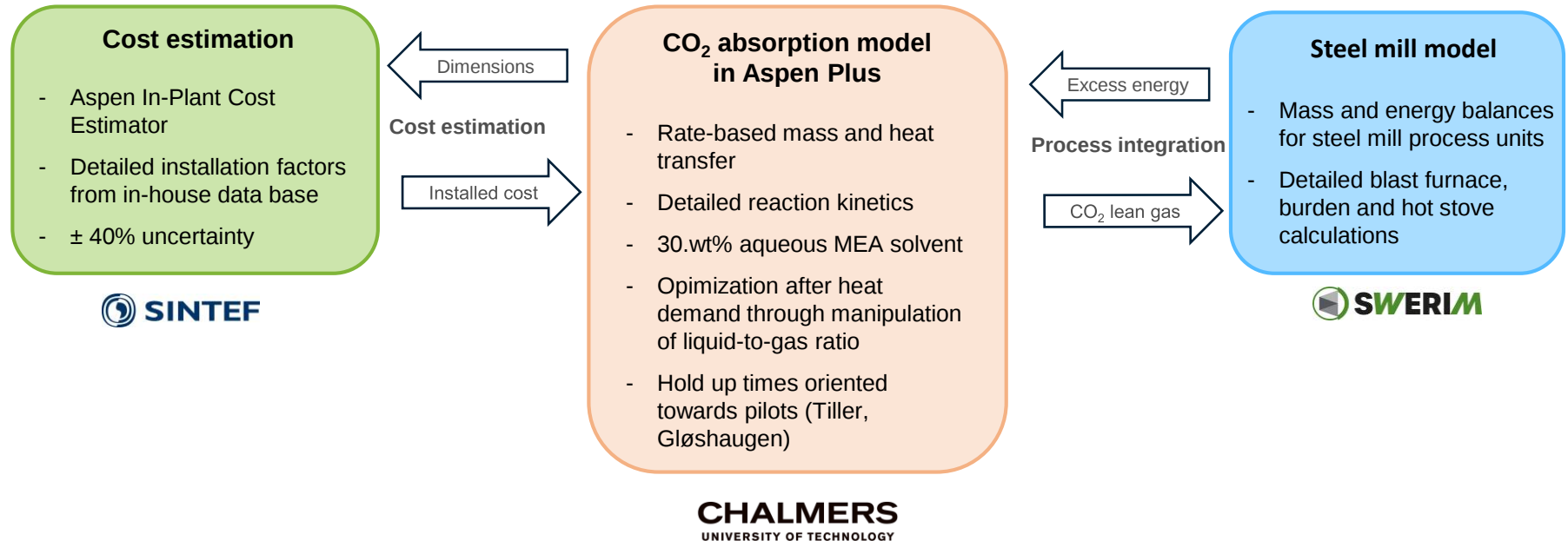
- Economic factors (cost reduction)
- Policy requirements (capture what is required)

Partial capture compared to full capture:

- Lower absolute energy need
- Lower absolute investment cost
- May beat economy of scale (€/t CO₂) 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

