

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

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Part of the CO<sub>2</sub>stCap project

CO<sub>2</sub>stCap

[Cutting Cost of CO<sub>2</sub> Capture in Process Industry](#)

**Financial support:**

Gassnova (CLIMIT Demo)  
The Swedish Energy Agency

**Project partners:**



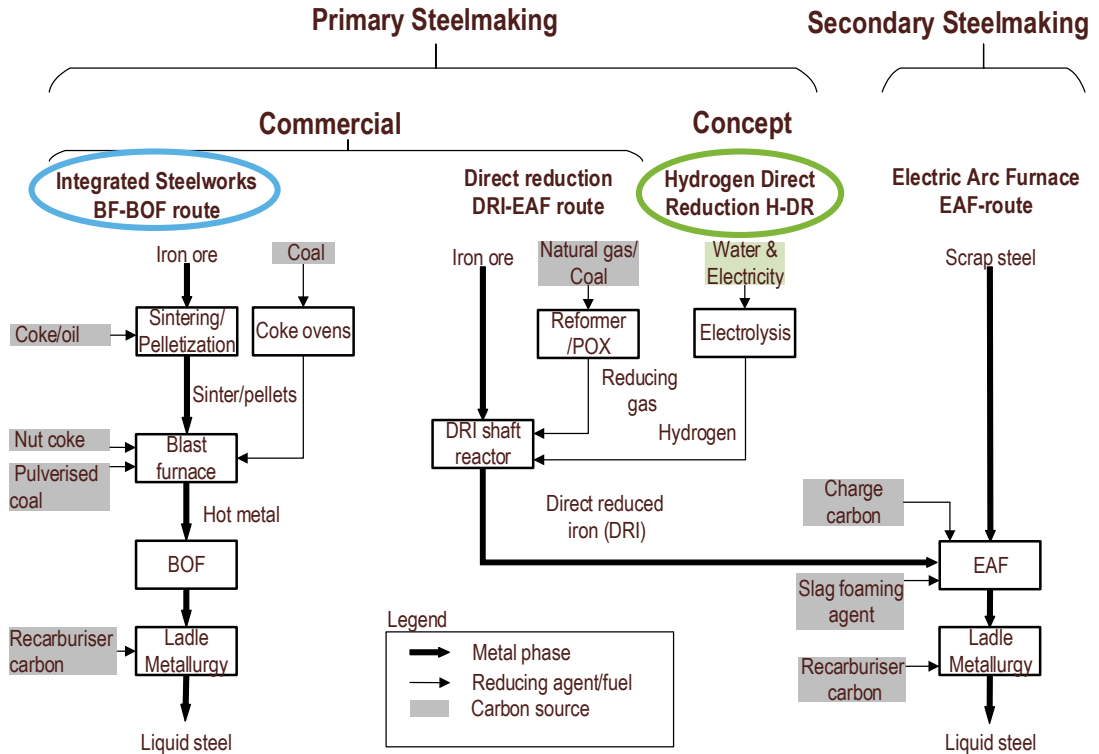
A Member of  
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# Background: Steelmaking

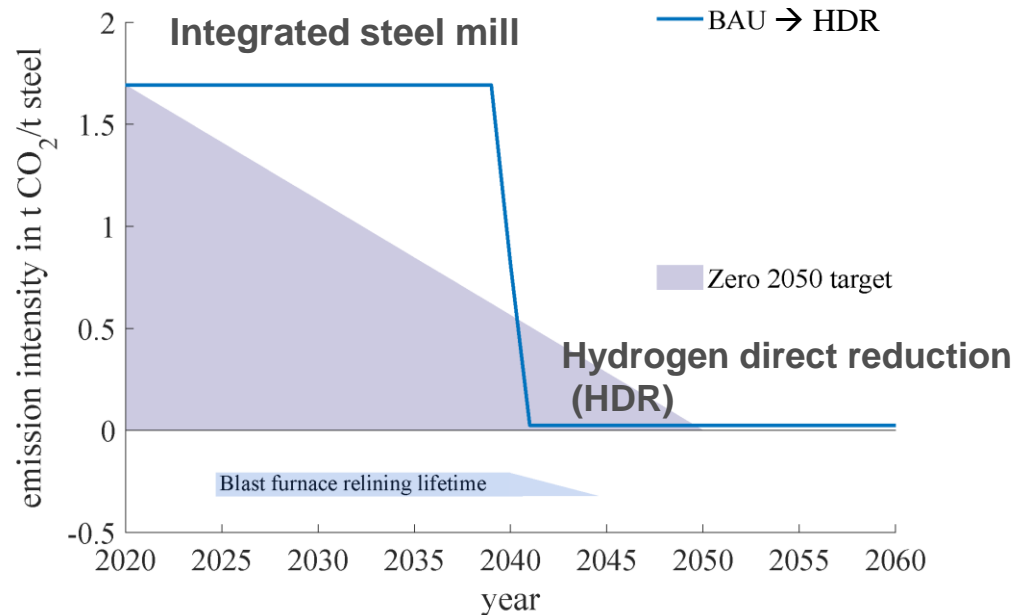
Carbon is used as reducing agent

→ 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<sub>2</sub> 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

