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Licentiate seminar, May 24th 2019

PARTIAL CAPTURE – AN OPPORTUNITY TO DECARBONIZE PRIMARY STEELMAKING

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

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Department of Space, Earth and Environment

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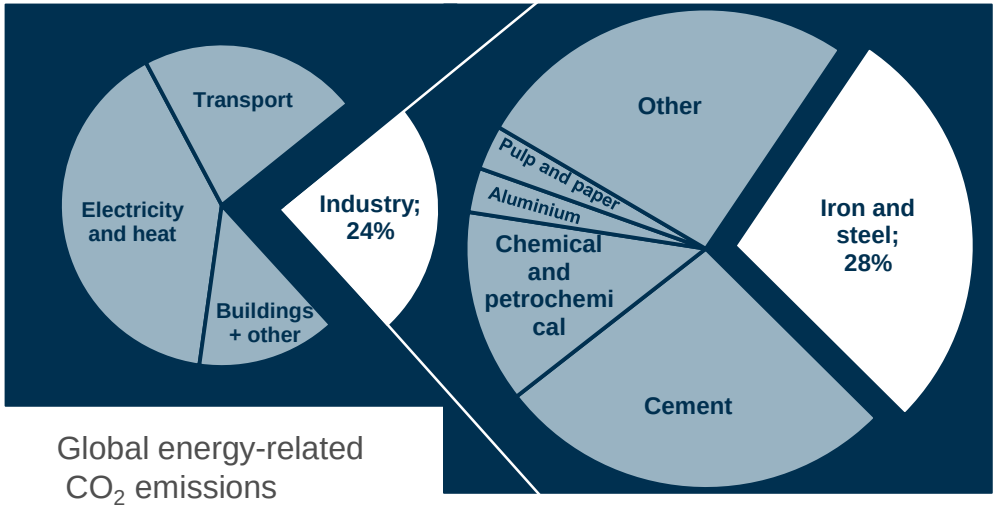
A Challenge: CO_2 emissions from industry



Global energy-related CO_2 emissions

By industrial sector

Challenge

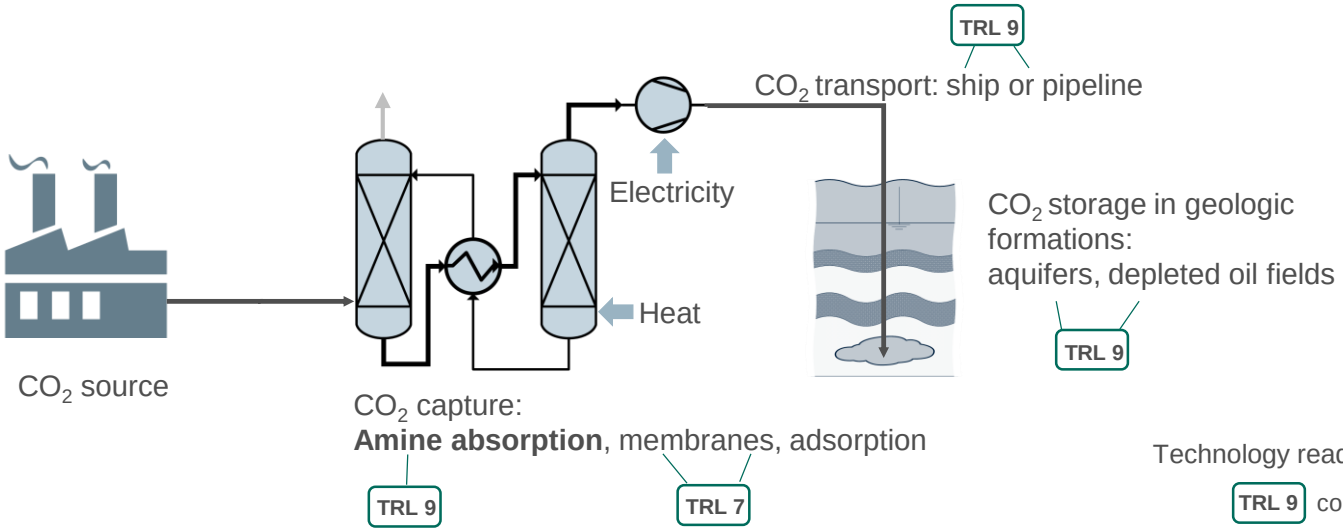
- CO_2 arises from the production process, not only from heating
  - Steel: C as reducing agent
  - Cement: CO_2 from calcination

CCS as opportunity

- Carbon capture and storage (CCS) is one of the few mitigation options
- Industry provides large point sources with high CO_2 concentrations

Data for 2014: *Energy Technology Perspectives 2017*, IEA

Carbon capture and storage



Technology readiness level (TRL)

TRL 9 commercial

TRL 7 demonstration

IChemE Energy Centre. *A Chemical Engineering Perspective on the Challenges and Opportunities of Delivering Carbon Capture and Storage at Commercial Scale*; 2018.

CCS – a cost problem?