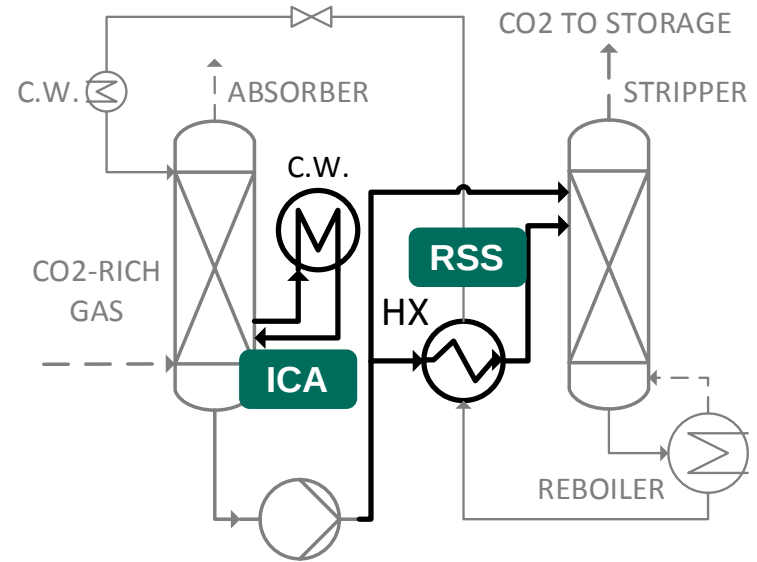


Method: Design choices for partial capture

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



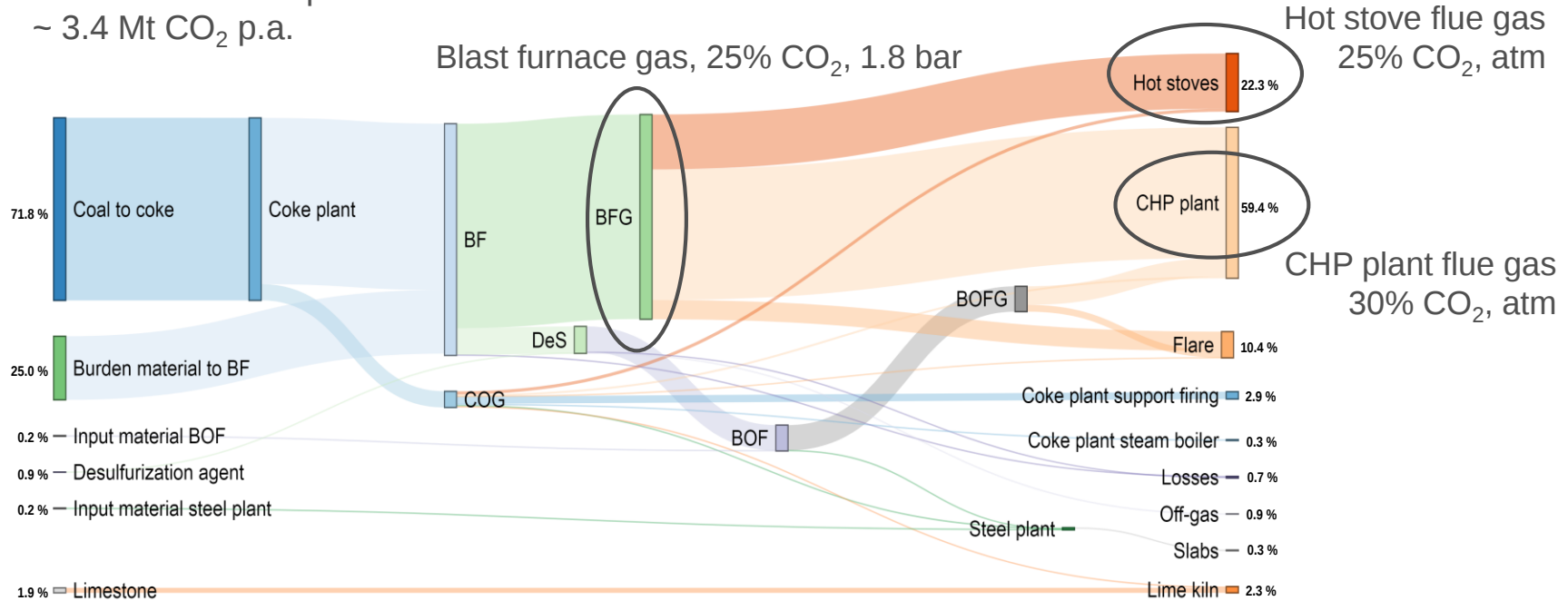
Biermann et al. *Partial Carbon Capture by Absorption Cycle for Reduced Specific Capture Cost.*
Ind. Eng. Chem. Res. **2018**

Method: Economic parameters

Parameter	Value	
Economic plant life time	25 years	
Construction time	2 years	
Plant availability	95%	← High availability of key steel units >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	← Average Spotmarket 2013-2016
Steam	assessed separately	← Bottom-up approach in assessing value of excess heat

Luleå steel mill - CO₂ sources

~ 2 Mt steel slabs p.a.
~ 3.4 Mt CO₂ p.a.

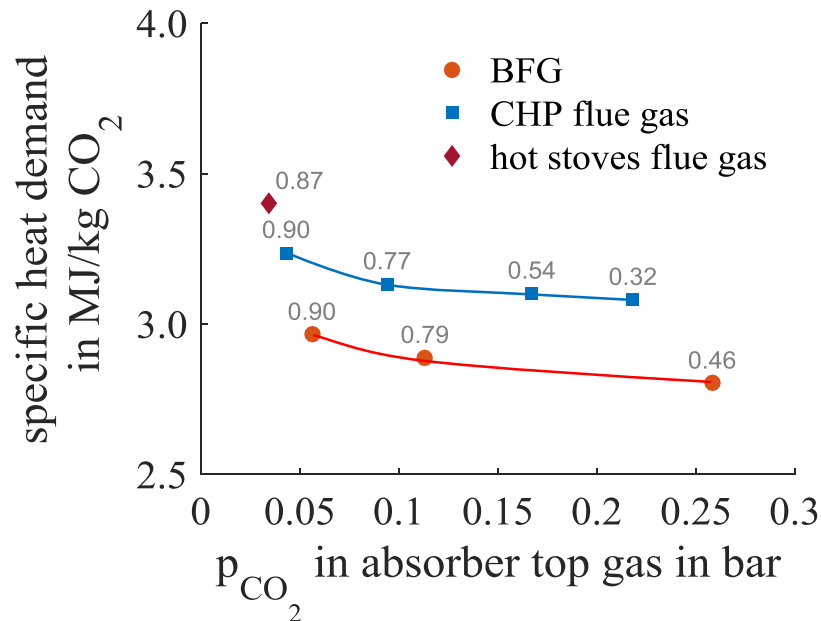


High- or low-level integration?