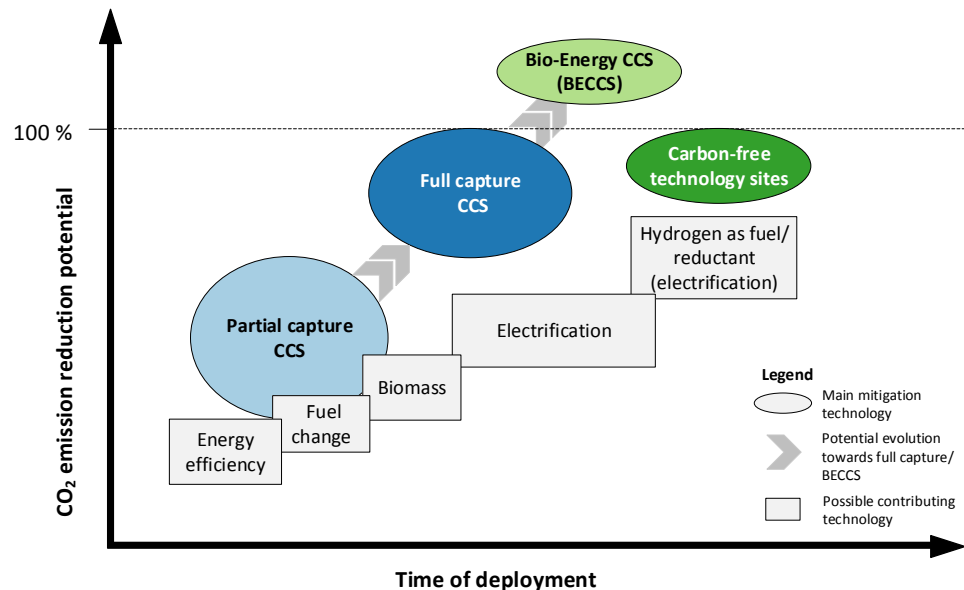
Idea: only a fraction of the accessible CO<sub>2</sub> is captured for storage.

This fraction is determined by

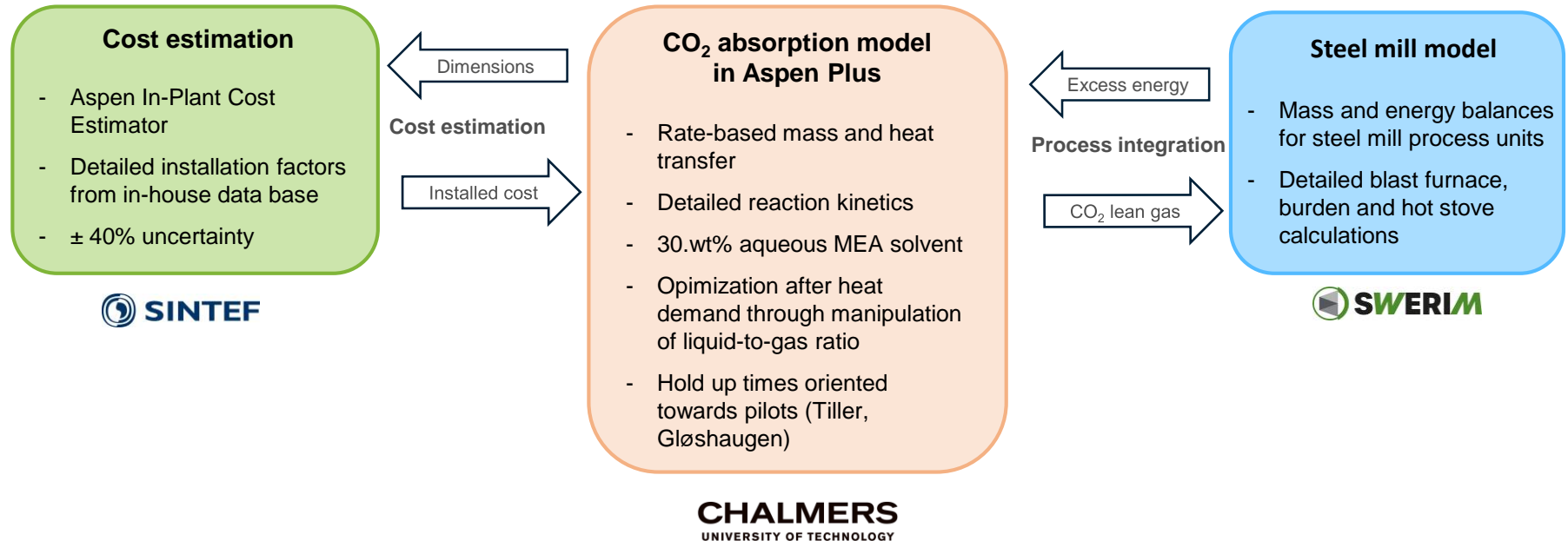
- Economic factors (cost reduction)
- Policy requirements (capture what is required)

## Partial capture compared to full capture:

- Lower absolute energy need
- Lower absolute investment cost
- May beat economy of scale (€/t CO<sub>2</sub>) 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



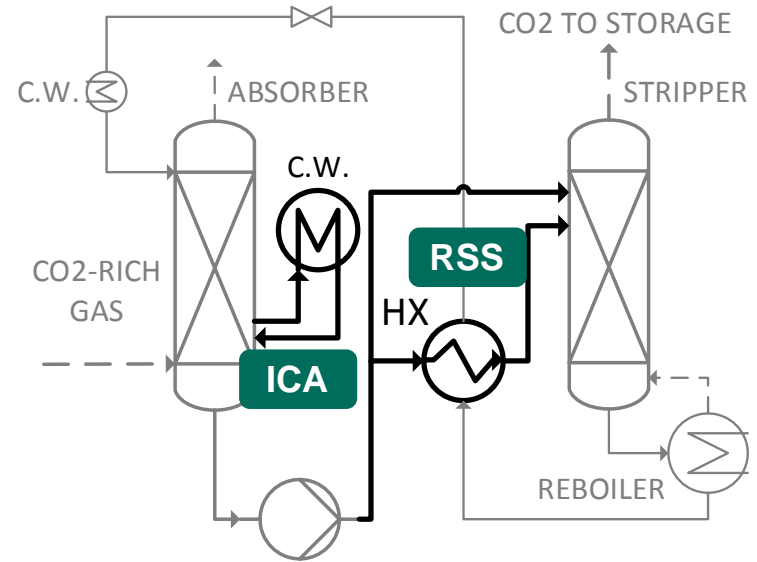
# Method: Design choices for partial capture