Status of large-scale CCUS units

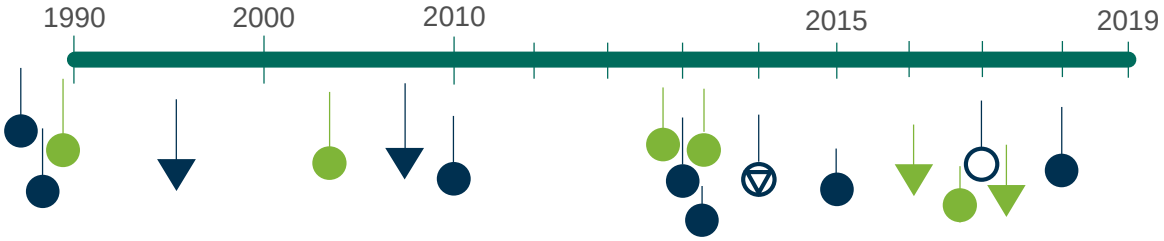
18 in operation ~ 40 Mt CO_2 p.a.
5 under construction
20 in development

Required to meet 2C

Thousands of units

Challenges:

- Legal & Regulatory
- Public acceptance
- Policies & Financing
- **Cost**



Large scale Carbon Capture Utilization and Storage (CCUS) facilities > 400 kt p.a. (in operation); commissioned after 1990

Dedicated storage	Gas processing	Power	Industry
Enhanced Oil Recovery	Gas processing	Power	Industry

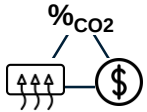
Global CCS Institute. *The Global Status of CCS: 2018*

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_2 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

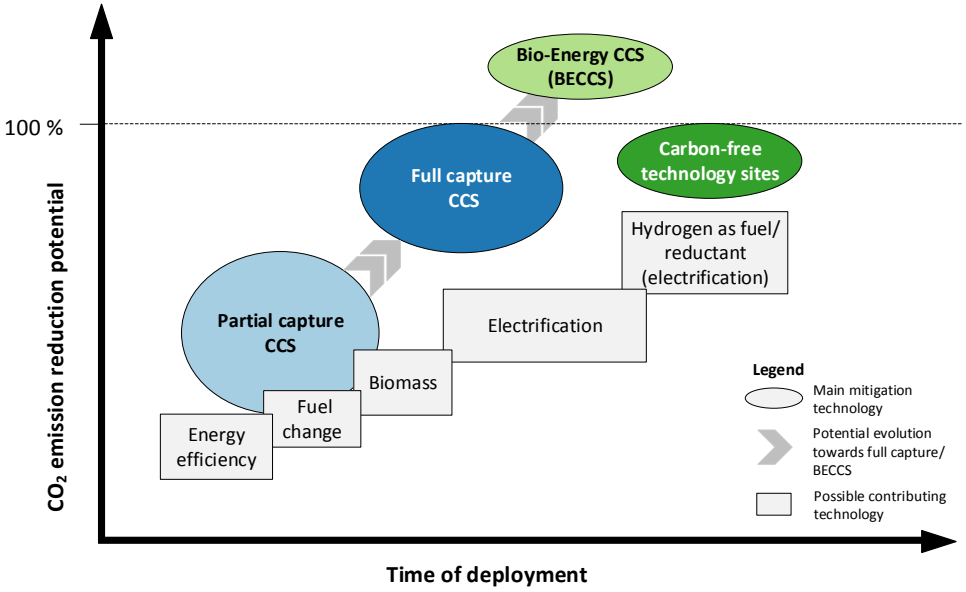
Idea: only a fraction of the accessible CO_2 is captured for storage.