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

The LHV of blast furnace gas increases with CO₂ capture

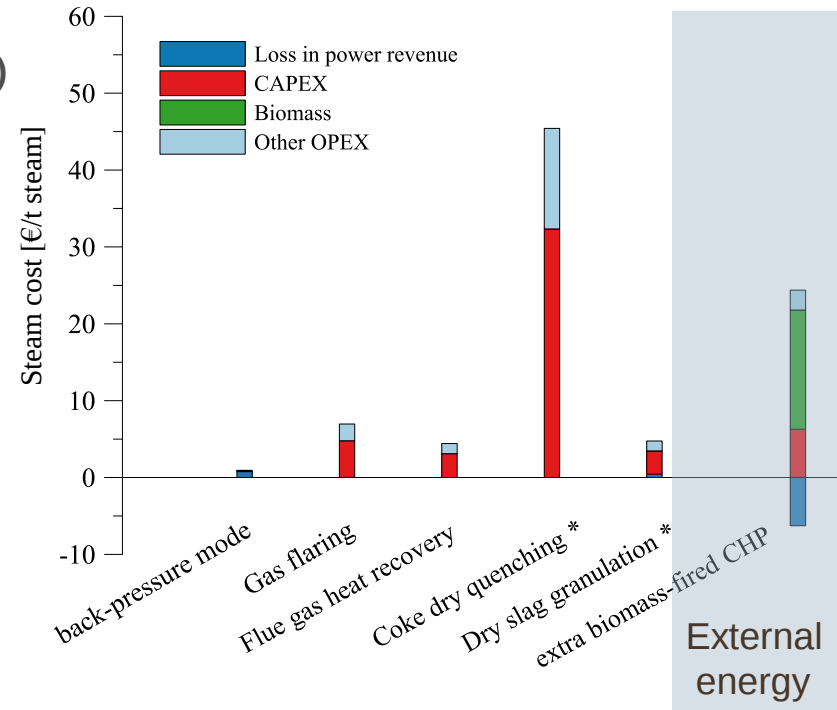
- Gas management on-site can be changed to supply more excess heat to CCS at the expense of electricity production



Excess heat at an integrated steel mill

Assumption: constant heat load (yearly average)

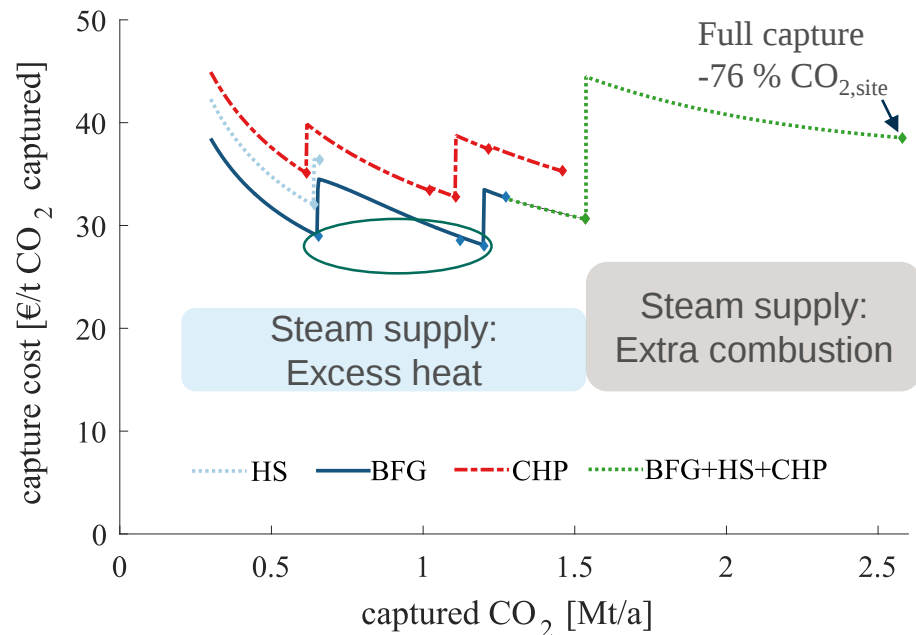
- 5 sources of excess heat to supply steam of 3 bar investigated
- Bottom-up approach: piping, equipment, OPEX (maintenance, power, cooling) included
- Most are implementable and low-cost compared to steam supply via combustion of external fuel



Emissions reductions and capture cost

- Capturing from blast furnace gas is most economic
→ 20%–38% less CO₂ emissions
- Partial capture with excess heat costs less than full capture with external energy