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                    |
| <b>Plant availability</b>           | <b>95%</b>                 |
| 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 <sup>3</sup>      |
| Cooling water                       | 0.022 €/m <sup>3</sup>     |
| <b>Electricity</b>                  | <b>0.030 €/kWh</b>         |
| <b>Steam</b>                        | <b>assessed separately</b> |

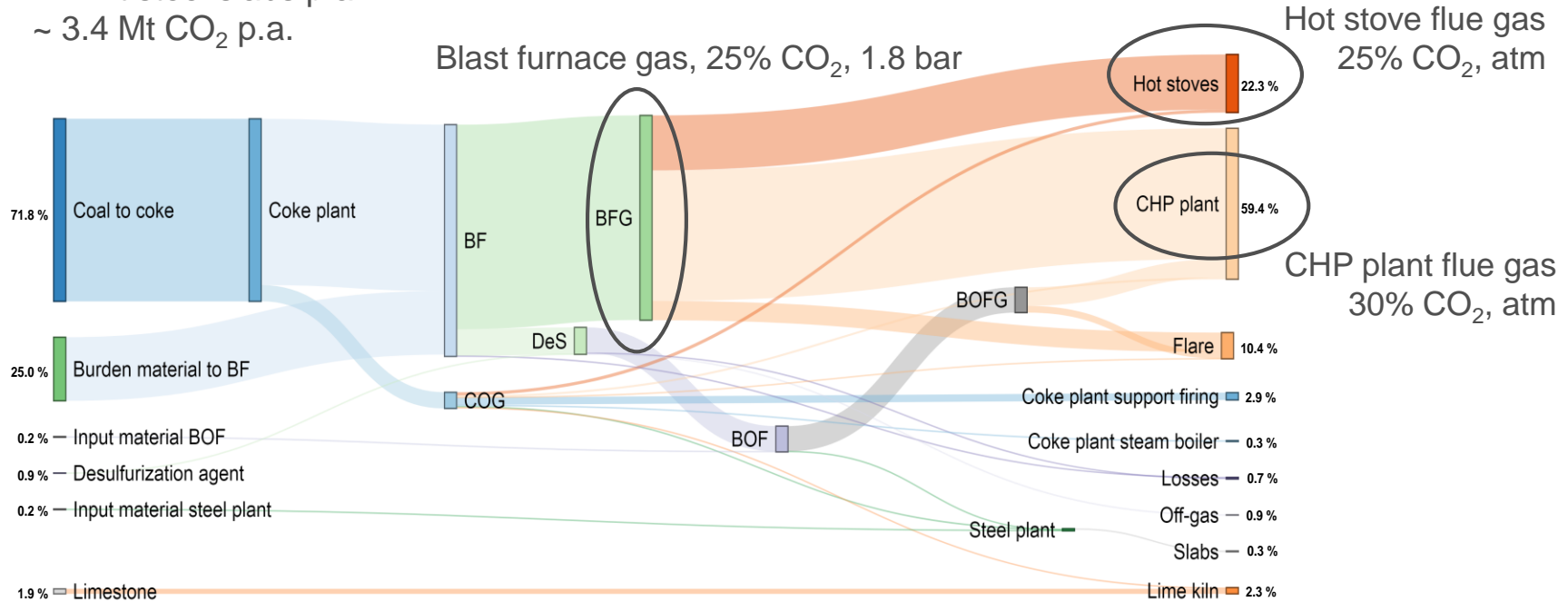
High availability of key steel units >95%

Average Spotmarket 2013-2016

Bottom-up approach in assessing value of excess heat

# Luleå steel mill - CO<sub>2</sub> sources

~ 2 Mt steel slabs p.a.  
~ 3.4 Mt CO<sub>2</sub> p.a.

