Efficient utilization of industrial excess heat for carbon capture and district heating

Heat integration options and seasonal effects on capture process design and operation

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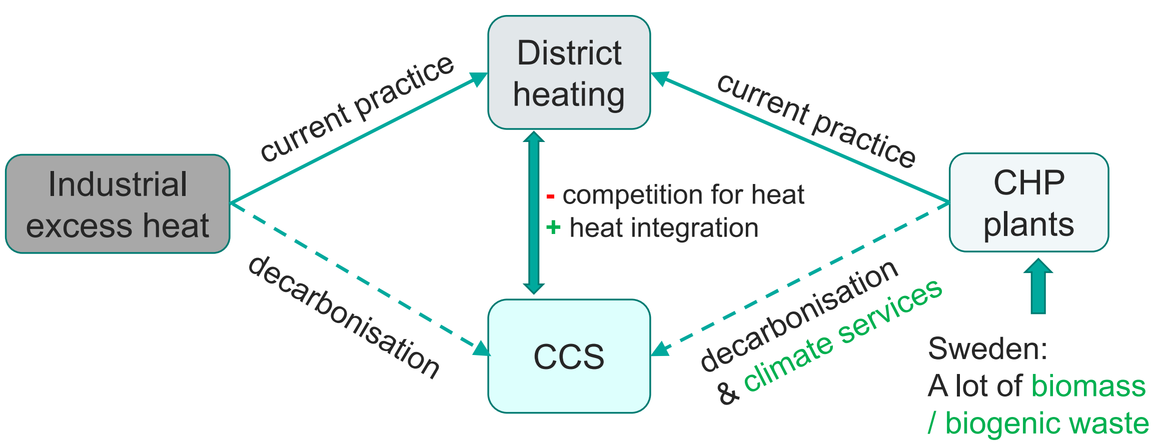
CCS versus district heating?



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Aim & Scope

Scope: process industry delivering excess heat to a DH network

- process industry that operates throughout the year
- DH heat demand low during summer
- heat not a main product

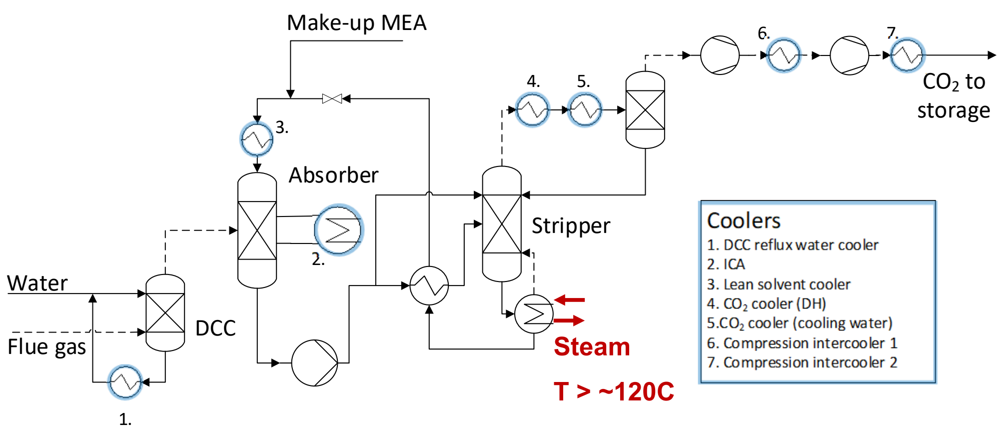
Aim:

1. Investigate the heat integration potential: how much heat can be recovered from the CCS process and delivered to the DH system?

2. Evaluate CCS operation modes techno-economically:
Is seasonally varying load or constant load preferable?

how much heat from the CCS process can be recovered and delivered to the DH system?

Potential heat sources for DH



seasonally varying load or constant load?