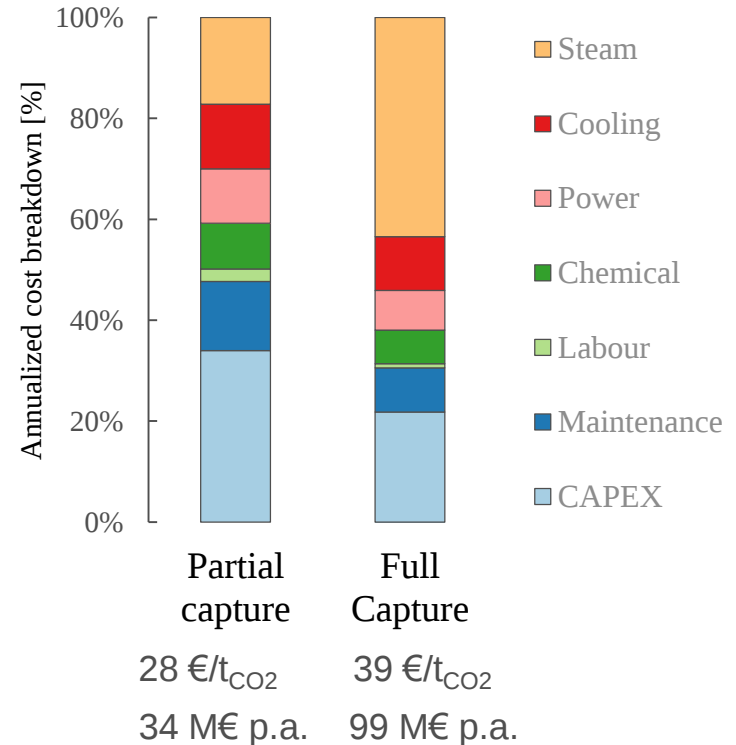
[shows capture cost! no transport and storage cost included]



Cost structure

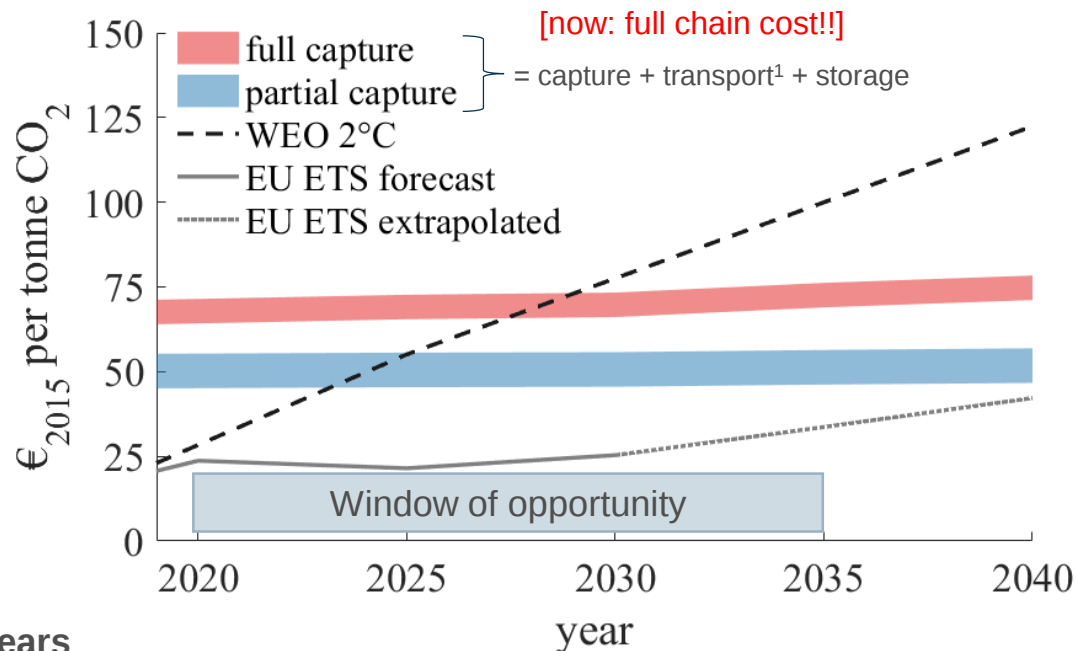
i) Partial capture with excess heat is dominated by CAPEX;

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



Near-term implementation

Partial capture with excess heat requires a carbon price of 40-60 €/tonne CO₂



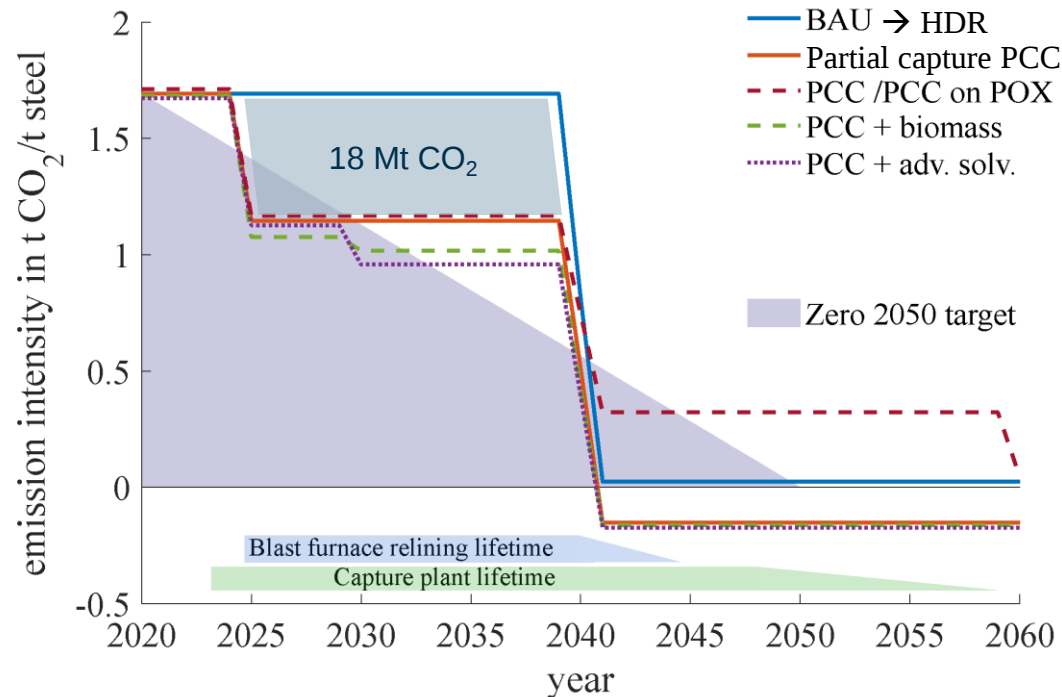
Window of opportunity: coming 5-15 years