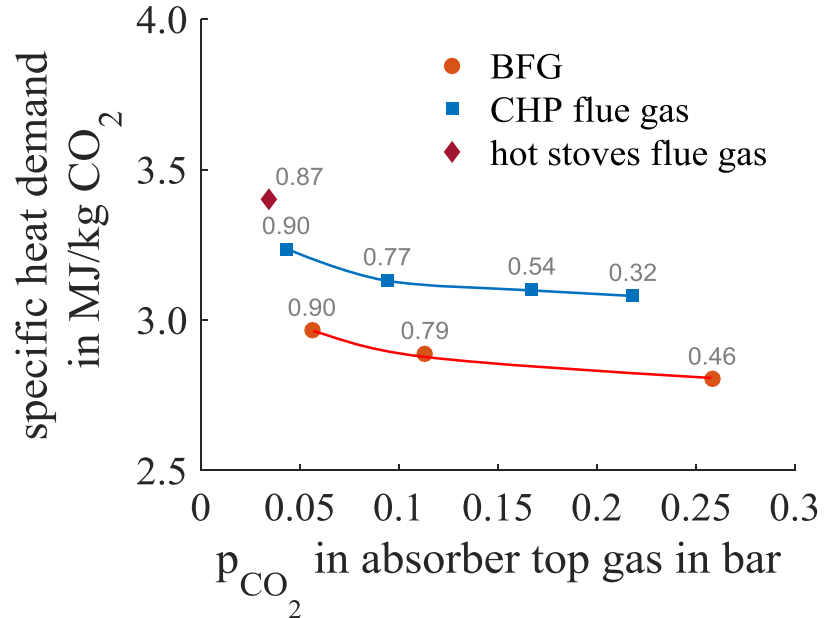


# High- or low-level integration?

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

The LHV of blast furnace gas increases with CO<sub>2</sub> capture

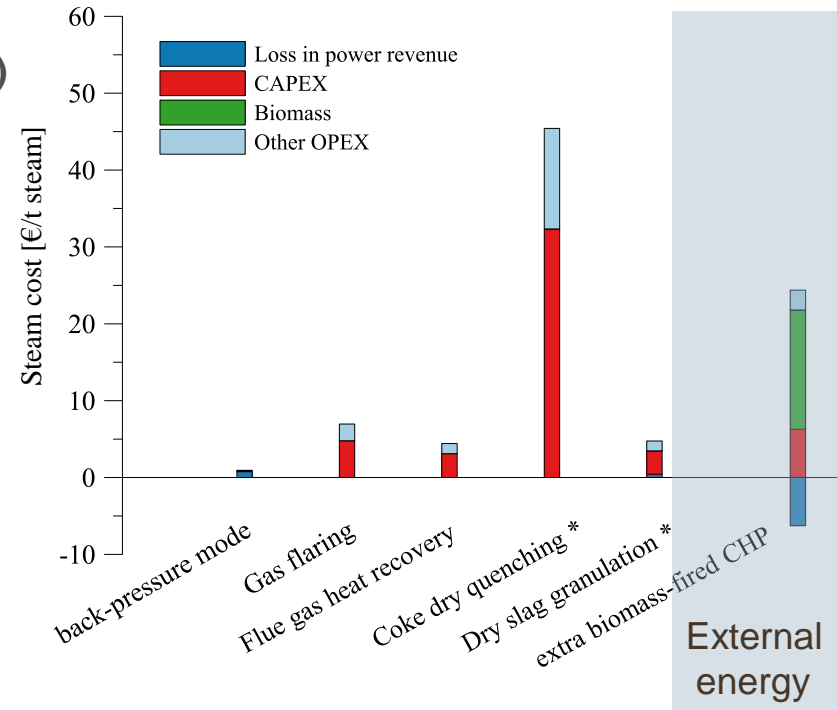
- Gas management on-site can be changed to supply more excess heat to CCS at the expense of electricity production



# Excess heat at an integrated steel mill

**Assumption: constant heat load (yearly average)**

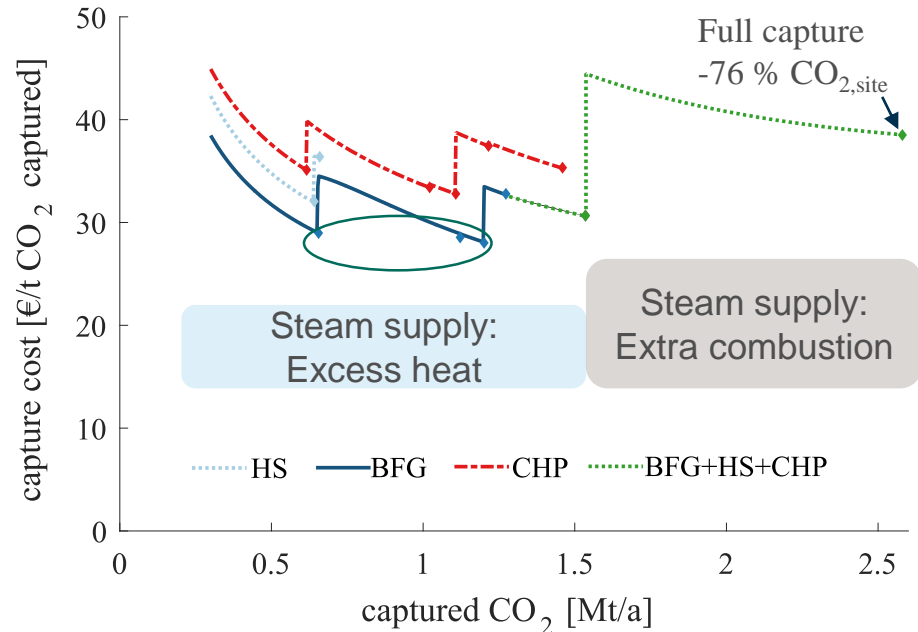
- 5 sources of excess heat to supply steam of 3 bar investigated
- Bottom-up approach: piping, equipment, OPEX (maintenance, power, cooling) included
- Most are implementable and low-cost compared to steam supply via combustion of external fuel



# Emissions reductions and capture cost

- Capturing from blast furnace gas is most economic  
→ 20%–38% less CO<sub>2</sub> emissions
- Partial capture with excess heat costs less than full capture with external energy

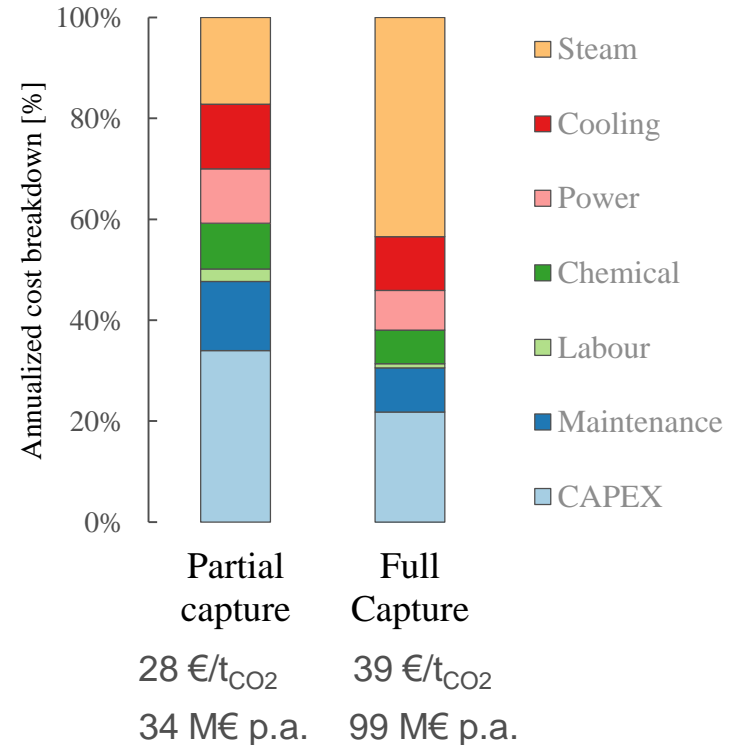
[shows capture cost! no transport and storage cost included]