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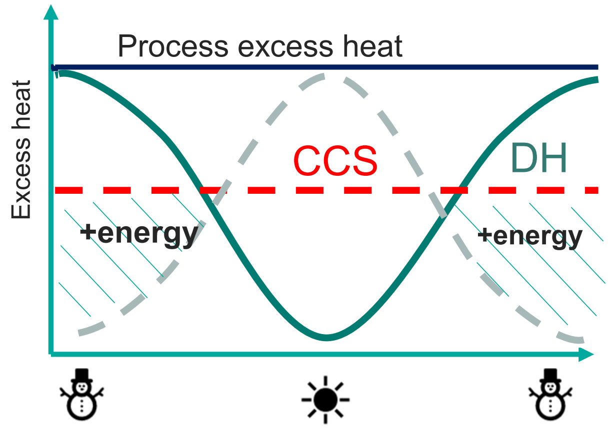
Operation modes and size of CCS



- Current landscape: Excess heat for DH
- M1): all excess heat to CCS, no DH
- M2): same sized CCS plant, seasonal varying load, DH upheld
- M3) smaller CCS plant, constant load + extra energy, DH upheld

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SETUP/METHOD

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Case study setup

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	Refinery flue gases	Steelmill blast furnace gas
annual emissions Mt CO_2 p.a.	0.45	1.20
CO_2 concentration [vol.%]	8.9	24.6
DH delivery [GWh/a]	550	850
Heat source	Process heat, heat collection network	Waste-gas fired CHP plant

- maximum available heat for CCS = amount currently delivered to DH
- capture rate = 90%; gas flow varied to scale CCS plant
- CO_2 liquefaction to 7 bar transport pressure;
- DH temperatures 50 – 90 °C

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RESULTS

how much heat can be recovered from CCS and delivered to the DH system?

→ Maximize heat supply to CCS;
→ DH delivery not maintained; M1

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CCS process cooling demand

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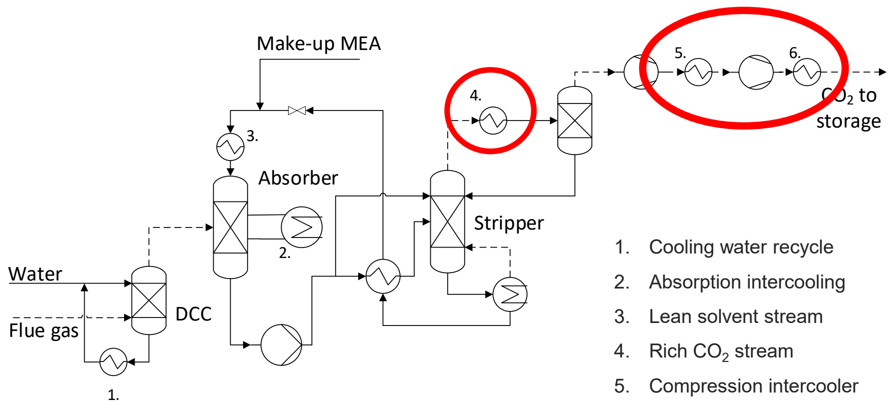
- Minimum temperature difference: 10 °C



1. Cooling water recycle
2. Absorption intercooling
3. Lean solvent stream
4. Rich CO_2 stream
5. Compression intercooler
6. Liquefaction precooler

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Heat recovery potential from the CCS plant to the district heating network

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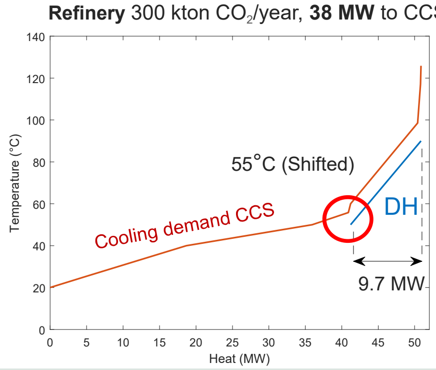
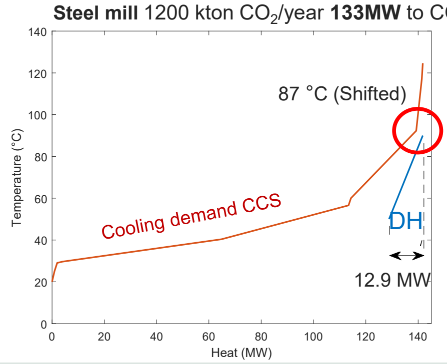
Refinery 300 kton CO_2/year, **38 MW** to CCS



Steel mill 1200 kton CO_2/year **133MW** to CCS



Recoverable heat / reboiler duty: 25.5 %

Recoverable heat / reboiler duty: 9.7 %

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OPERATION MODES AND SIZE OF CCS (STEEL MILL EXAMPLE)

Is seasonally varying load or constant load preferable?