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

¹Assuming 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 CO₂
- Window of opportunity for implementation of partial capture, before low-carbon technologies are required to meet CO₂ 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!

Maximilian Biermann, PhD student, Chalmers
max.biermann@chalmers.se



[Project home page](#)
with publication list



CHALMERS
UNIVERSITY OF TECHNOLOGY

This work is part of the CO₂stCap project
[Cutting Cost of CO₂ Capture in Process Industry](#)

CO₂stCap

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

Project partners:



CO2stCap project

Project duration: 2015-2019
Project manager: Ragnhild Skagestad
ragnhild.skagestad@sintef.no

Cutting Cost of CO₂ Capture in Process Industry

Aim: Reduce cost for CO₂ capture from process industry

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

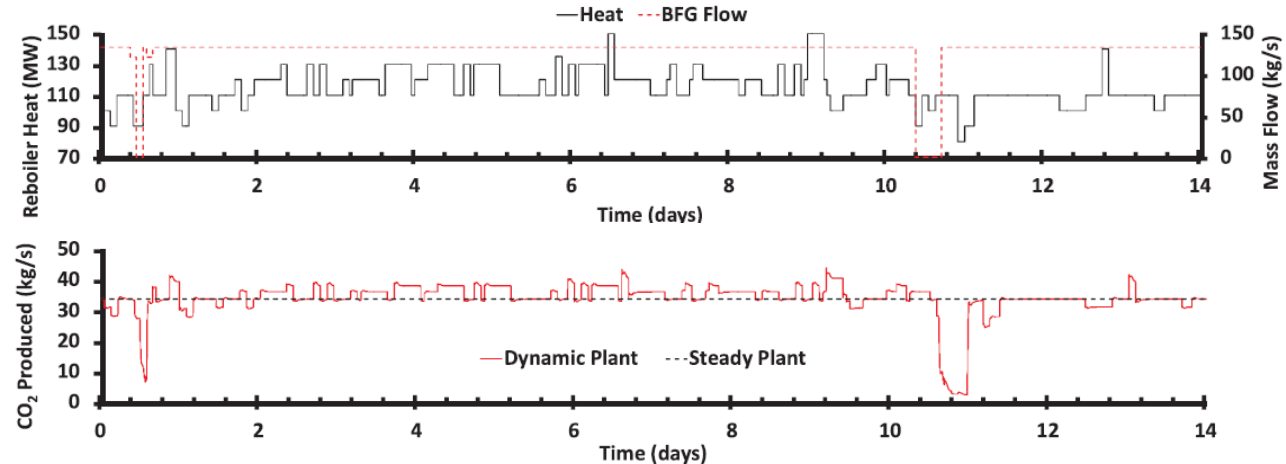
Idea: Apply partial CO₂ capture, i.e. capture the most cost-effective share of CO₂ [€/t CO₂]

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 CO₂ 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.](#)

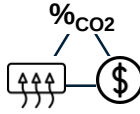
How can partial capture function in synergy with and transition to other mitigation options for steel?

[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?