# Cost structure

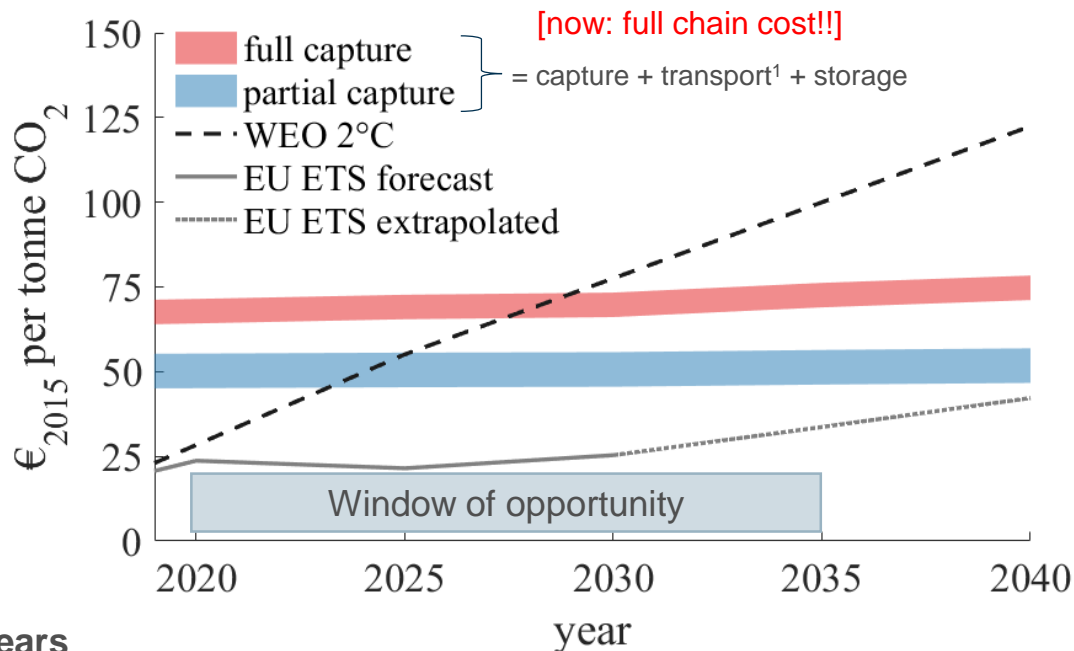
i) Partial capture with excess heat is dominated by CAPEX;

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 CO<sub>2</sub>



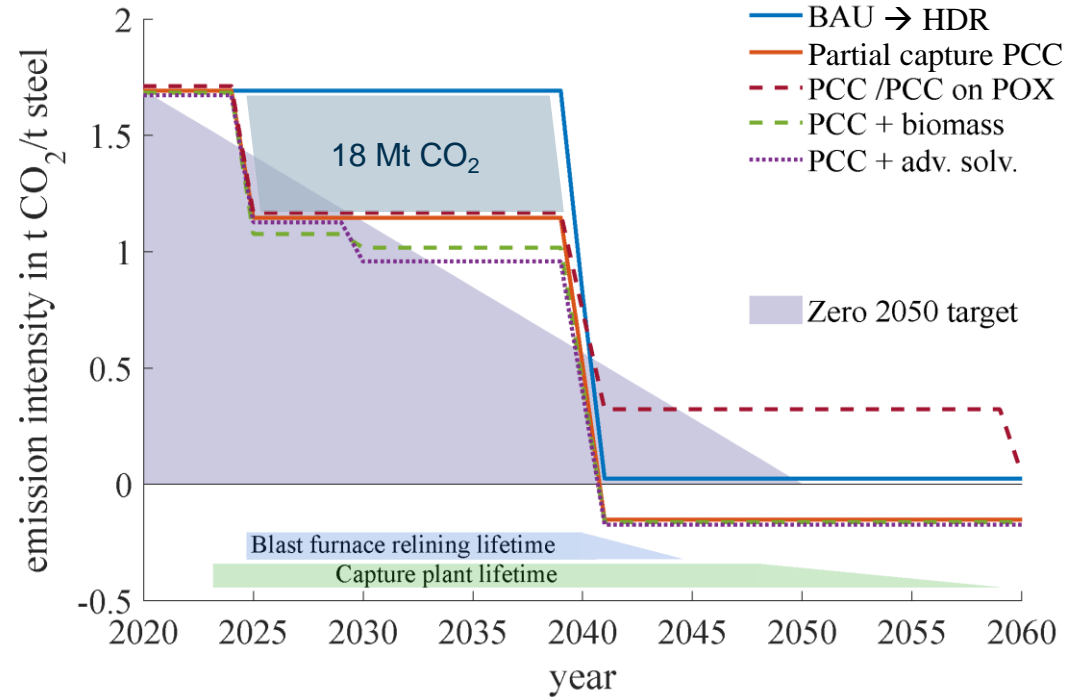
**Window of opportunity: coming 5-15 years**

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

<sup>1</sup>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<sub>2</sub>
- Window of opportunity for implementation of partial capture, before low-carbon technologies are required to meet CO<sub>2</sub> 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



**CHALMERS**  
UNIVERSITY OF TECHNOLOGY

This work is part of the CO<sub>2</sub>stCap project  
[Cutting Cost of CO<sub>2</sub> Capture in Process Industry](#)

CO<sub>2</sub>stCap

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](mailto:ragnhild.skagestad@sintef.no)