%CO2

→ DH delivery maintained
→ Only excess heat not used in DH is used for CCS; M2 vs M3

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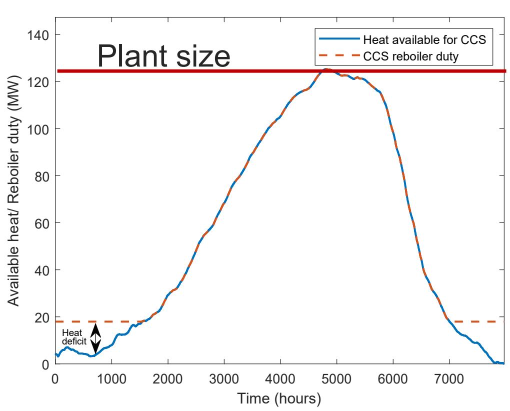
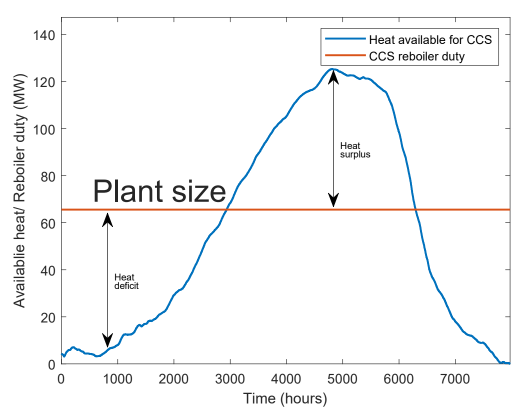
Varying vs constant CCS load

Seasonally varying load



Minimum load; no shut down

Constant load



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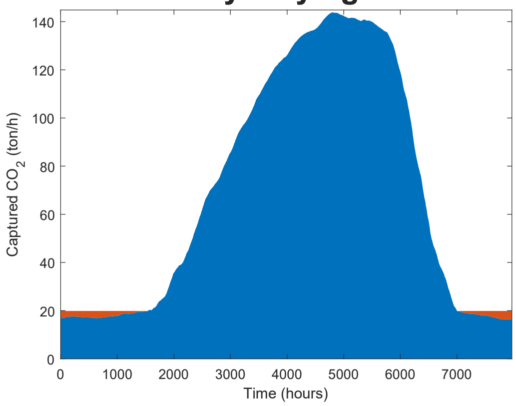
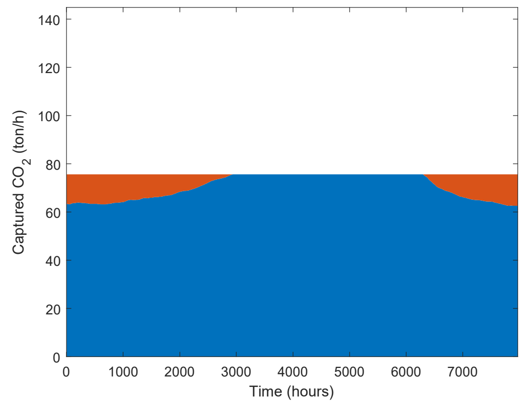
Blue: CO_2 avoided
Orange: CO_2 from natural gas firing to compensate for heat deficit
Total area: CO_2 captured

Seasonally varying load → Same CO_2 avoided ← Constant load





99% of captured CO_2 is avoided CO_2

93% of captured CO_2 is avoided CO_2

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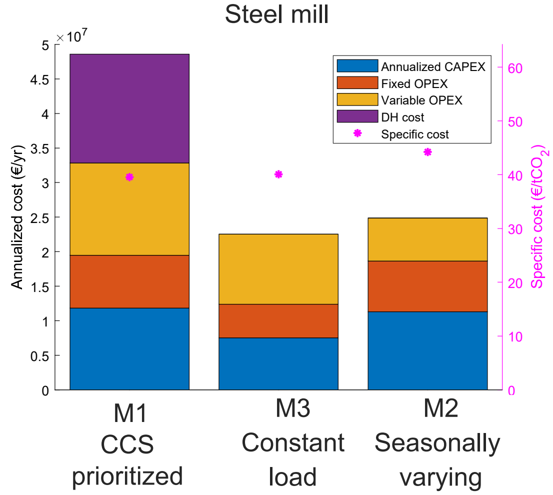
Economic evaluation

- High impact on cost from DH revenue loss
- Seasonally varying and constant load operation comparable in cost

Steel mill



Capture & liqueufaction cost only!

