

# PARTIAL CAPTURE – AN OPPORTUNITY TO DECARBONIZE PRIMARY STEELMAKING

A TECHNO-ECONOMIC ASSESSMENT OF AMINE ABSORPTION  
OF CARBON DIOXIDE AT AN INTEGRATED STEEL MILL

**Licentiate candidate:**

Maximilian Biermann

**Discussion leader:**

Dr. Lawrence Hooley, Swerim AB, Luleå

**Supervisor of  
the candidate:**

Assoc. Prof. Fredrik Normann

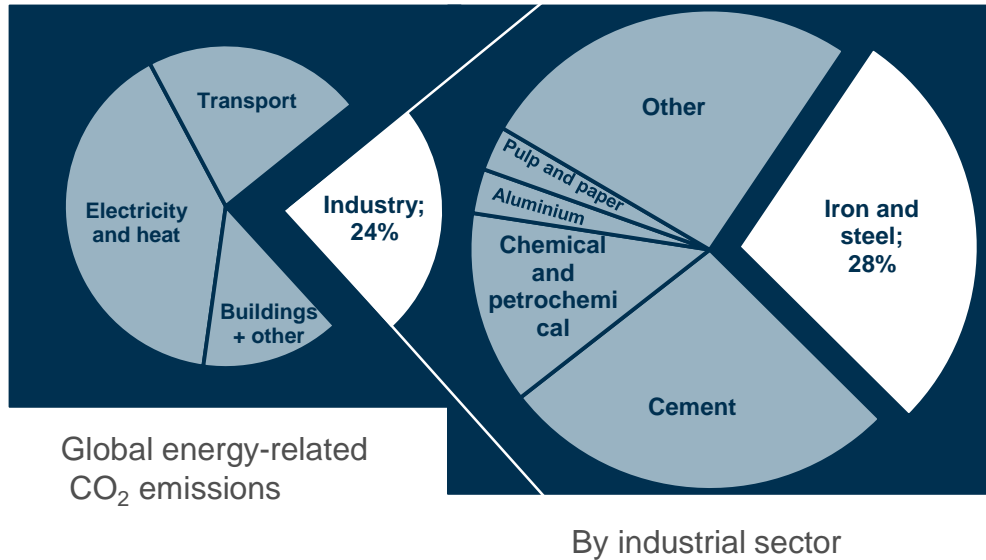
**Examiner and  
chair of this seminar:**

Prof. Filip Johnsson

**This work has been carried out at:**  
The Division of Energy Technology  
Department of Space, Earth and Environment

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

# A Challenge: CO<sub>2</sub> emissions from industry



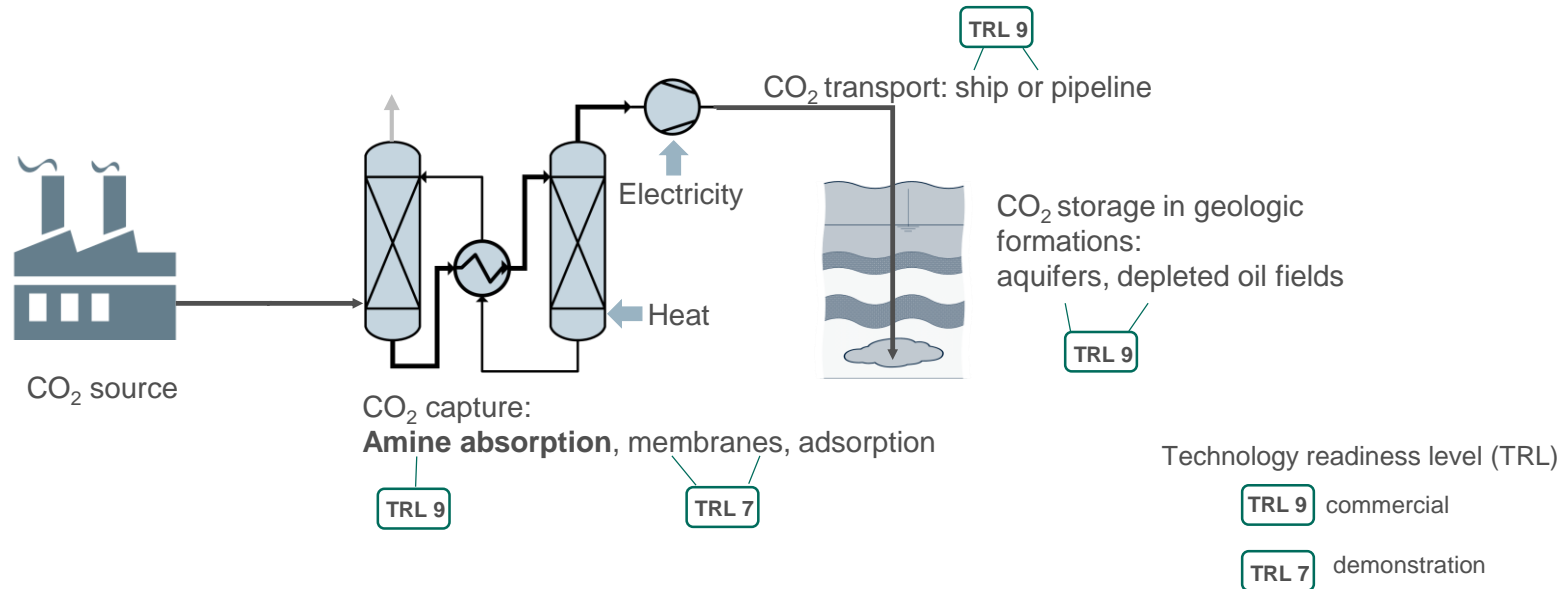
## Challenge

- CO<sub>2</sub> arises from the production process, not only from heating
  - Steel: C as reducing agent
  - Cement: CO<sub>2</sub> from calcination