## Cutting Cost of CO<sub>2</sub> Capture in Process Industry

Aim: Reduce cost for CO<sub>2</sub> capture from process industry

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

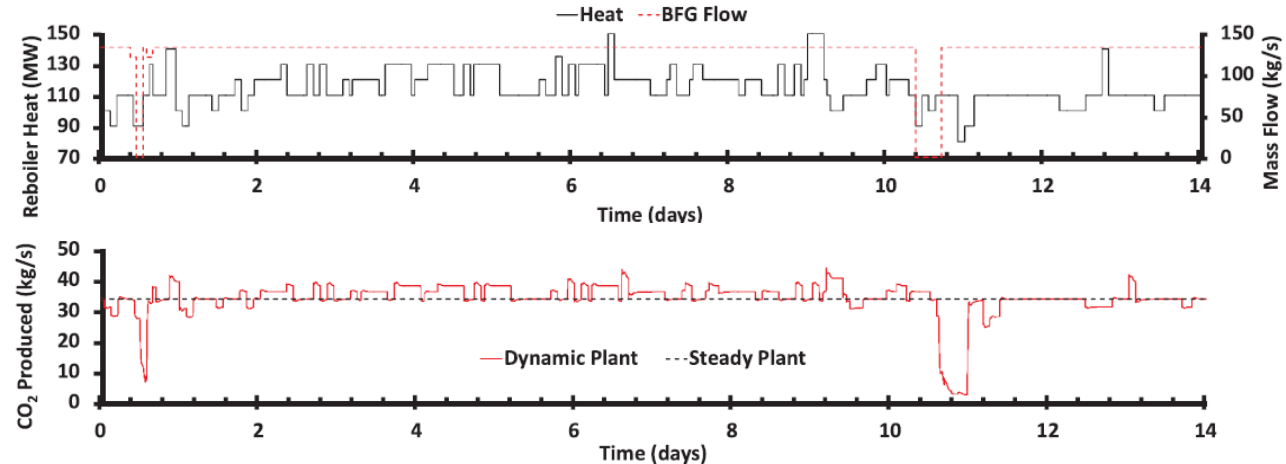
Idea: Apply partial CO<sub>2</sub> capture, i.e. capture the most cost-effective share of CO<sub>2</sub> [€/t CO<sub>2</sub>]

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<sub>2</sub> 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\*\*](#)

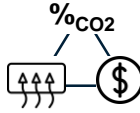
How can partial capture function in synergy with and transition to other mitigation options for steel?

[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?

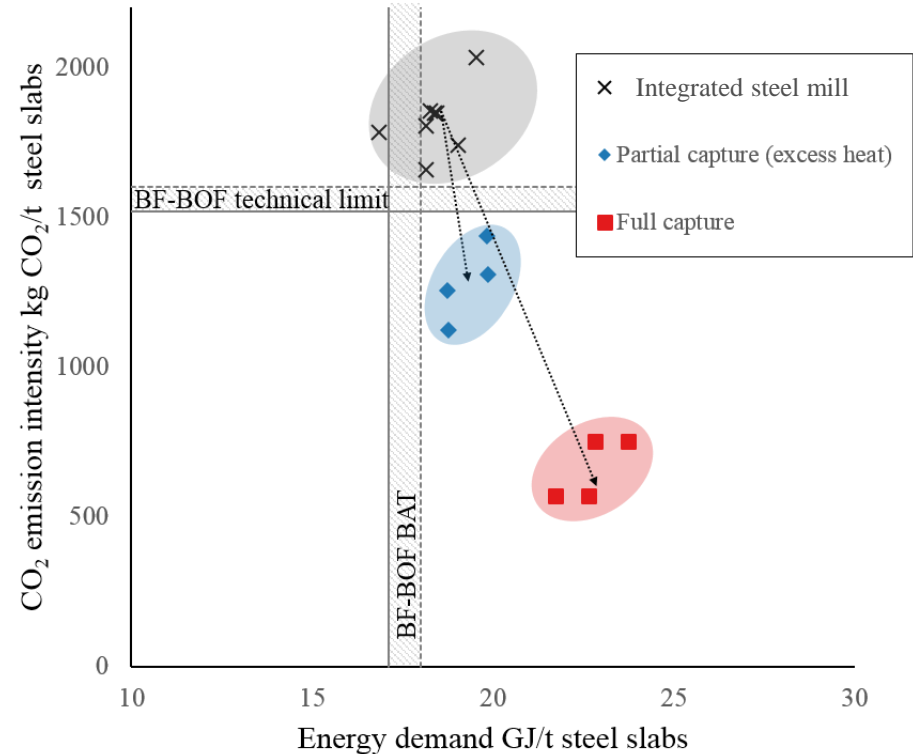
[Biermann et al. \*Evaluation of Steel Mills as Carbon Sinks\*.  
In \*International Conference on Negative Emissions\*; Chalmers University of Technology: Gothenburg. \*\*2018\*\*](#)

# Carbon versus energy intensity?



Partial capture with excess heat  
can reduce CO<sub>2</sub> intensity of primary steel ...

...without affecting significantly the energy  
demand!



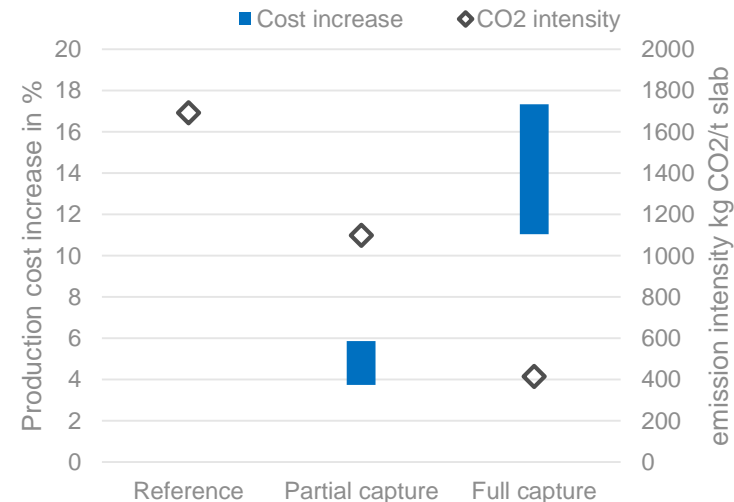
# Steel product: CO<sub>2</sub> vs product cost?