CO_2 avoided kt/yr: 1228 562 562

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CONCLUSIONS

- recoverable heat from CCS for DH ~ 10 – 25 % of reboiler duty
  → depends on dTmin, stripper top gas temperature, process configuration
- Seasonal CCS operation with excess heat has comparable cost (€/t CO_2 avoided) to constant load operation
  → Highly sensitive towards ratios in energy price (electricity/fuel), scale of the process industry, sizing of the CCS plant, shape of the excess heat load curve
- Seasonal operation uses less primary heat, and allows future scale up of capture (excess capacity due to large CCS plant)
- Revenue loss from decreased delivery of district heat is considerable → for process industry to move away from supplying DH needs to be motivated via emission regulation /funding mechanisms

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THANK YOU FOR LISTENING!!

Relevant publications from our group:

M.Sc. Thesis report on the topic of this talk:

Eliasson, Fahrman,2020. Utilization of Industrial Excess Heat for CO_2 Capture:
Effects on Capture Process Design and District Heating Supply https://hdl.handle.net/20.500.12380/300819

Power plant flexibility and their products/service:

J. Beiron, 2020 - *Combined heat and power plant flexibility - Technical and economic potential and system interaction*
Licentiate thesis https://research.chalmers.se/en/publication/516671

Dynamic performance of CCS plants in process industry:

Martinez Castilla et al., 2019, Int. J. Greenh. Gas Control 82, 192–203. https://doi.org/10.1016/j.ijggc.2019.01.015

Reduction of CCS cost in process industry with partial capture and excess-heat:

Normann et al. 2019. CO2stCap project report, https://research.chalmers.se/en/publication/512527

Biermann 2020 *Partial carbon capture – an opportunity to decarbonize primary steelmaking* Licentiate thesis
https://research.chalmers.se/publication/509851

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Methodology

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Estimation of available heat	Simulations in Aspen PLUS	Economic evaluation	Estimation of recoverable heat
Published data and literature	Rate-based modeling of CO_2 absorption in 30wt.% MEA	Cost estimation of installed cost for each piece of equipment	Hot composite curves

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METHOD

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Technical modelling of CO_2 capture process

- Aspen Plus rate-based CO_2 absorption model using 30 wt.% MEA [1]
  - Absorber CO_2 separation rate 90%
  - Packing height: 20m absorber, 15 m stripper
  - Lean loading 0.30
  - Compressors in liquefaction plant: 20 bar (2 stage)

CAPEX estimations

- Equipment cost from cost functions derived from detailed cost literature
- Liquefaction cost scaled from Deng et al. [2]
- Total plant cost estimation with enhanced-detailed factor method [3]
- Individual cost factor for each piece of equipment [3]
- No transport and storage cost considered

OPEX included:

- Electricity price profiles (Sweden)
- District heat price profiles (marginal system cost)
- Cooling water, amine solvent, maintenance, labor, steam supply cost,

[1] Garðarsdóttir et al., Ind. Eng. Chem. Res. 54, 681–690. 2015
[2] Deng et al., Int. J. Refrig. 103, 301–315, 2019
[3] Ali et al., Int. J. Greenh. Gas Control 88, 10–23, 2019

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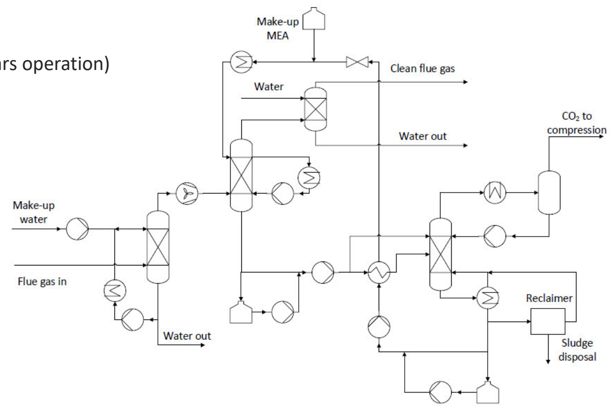
COST SCOPE

Equipment included:

Plant life time 25 years (2 years construction, and 23 years operation)
Cost year 2016
Discount rate 7.5 %
First-of-a-kind or N:th-of-a-kind N:th-of-a-kind
Greenfield or brownfield Brownfield
Location Rotterdam (Location factor 1)
Currency conversion factor (€ to NOK 2016) 9.7 NOK/€
Material flue gas fan CS (f_{mat} 1)
Material pumps SS316 Machine (f_{mat} 1.3)
Material other equipment SS316 Welded (f_{mat} 1.75)