## CCS as opportunity

- Carbon capture and storage (CCS) is one of the few mitigation options
- Industry provides large point sources with high CO<sub>2</sub> concentrations

# Carbon capture and storage

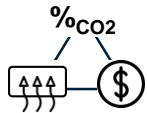




# Aims

*...to support a rapid and sustainable transition of carbon-intensive industries to function in a carbon-constrained society.*

- i. Contribute to the cost-effective design of amine absorption cycles for partial CO<sub>2</sub> capture from industrial processes
- ii. Evaluate how cost, energy need, and capture rates are related for CCS in integrated steel mills
- iii. Assess the near-term implementation of partial capture in integrated steel mills
- iv. Construct a perspective of partial capture in synergy with and in transition to other mitigation options for steel industry



# Partial capture - a CCS concept

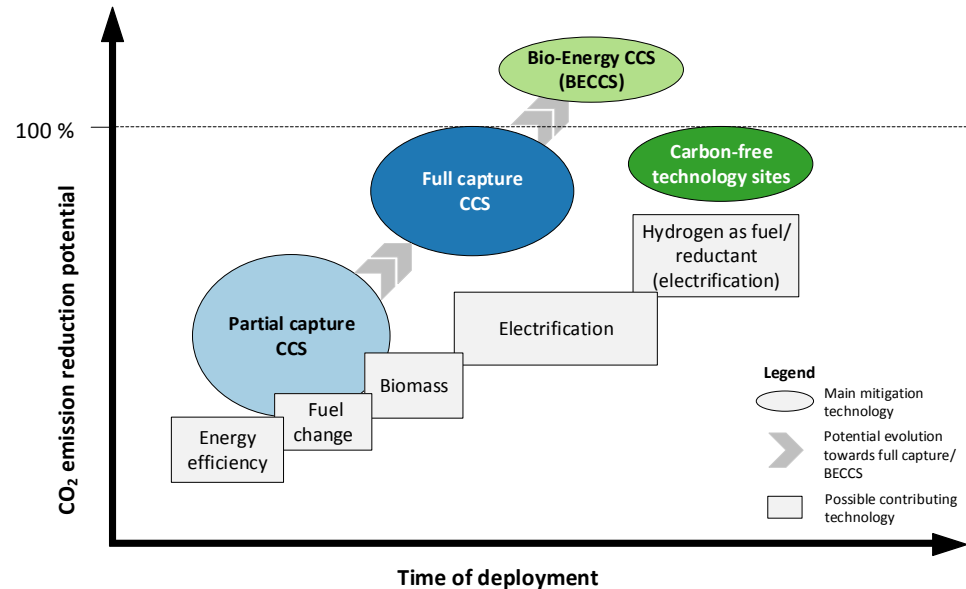
Idea: only a fraction of the accessible CO<sub>2</sub> is captured for storage.

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



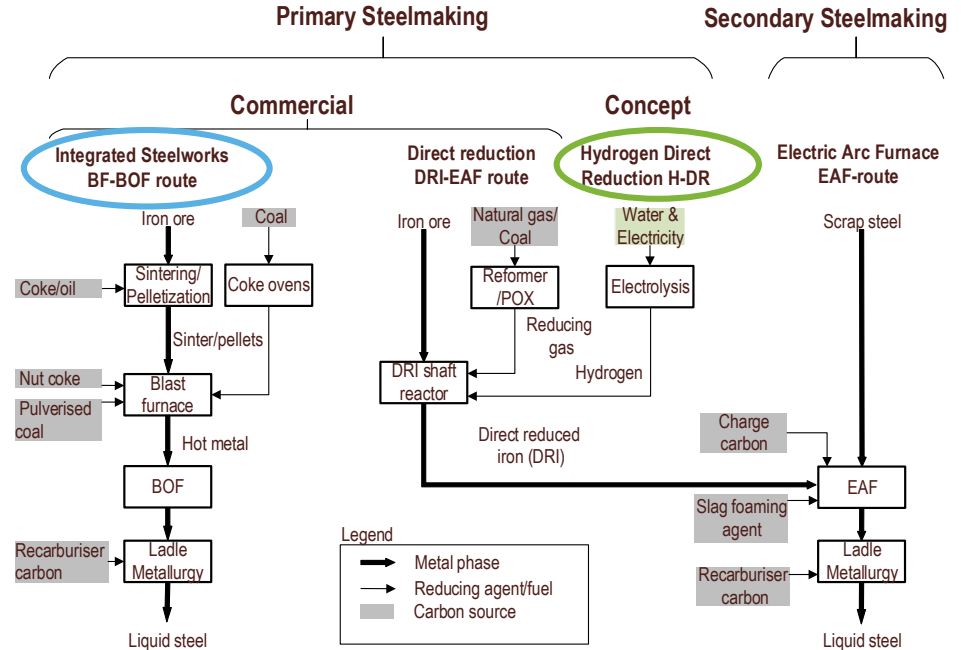
# Primary steelmaking

Carbon is used as reducing agent

primary steelmaking widely applied in 21st century, because of:

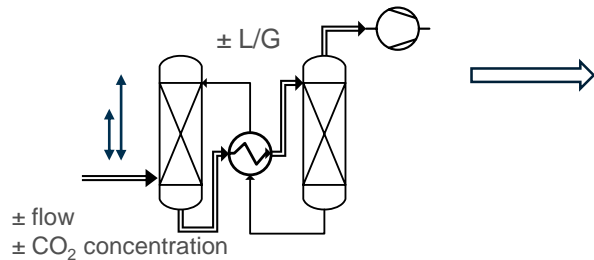
- i. Globally rising steel demand
- ii. Long blast-furnace lifetimes ~40-60 yrs
- iii. Purity demands for high quality steel