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

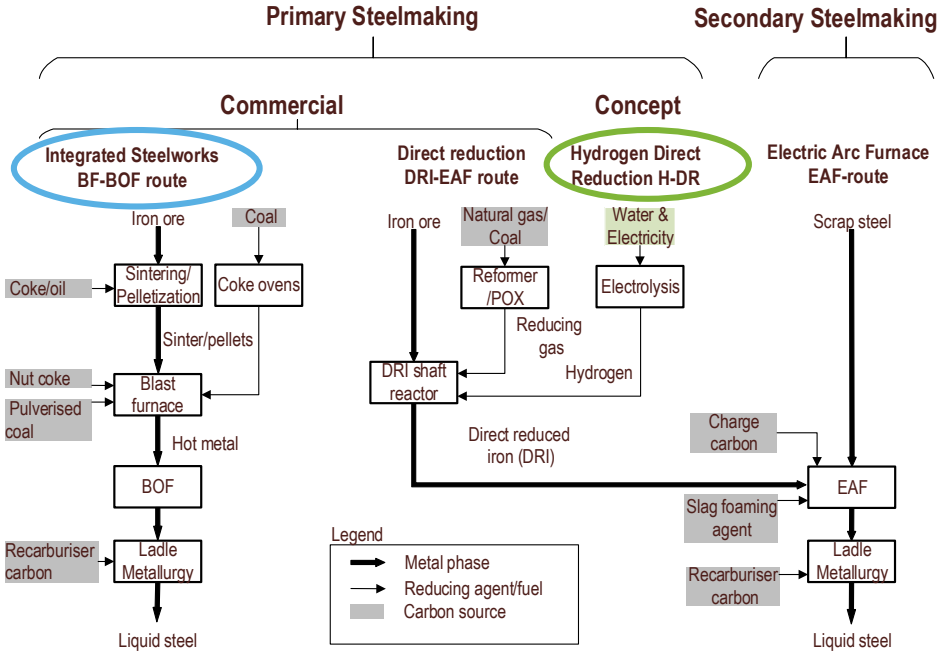


Primary steelmaking

Carbon is used as reducing agent

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

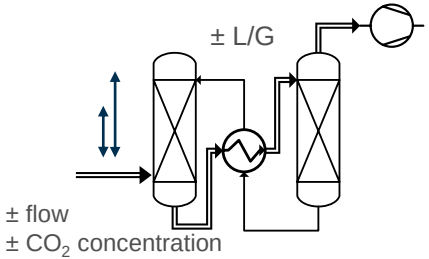
i. Globally rising steel demand
ii. Long blast-furnace lifetimes ~40-60 yrs
iii. Purity demands for high quality steel



→ Primary steelmaking has to be decarbonized

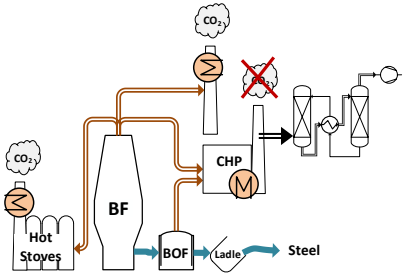
Scope of work

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

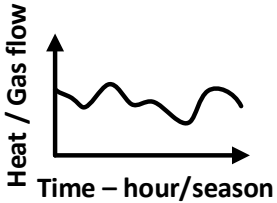
capture rate from CO_2 sources

heat sources

€€€ OPEX & CAPEX

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

Paper I
Absorption cycle design – techno-economic evaluation

Paper II
Capture from steel mill off-gases with excess heat

Paper III
Techno-economic evaluation of partial CO_2 capture from steel mill off-gases

Paper A
Dynamic modelling of capture from a steel mill off-gas; control structure, load change, capture performance

CO_2 absorption model in Aspen Plus

- Rate-based mass and heat transfer
- Detailed reaction kinetics
- 30.wt% aqueous Monoethanolamine (MEA) solvent
- Opimization after heat demand through manipulation of liquid-to-gas ratio

Steel mill model
(Swerim AB)

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

Cost estimation
(SINTEF Industry)

- Aspen In-Plant Cost Estimator

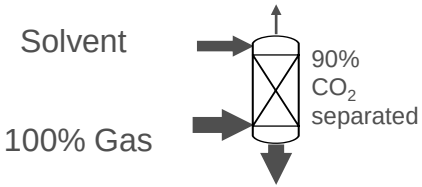
- Detailed installation factors from in-house data base
- ± 40% uncertainty

Dynamic absorption model - Dymola

- GLC library by Modelon
- Rate-based mass and heat transfer
- Equilibrium reactions

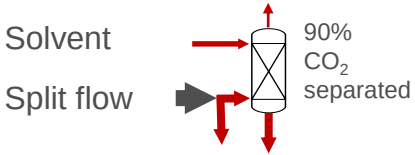
Design of partial capture

Full capture



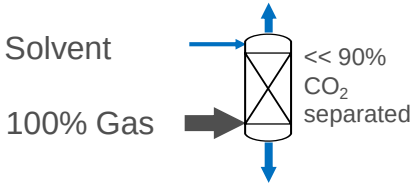
Two principle paths for partial capture design:

Split Stream Path (SSP)

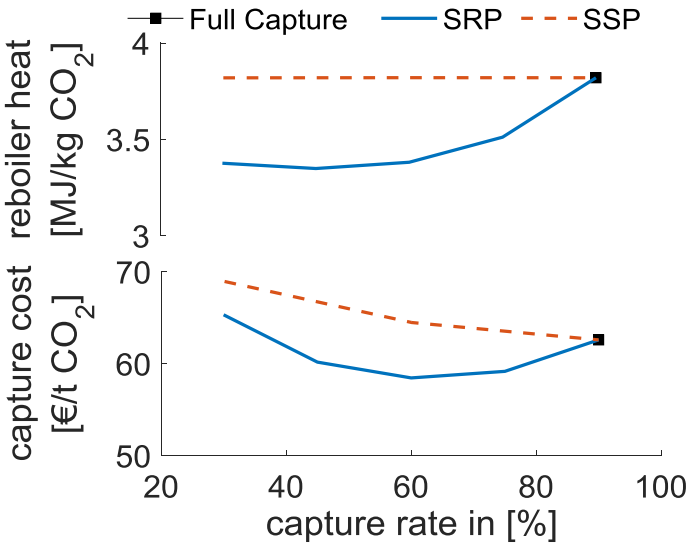


++ Lower specific CAPEX

Separation Rate Path (SRP)