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

## Mechanisms required to pass on production cost?

→ a price of 50 €/t CO<sub>2</sub> 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



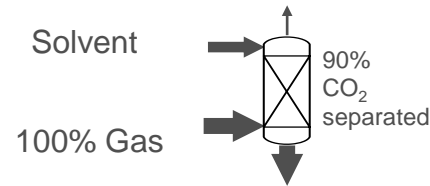
### Reference production cost:

280 – 450 €/t slab

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

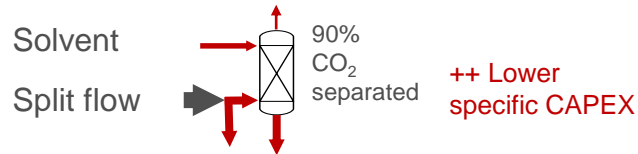
# Design of partial capture

## Full capture

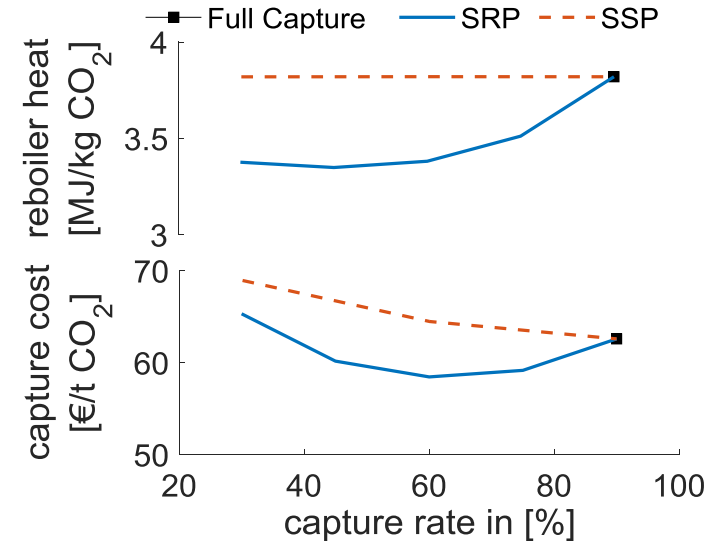
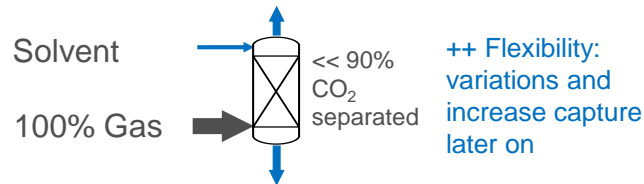


## Two principle paths for partial capture design:

### **Split Stream Path (SSP)**



### **Separation Rate Path (SRP)**



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

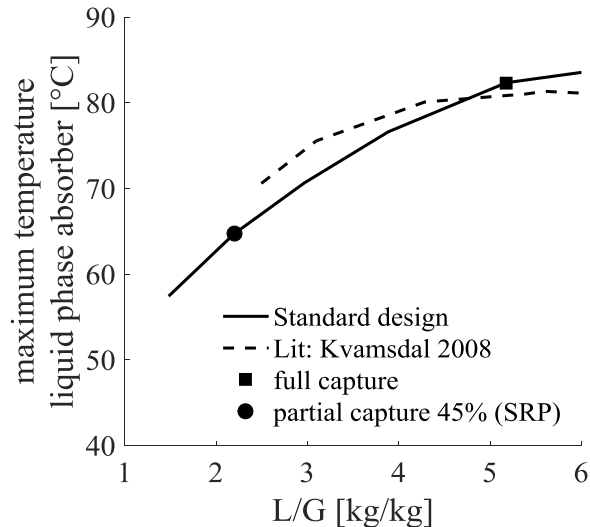


# Design of partial capture

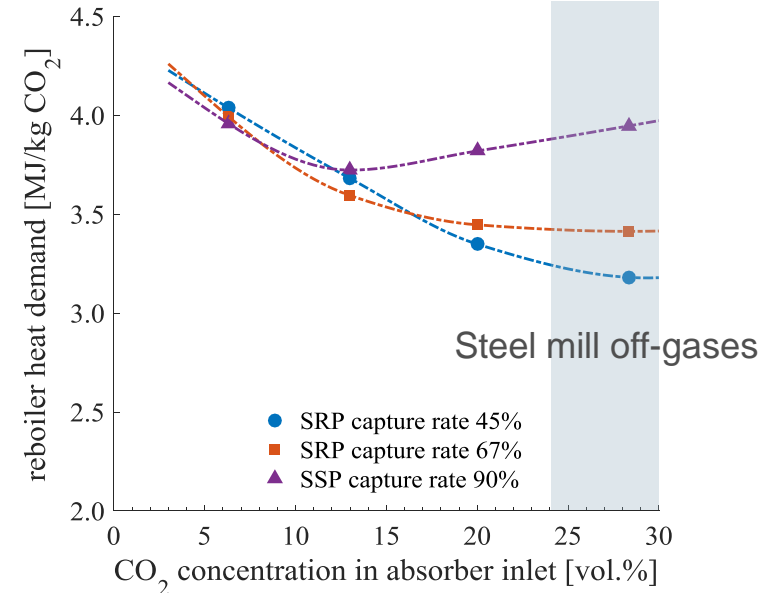
Impact of changing separation rate depends on CO<sub>2</sub> concentration