→ Primary steelmaking has to be decarbonized



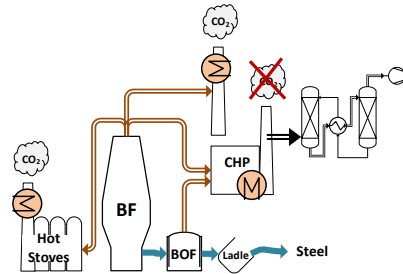
# Scope of work

## Paper I



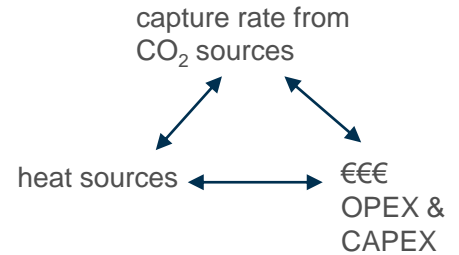
Design of amine absorption cycles for partial capture

## Paper II



Partial capture from steel-mill off-gases with excess heat at *constant* load

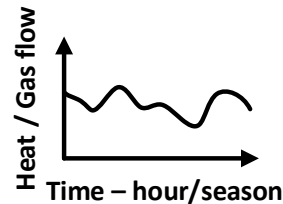
## Paper III



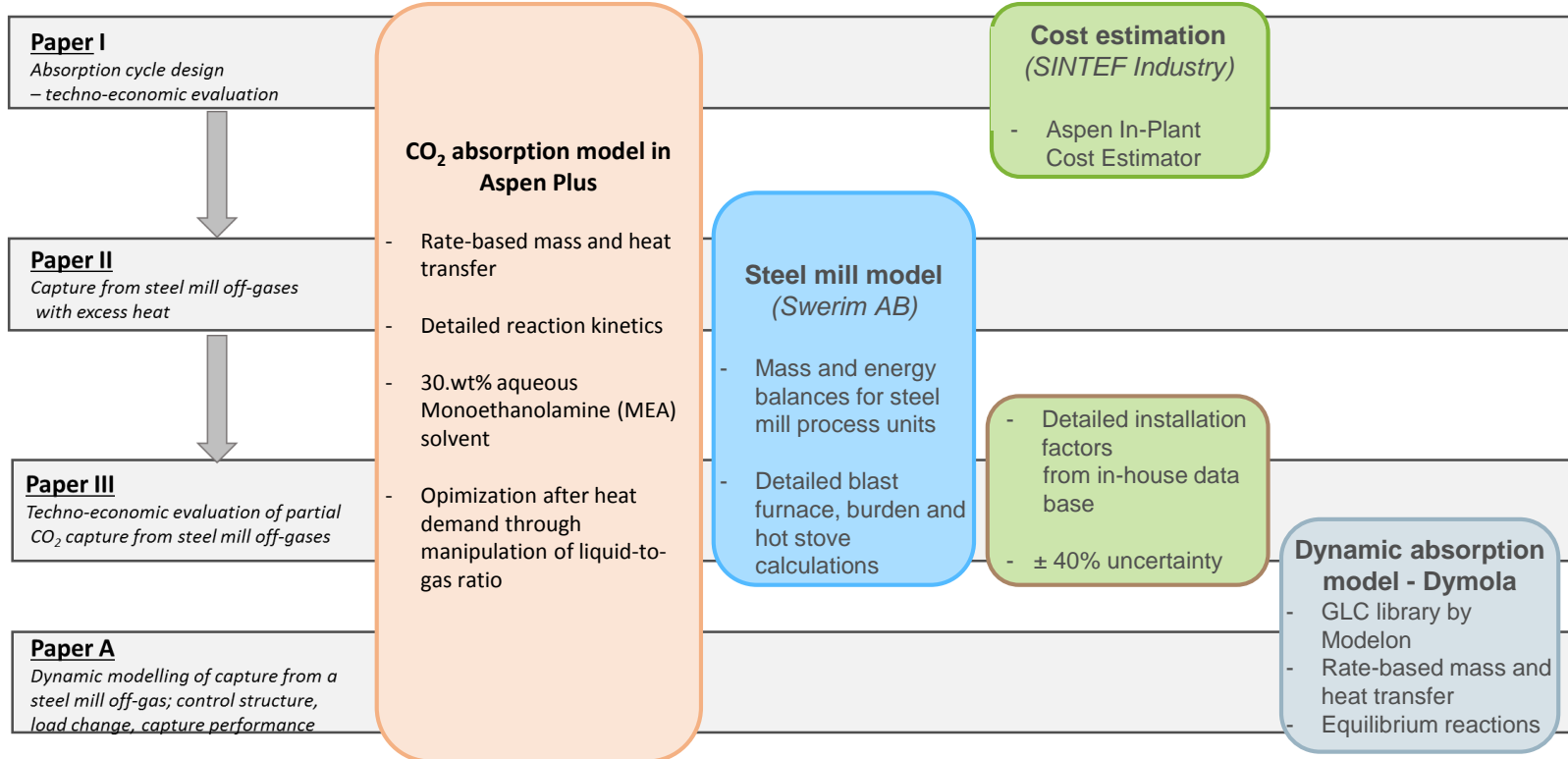
Techno-economic assessment of partial capture from steel mill off-gases

## Paper A

Dynamic performance of partial capture from a steel-mill off-gas at varying load of excess heat and gas flow