++ Flexibility: variations and increase capture later on



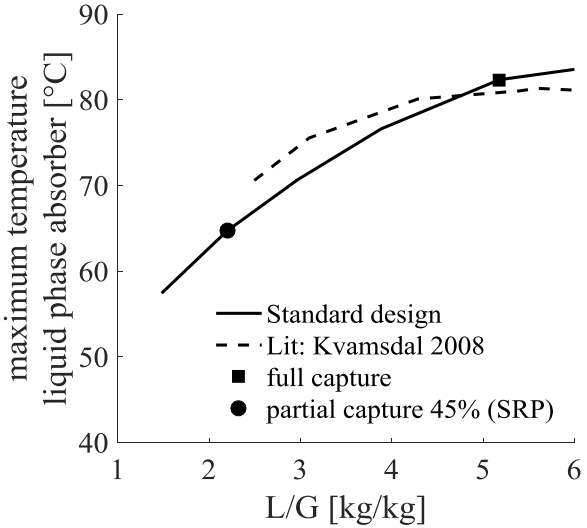
→ The choice of design path affects heat demand and specific cost

Design of partial capture

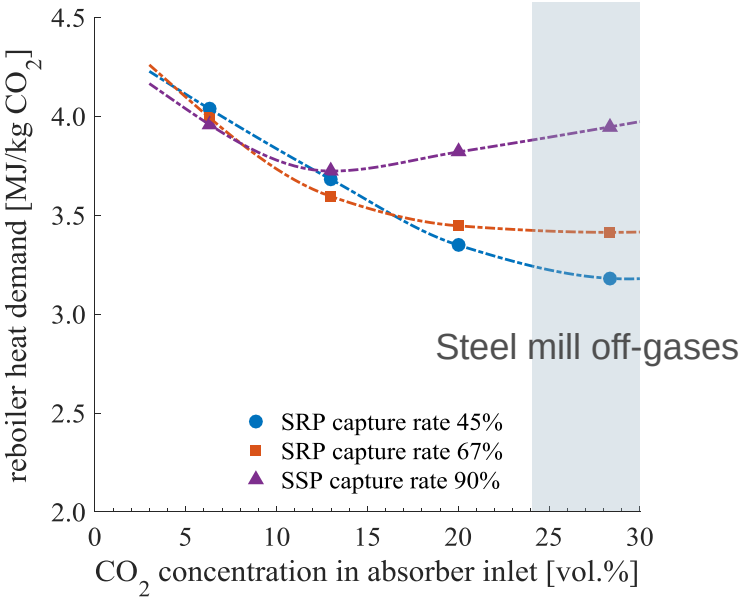
Impact of changing separation rate depends on CO_2 concentration

Separation Rate Path

lower L/G → maximum T in liquid phase lowered



relevant for high CO_2 concentrations!

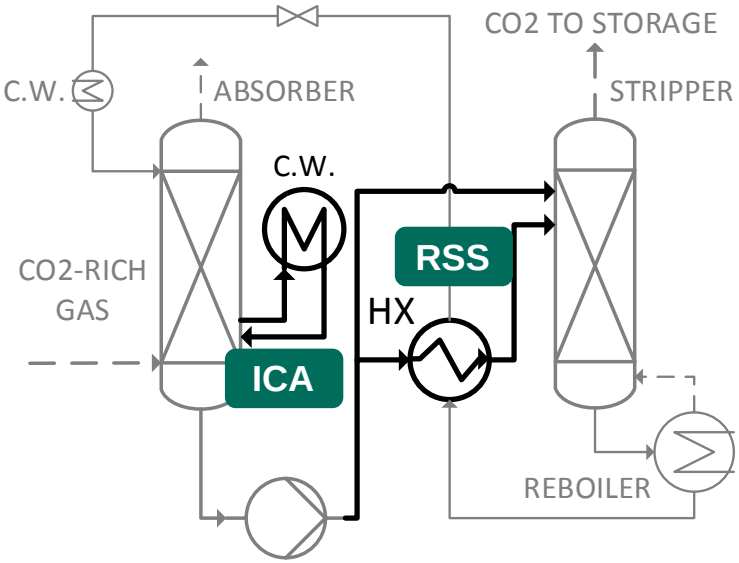


Design of partial capture

How to bring down heat demand?