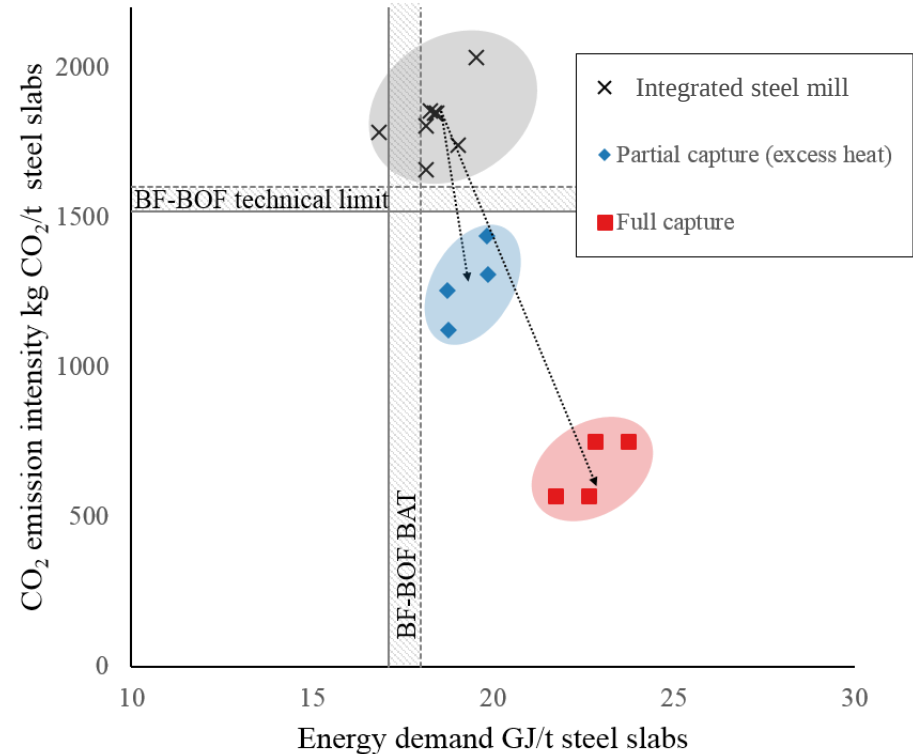
[Biermann et al. *Evaluation of Steel Mills as Carbon Sinks*.
In *International Conference on Negative Emissions*; Chalmers University of Technology: Gothenburg. 2018.](#)

Carbon versus energy intensity?



Partial capture with excess heat
can reduce CO₂ intensity of primary steel ...

...without affecting significantly the energy
demand!



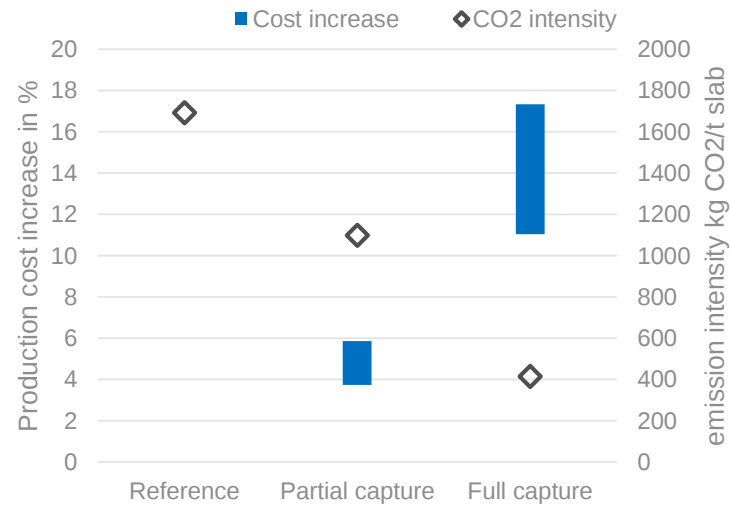
Steel product: CO₂ vs product cost?

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

Mechanisms required to pass on production cost?

→ a price of 50 €/t CO₂ 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**



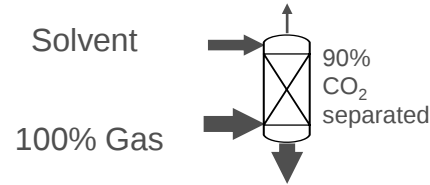
Reference production cost:

280 – 450 €/t slab

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

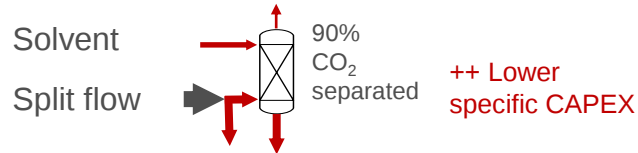
Design of partial capture

Full capture

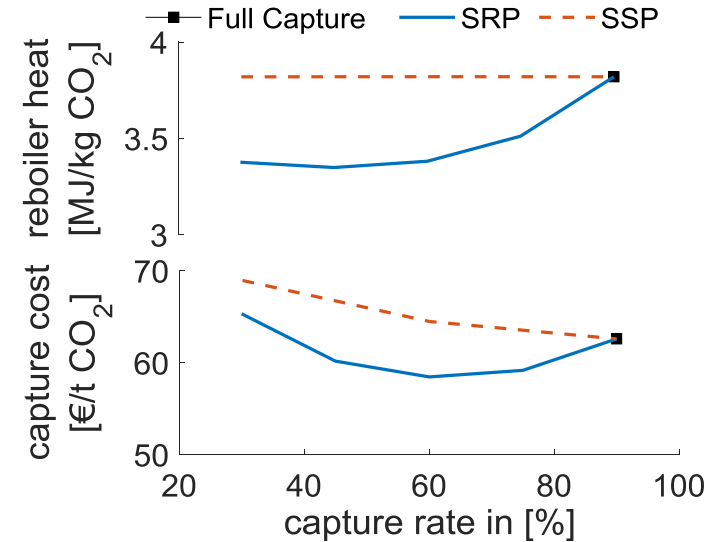
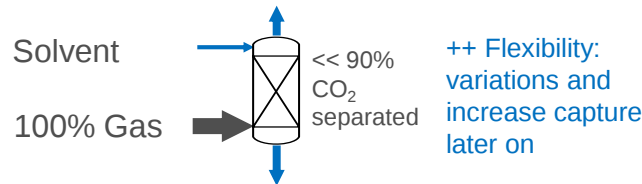