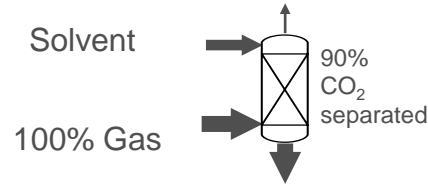
# Overview on methods





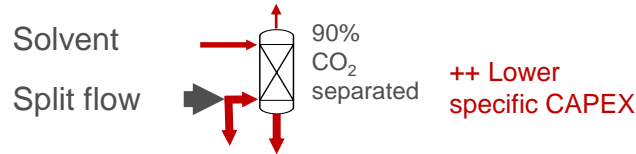
# Design of partial capture

## Full capture

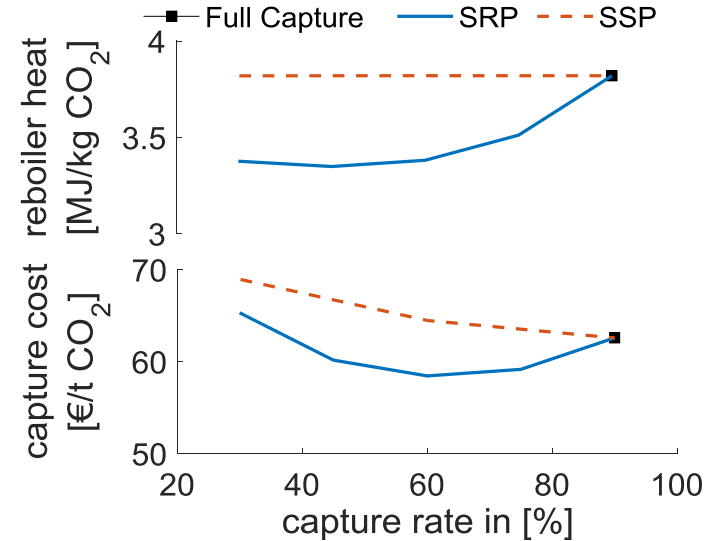
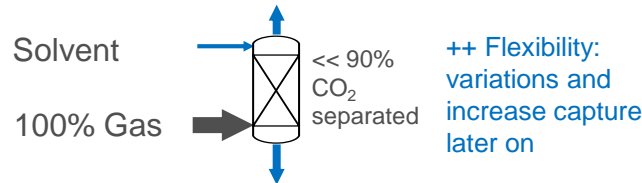


## Two principle paths for partial capture design:

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



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



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

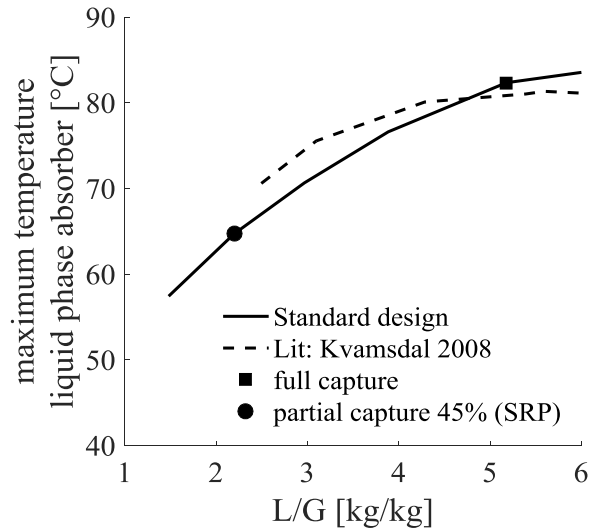


# Design of partial capture

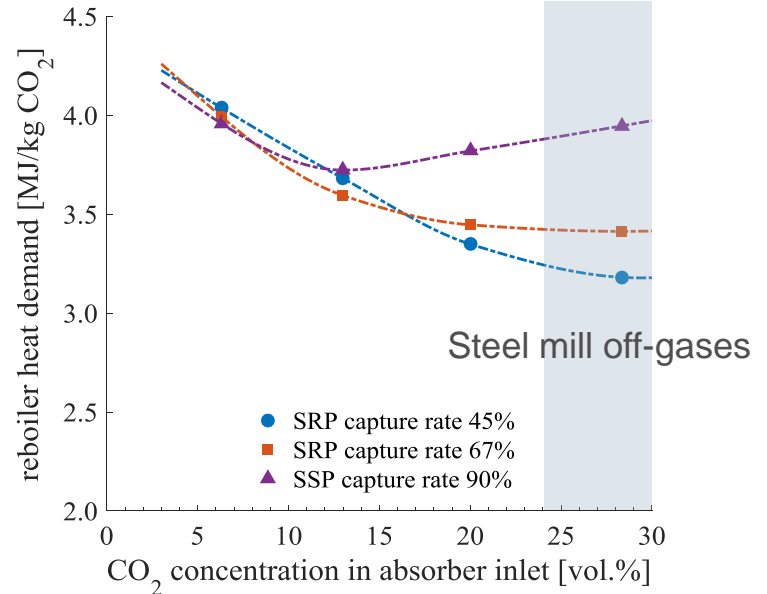
Impact of changing separation rate depends on CO<sub>2</sub> concentration

## Separation Rate Path

lower L/G → maximum T in liquid phase lowered



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

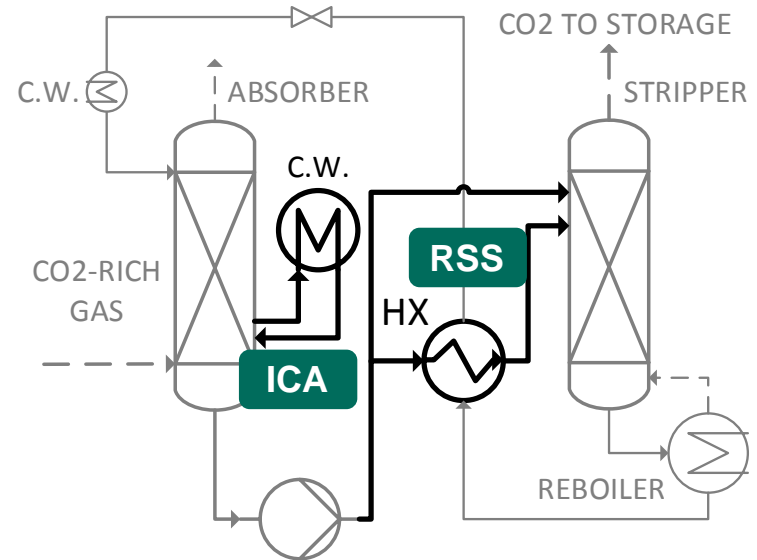




# Design of partial capture

How to bring down heat demand?