- High CO_2 concentrations: separation rate path

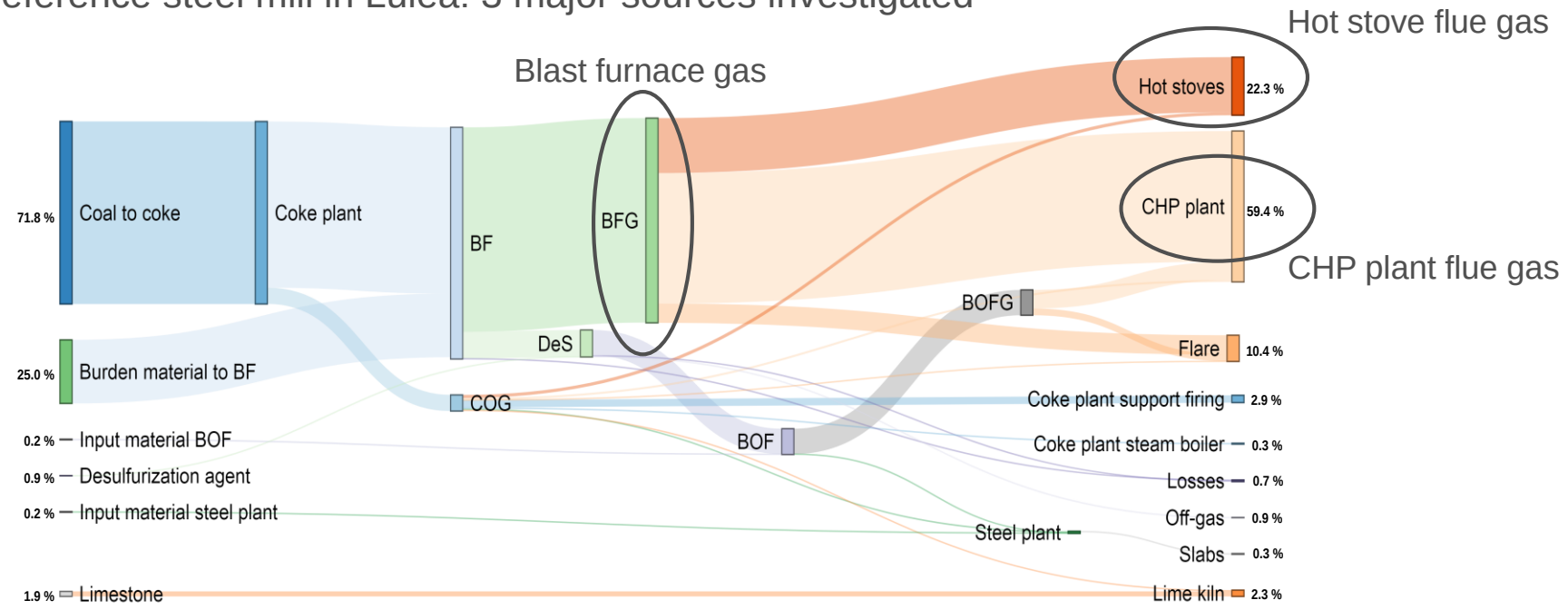
- Process modifications:
  - Rich solvent splitting (RSS)
  - Absorber intercooling (ICA)



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

Steel mill CO_2 sources

Reference steel mill in Luleå: 3 major sources investigated

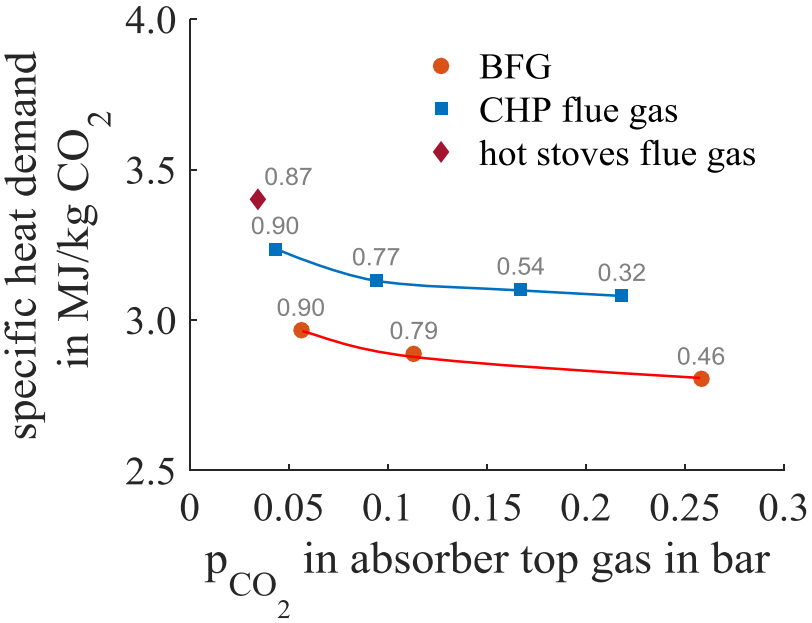


High- or low-level integration?