Two principle paths for partial capture design:

Split Stream Path (SSP)



Separation Rate Path (SRP)



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

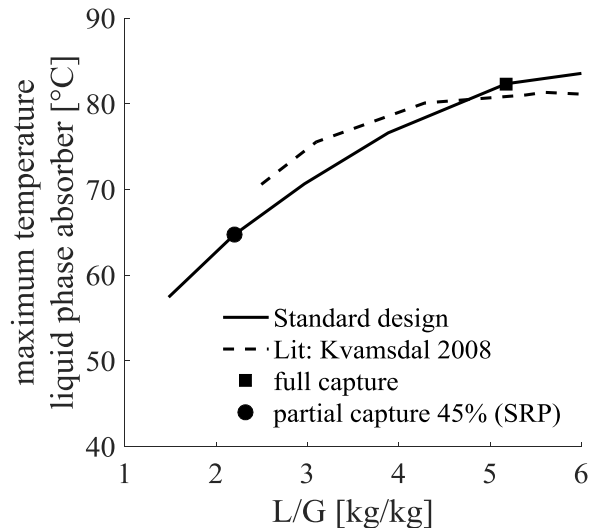


Design of partial capture

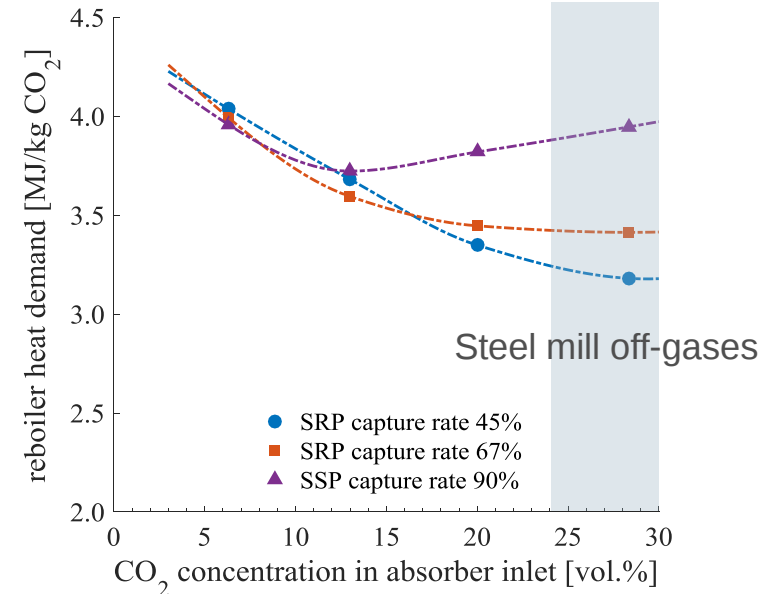
Impact of changing separation rate depends on CO₂ concentration