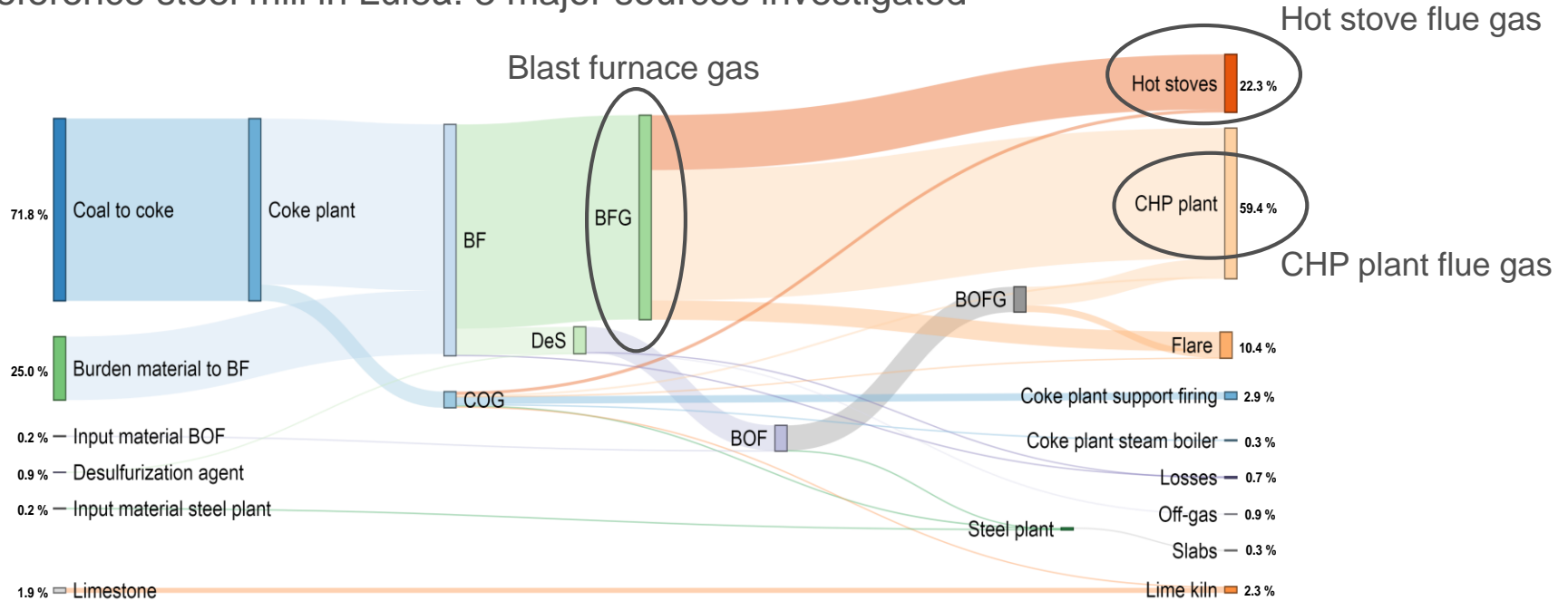
- High CO<sub>2</sub> concentrations: separation rate path
- Process modifications:  
Rich solvent splitting (RSS)  
Absorber intercooling (ICA)



→ Design choice for partial capture at a steel mill: Separation rate path + ICA + RSS