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

The LHV of blast furnace gas increases with CO_2 capture

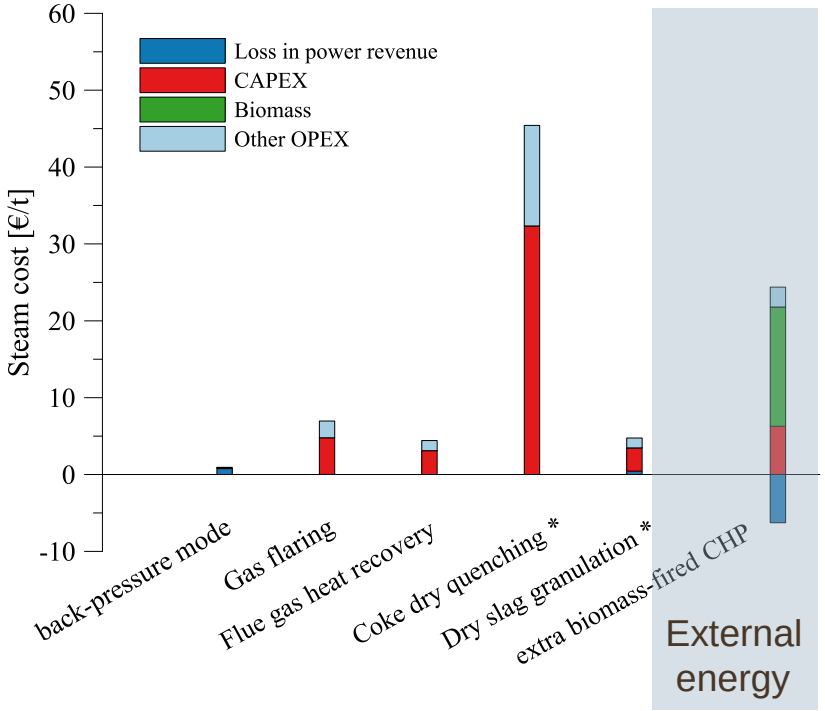
- Gas management on-site can be changed to supply more excess heat to CCS at the expense of electricity production



Excess heat at an integrated steel mill

Assumption: constant heat load (yearly average)

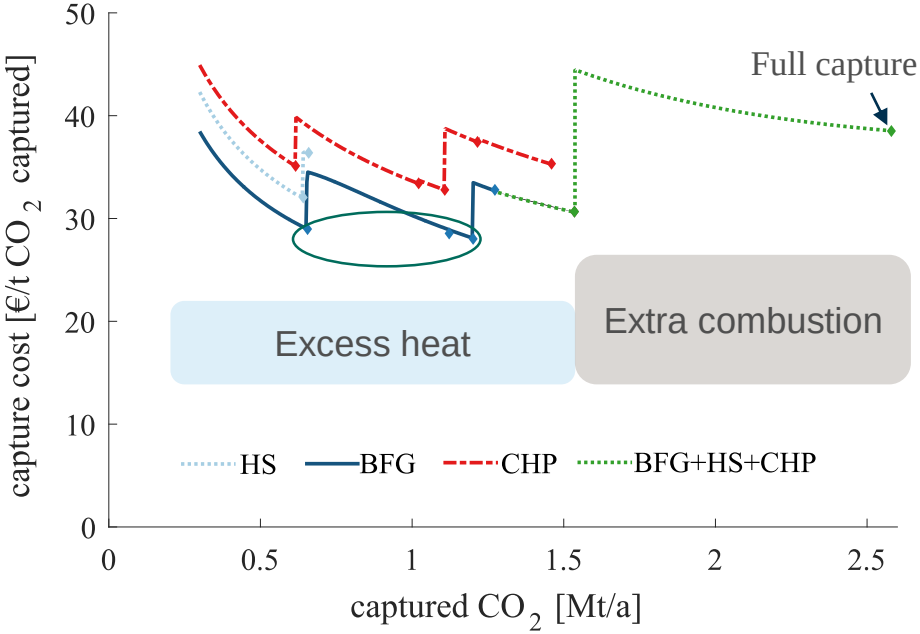
- 5 sources of excess heat to supply steam of 3 bar investigated
- Most are implementable and low-cost compared to steam supply via combustion of external fuel



Emissions reductions and capture cost

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

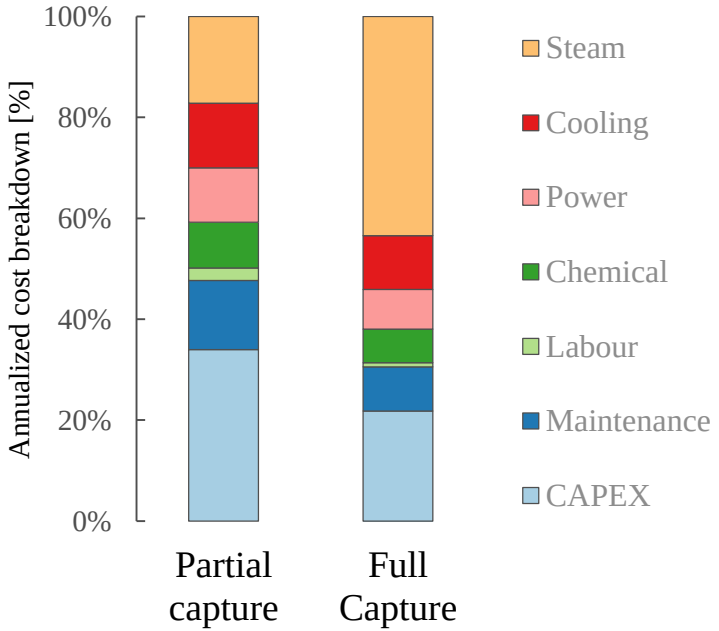
- Partial capture with excess heat costs less than full capture with external energy