Separation Rate Path

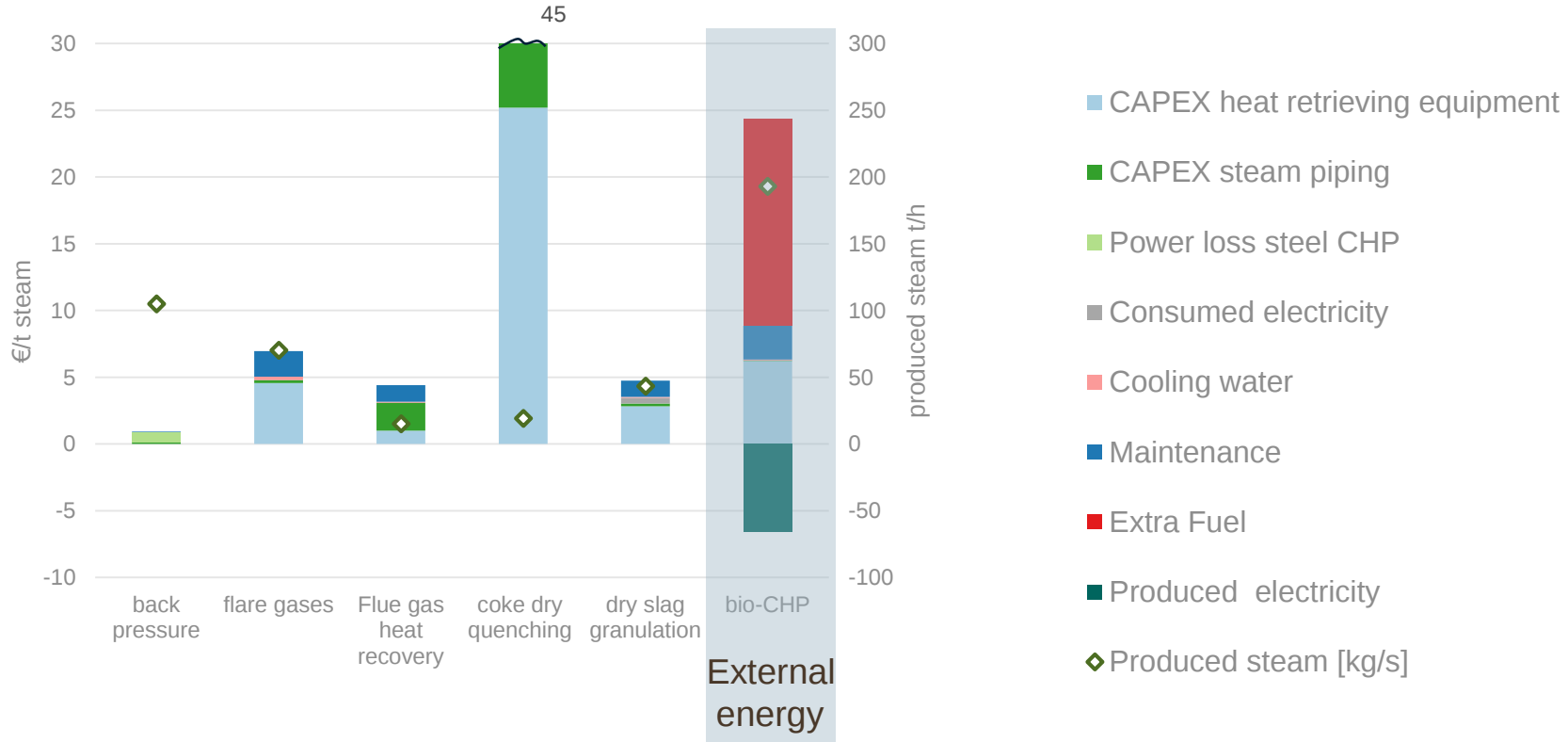
lower L/G → maximum T in liquid phase lowered



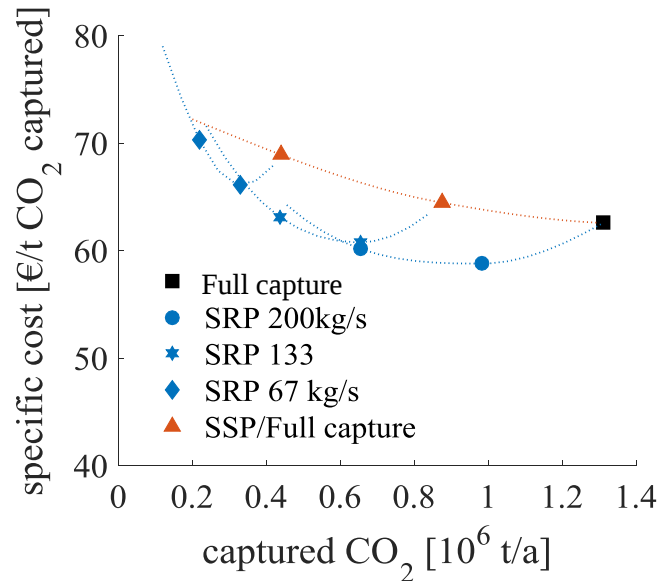
relevant for high CO₂ concentrations!



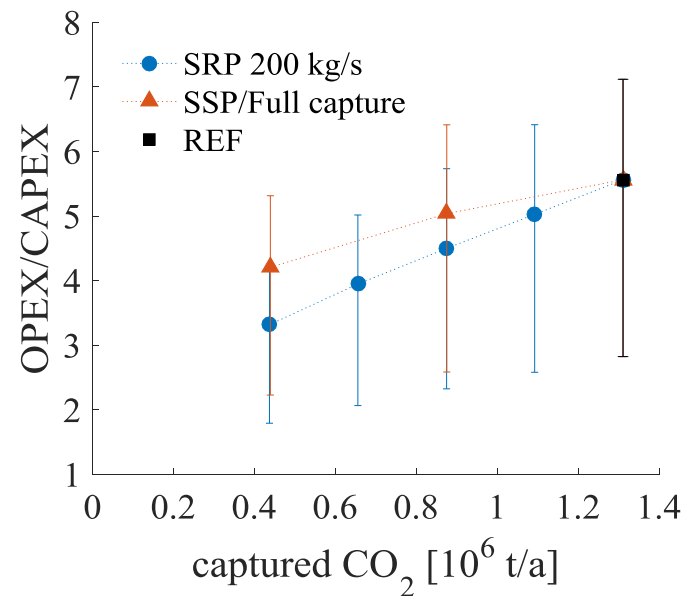
Cost of steam – example: integrated steel mill



Impact of scale and steam price on capture cost



CO₂ 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 CO₂

Full capture:
BFG + HS + CHP, 39 €/t CO₂