# Steel mill CO<sub>2</sub> sources

Reference steel mill in Luleå: 3 major sources investigated

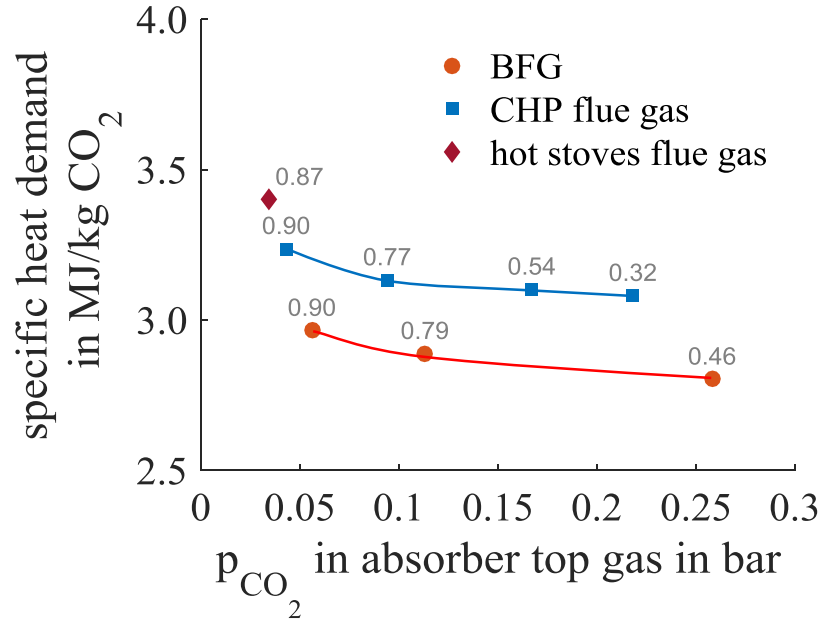


# High- or low-level integration?

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

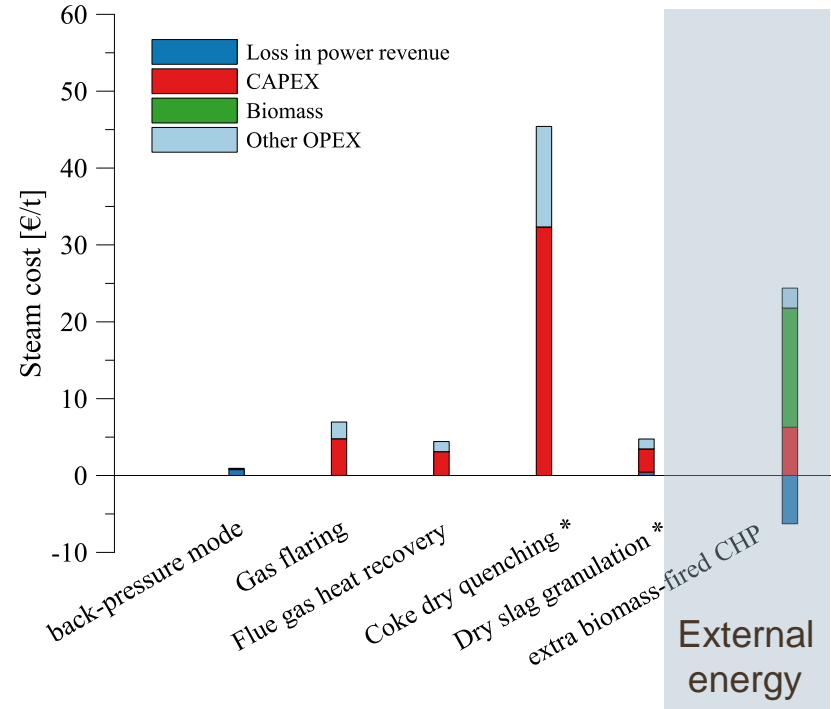
- Gas management on-site can be changed to supply more excess heat to CCS at the expense of electricity production



# Excess heat at an integrated steel mill

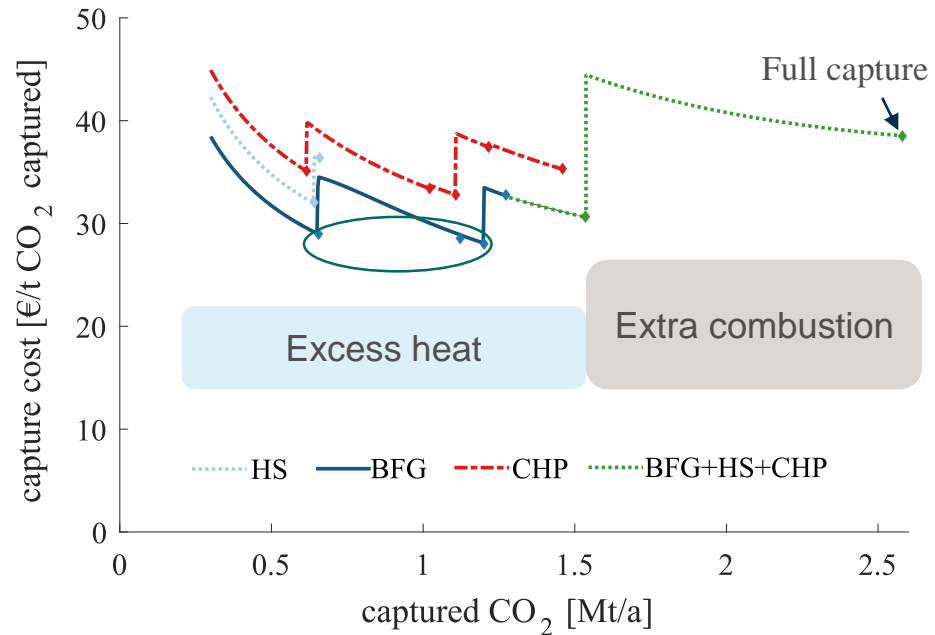
**Assumption: constant heat load (yearly average)**

- 5 sources of excess heat to supply steam of 3 bar investigated
- Most are implementable and low-cost compared to steam supply via combustion of external fuel



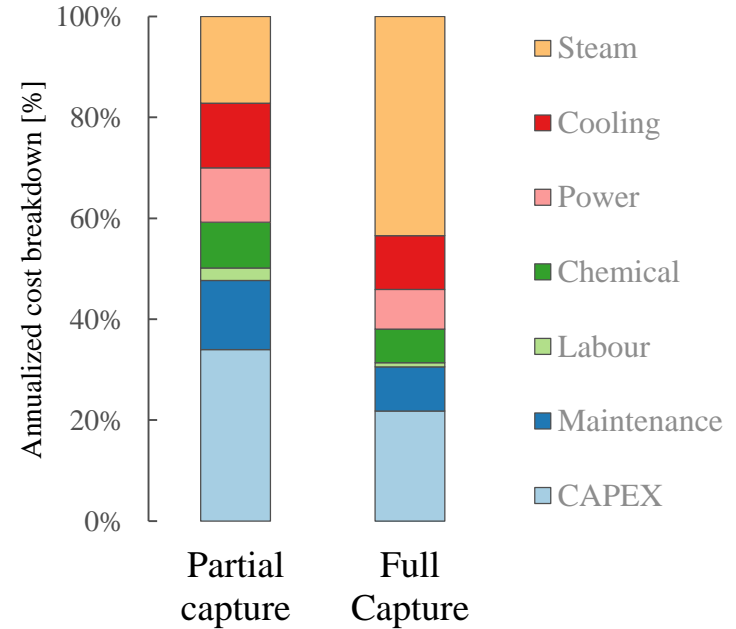
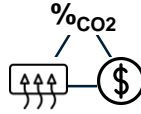
# Emissions reductions and capture cost