Cost structure

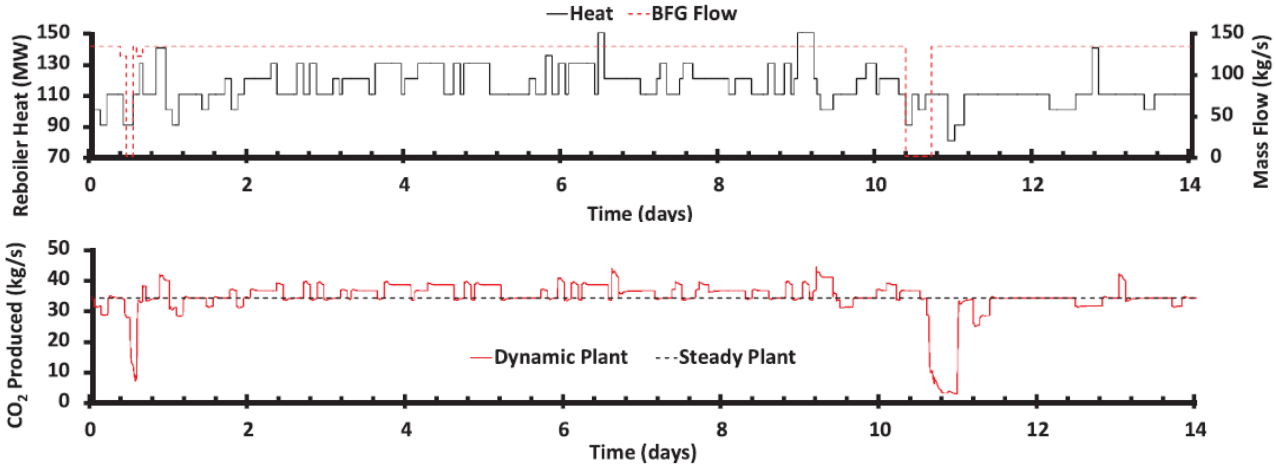
i) Partial capture with excess heat is dominated by CAPEX;

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

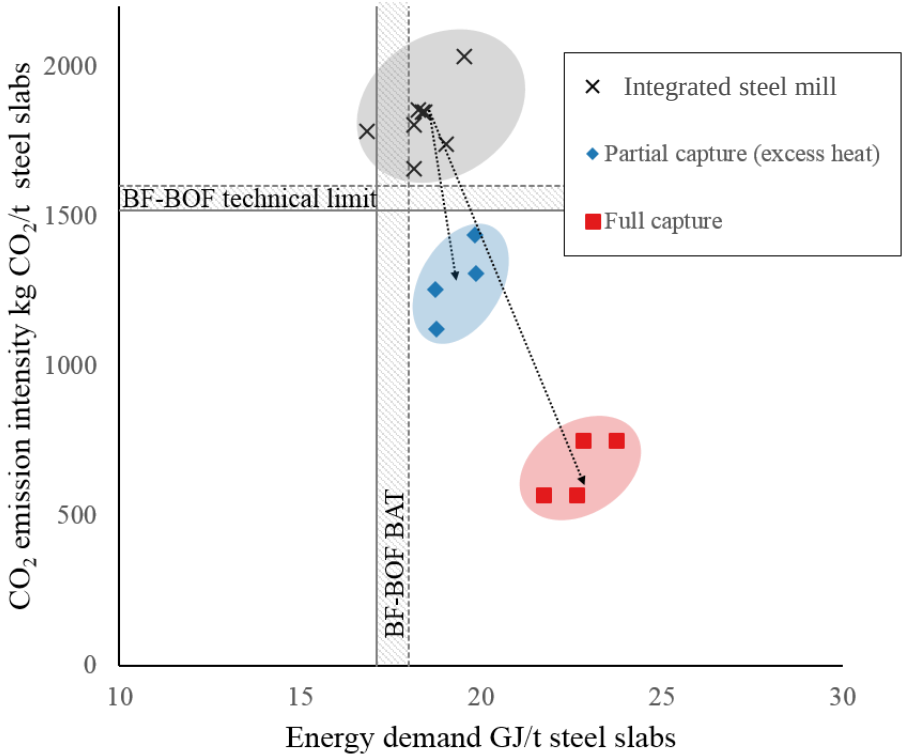


→ **Capture performance similar to steady-state if:**
the unit is designed to manage the entire span of experienced loads in heat and gas flow;

Carbon versus energy intensity?

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

…without affecting significantly the energy demand!