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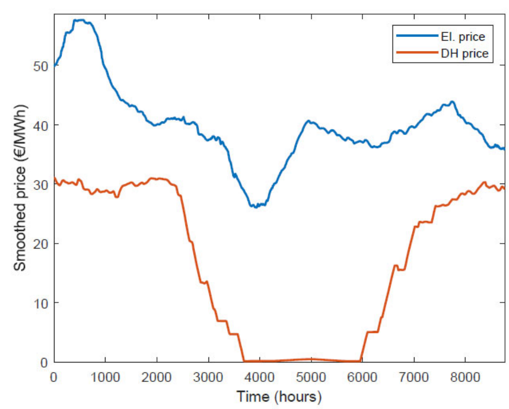
OPEX

Fixed OPEX	
Maintenance, insurance and labor cost	6% of TIC
Variable OPEX	
Electricity price	Varying
Average electricity price	40 €/MWh
DH price	Varying
Cooling water price	0.02 €/m^3
MEA price (including sludge disposal)	2000 €/m^3
Steam price, steel mill case	1 €/t
Steam price, refinery case	3 €/t
Natural gas price	16 €/MWh
NaOH price	270 €/t



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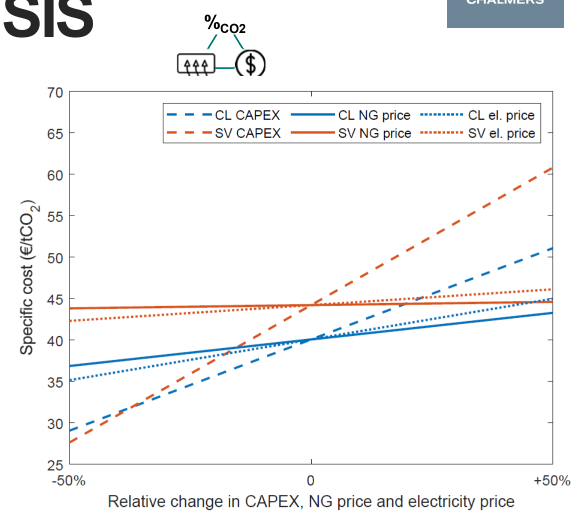
SENSITIVITY ANALYSIS

Seasonal varying = red

Constant load = blue

Parameter	-50%	0	+50%
Absolute CAPEX (M€), SV	61.1	122.2	183.3
Absolute CAPEX (M€), CL	40.6	81.1	121.7
Average electricity price (€/MWh)	20	40	60
NG price (€/MWh)	8	16	24



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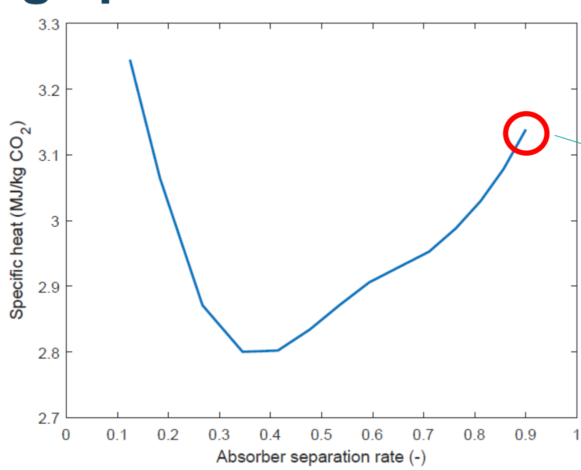
Off-design performance



Steel case

Design point

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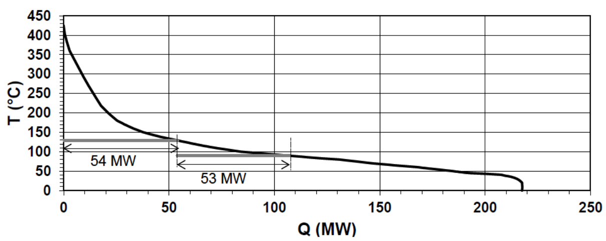
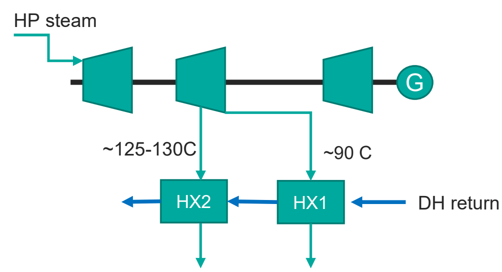
Heat supply – excess heat



Refinery: Heat collection network



Steel mill CHP: turbine bleed steam; power generation loss

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