- 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



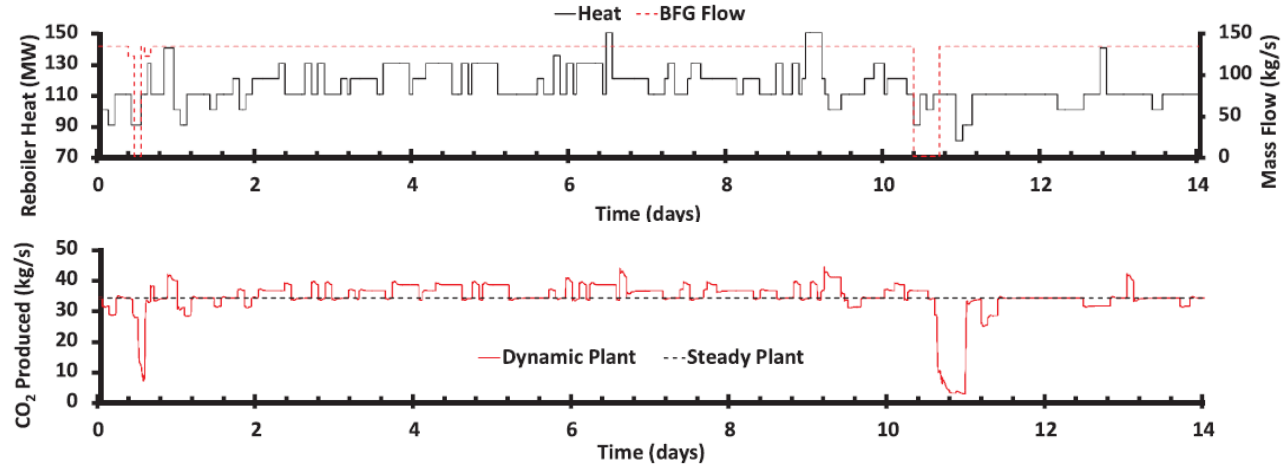
# Cost structure

- 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



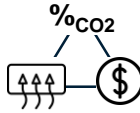
# Dynamic partial capture from BFG

Hourly changes can be coped with well



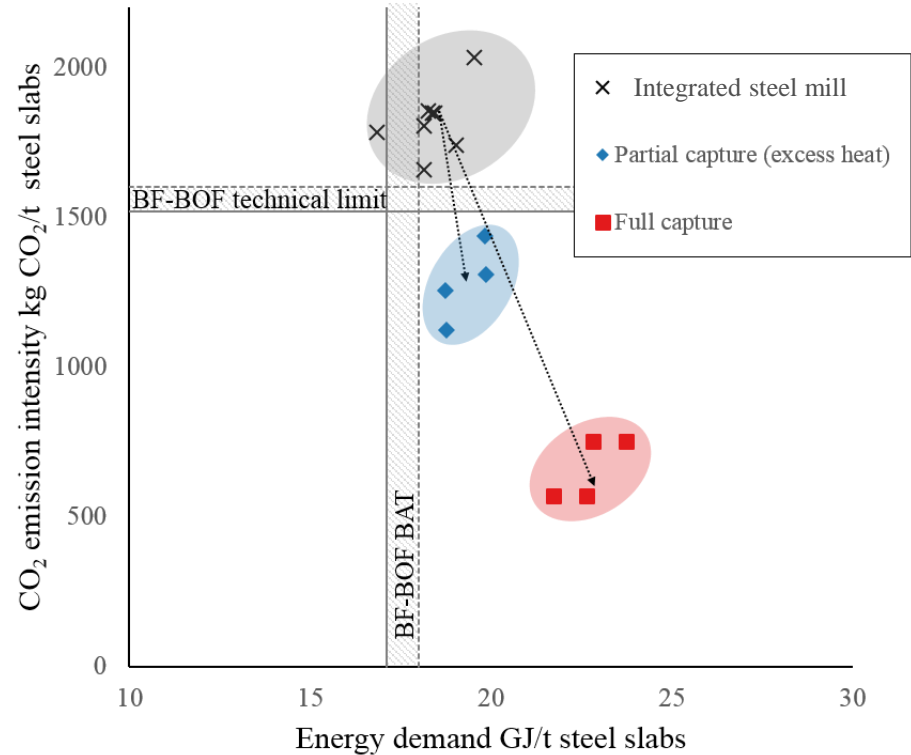
→ **Capture performance similar to steady-state if:**  
the unit is designed to manage the entire span of experienced loads in heat and gas flow;