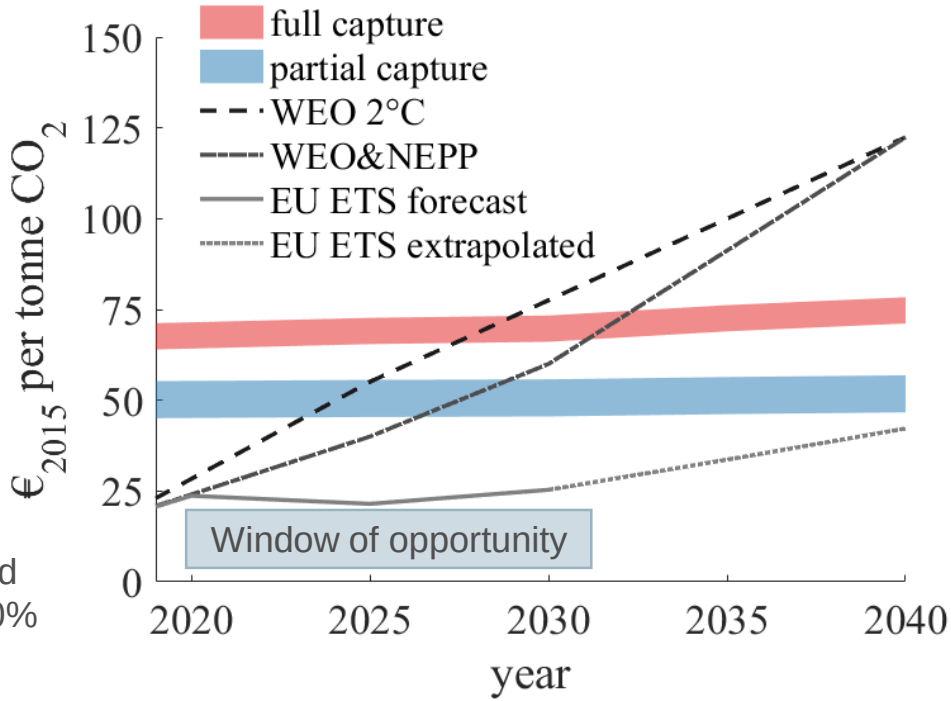


Near-term implementation

Full chain cost = capture + transport[1] + storage
versus
CO_2 price scenarios

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



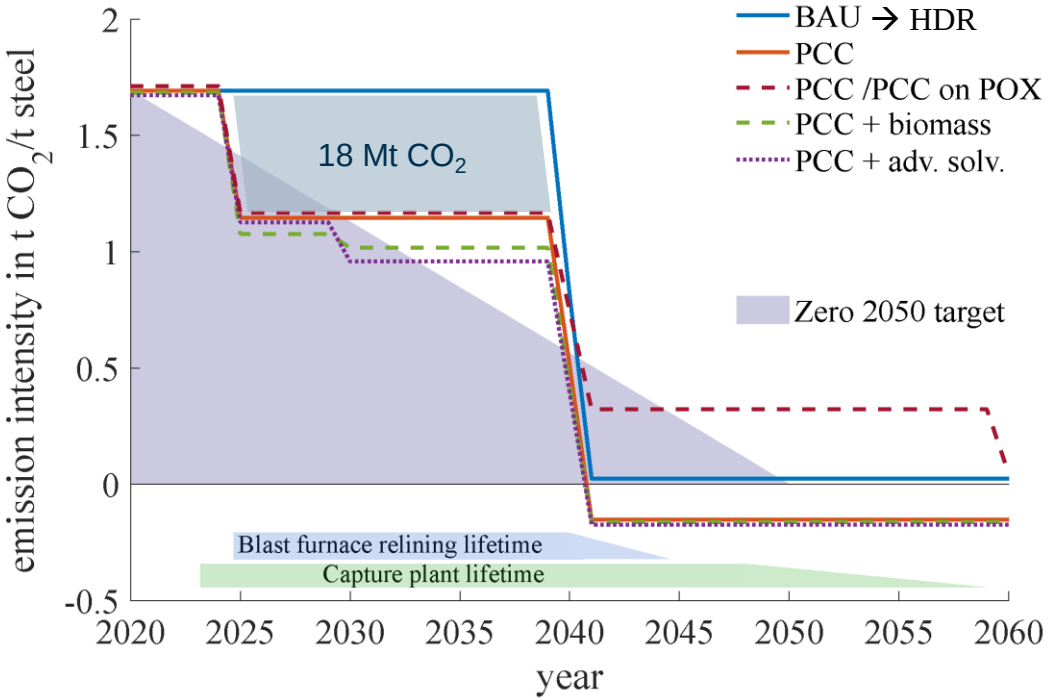
[1]Assuming ship transport to storage

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

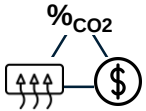


Integrated steel works with 2Mt steel slabs p.a.

Conclusions

- Amine absorption cycles can be designed for separation rates << 90%
  →save energy and possibly cost compared to full capture; target: industry with 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 CO_2 footprint without significant energy penalty

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

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