## Separation Rate Path

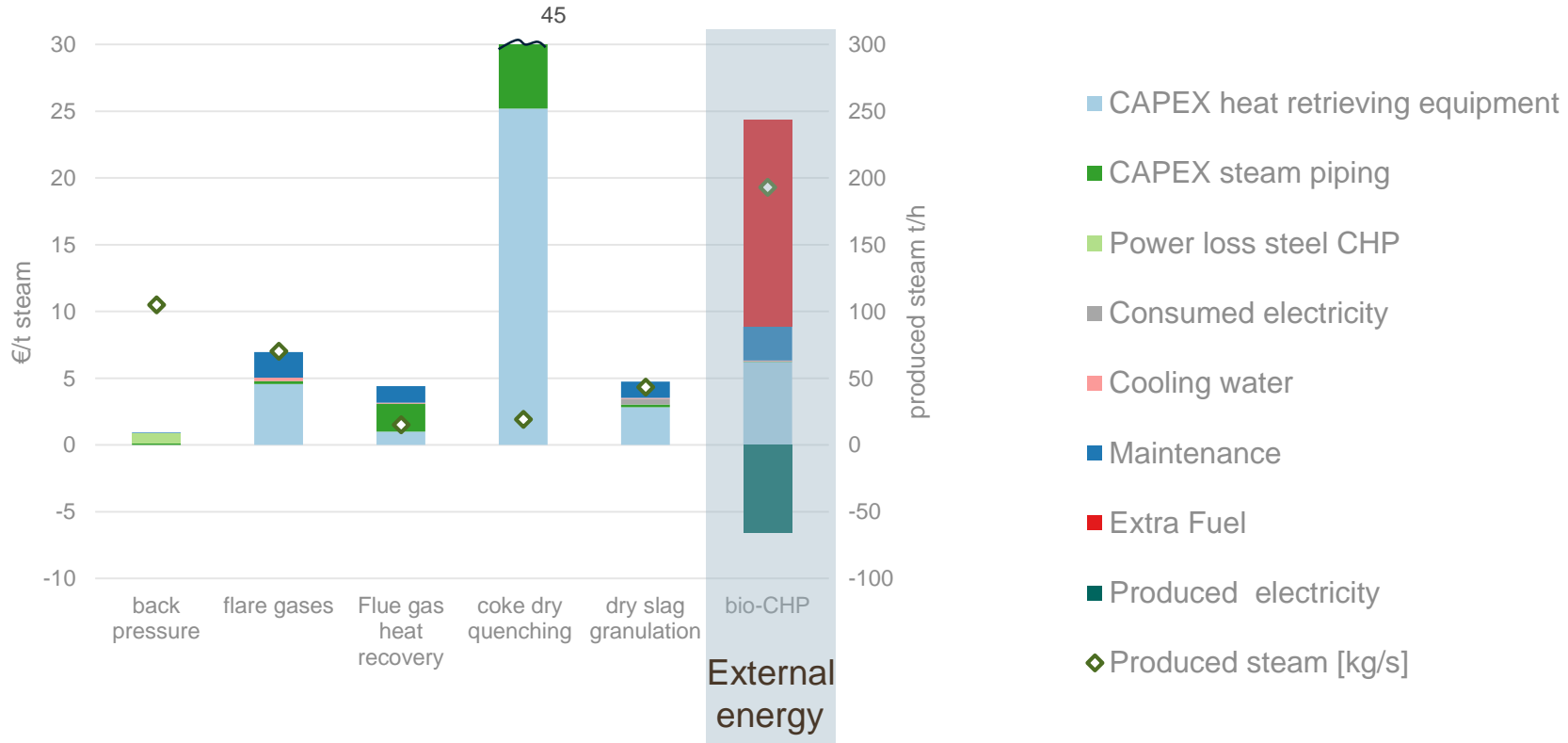
lower L/G → maximum T in liquid phase lowered



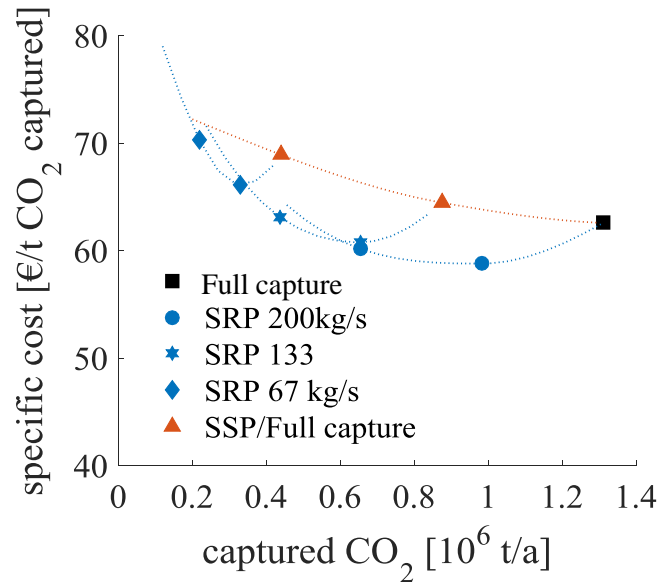
relevant for high CO<sub>2</sub> concentrations!



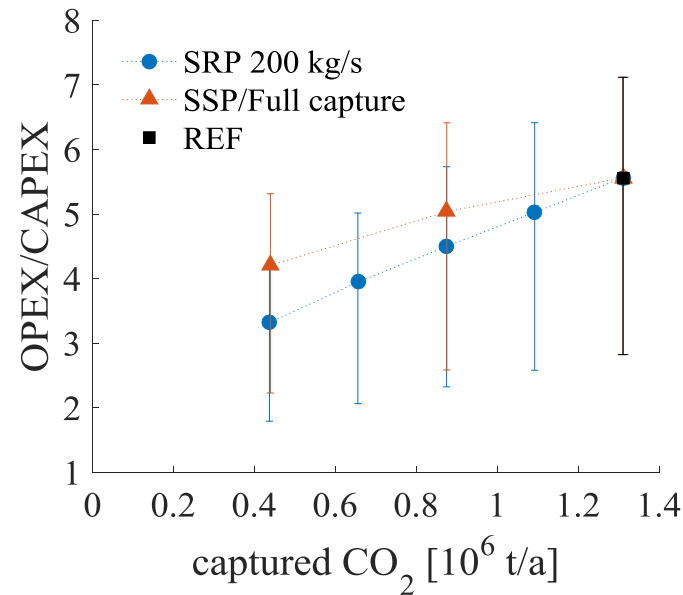
# Cost of steam – example: integrated steel mill



# Impact of scale and steam price on capture cost



CO<sub>2</sub> 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<sub>2</sub>

Full capture:  
BFG + HS + CHP, 39 €/t CO<sub>2</sub>