# 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!



# Near-term implementation

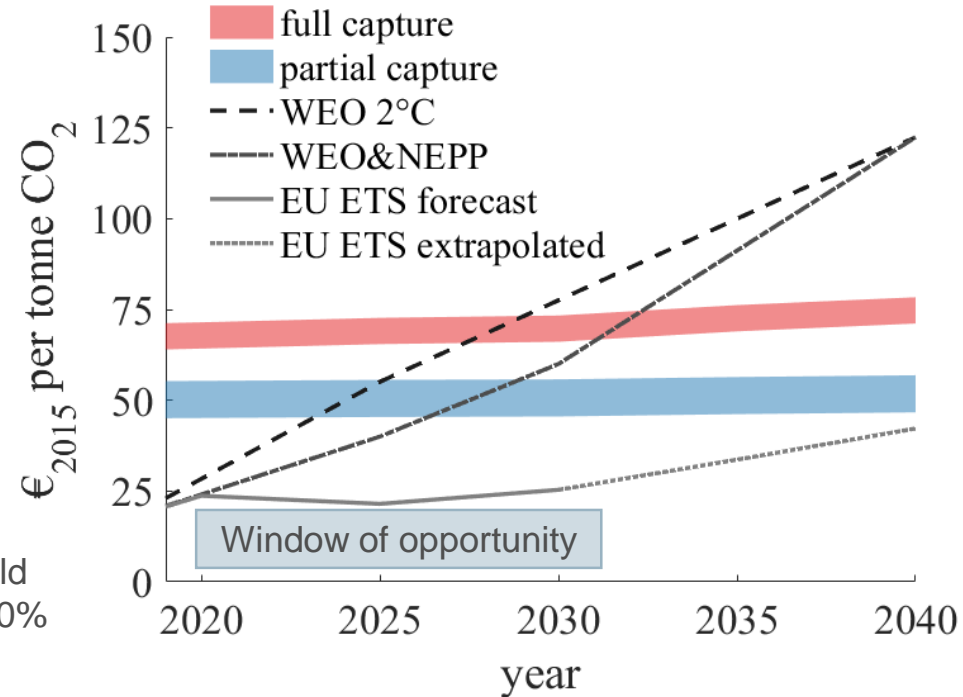


Full chain cost = capture + transport<sup>1</sup> + storage  
*versus*  
CO<sub>2</sub> price scenarios

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 would be too short before policies will require close to 100% emission reduction

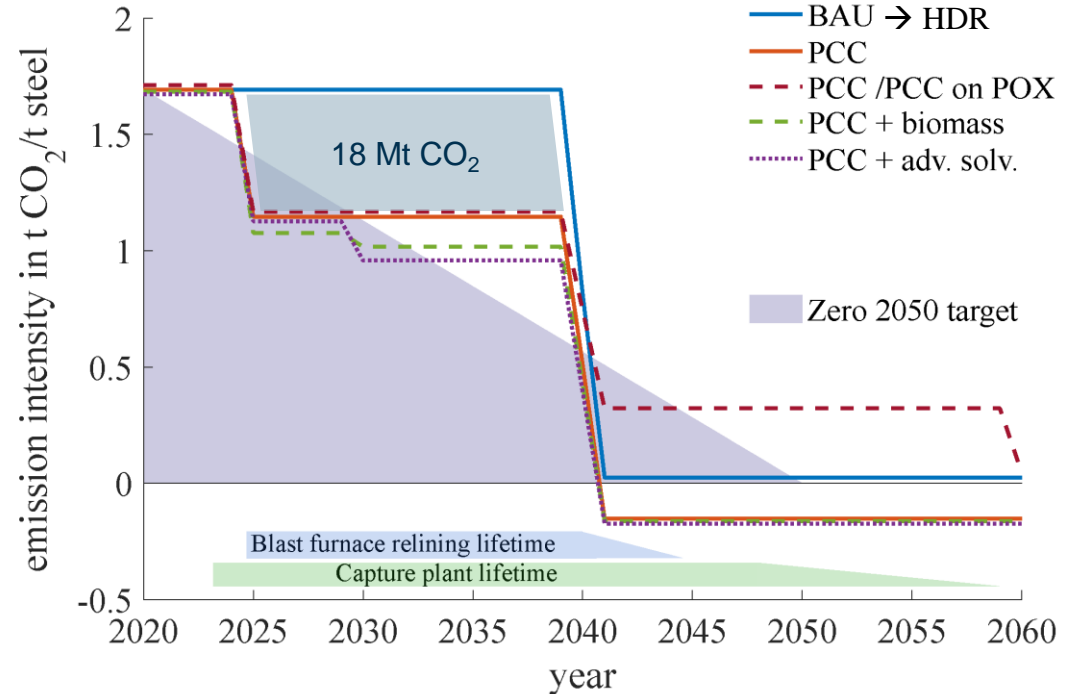


<sup>1</sup>Assuming ship transport to storage

# Transition to low-carbon technologies



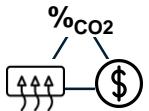
- i. Accumulated emissions are relevant!  
Partial capture could de-risk late arrival of HDR
- ii. CCS infrastructure could be used in HDR concepts
  - capture remaining fossil & biogenic emissions
  - produce "blue" hydrogen from fossil fuels
- iii. Partial capture could evolve
  - co-mitigation with biomass
  - solvent improvement



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

# Conclusions

- Amine absorption cycles can be designed for separation rates  $\ll 90\%$   
→ save energy and possibly cost compared to full capture; target: industry with  $\text{CO}_2$  conc.  $> 20$  vol.%
- Steel mill: Partial capture powered by excess heat is more cost-efficient than full capture that relies on external energy
- Steel product: Partial capture can reduce  $\text{CO}_2$  footprint without significant energy penalty
- Near-term implementation in 2020s: possible if policies value carbon at 40-60 €/t  $\text{CO}_2$
- Partial capture may allow for synergies with other mitigation options (biomass, electrification) and could be a step toward the transition to low-carbon economies





# CHALMERS

UNIVERSITY OF TECHNOLOGY



Icon made by [daniel bruce](#) from [www.flaticon.com](#)

Icon made by [Freepik](#) from [www.flaticon.com](#)

Icon made by [geotatah](#) from [www.flaticon.com](#)

Icon made by [darius-dan](#) from [www.flaticon.com](#)