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CO$_2$stCap

CO_2 capture opportunities in the Norwegian silicon industry

TCCS – 10, Session A4

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About CO_2stCap

- Is a Norwegian-Swedish research initiative initiated to reduce the cost of carbon capture in the process industry by developing concepts for partial capture
- Partners:
  - SSAB, Elkem AS, Norcem Brevik AS and AGA Gas AB
  - IEAGHG and Global CCS Institute
  - Gassnova via the CLIMIT–Demo Programme and The Swedish Energy Agency
  - SINTEF, Chalmers, RISE, SWERIM and University of South-Eastern Norway

www.sintef.no/CO2stcap

The industries

- Iron & steel
  - 5% of the global energy-related GHG emissions
  - The blast-furnace route requires coal for the reduction of the iron-ore
- Cement
  - 7% of the global energy-related GHG emissions
  - Emissions from burning of fuels for process heat, and due to the calcination of calcium carbonate
- Silicon
  - Consumes carbon and electricity
- Pulp & paper
  - Biomass could be utilised by creating negative CO_2 emissions on site through CCS or by replacing fossil fuels in more difficult emission sources

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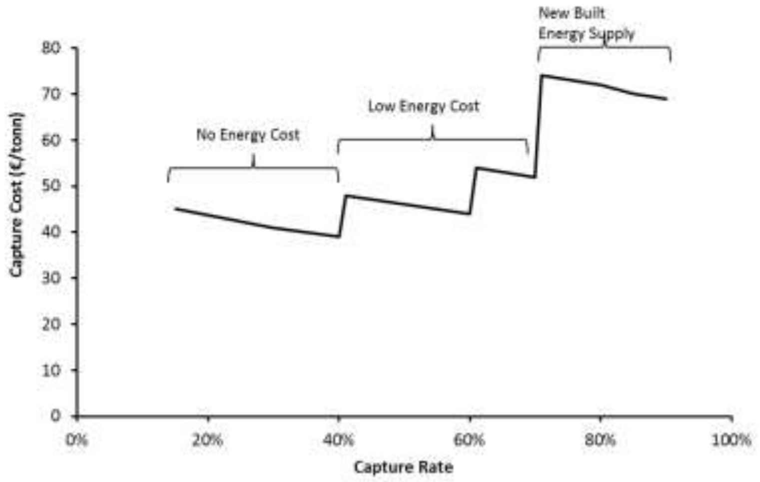
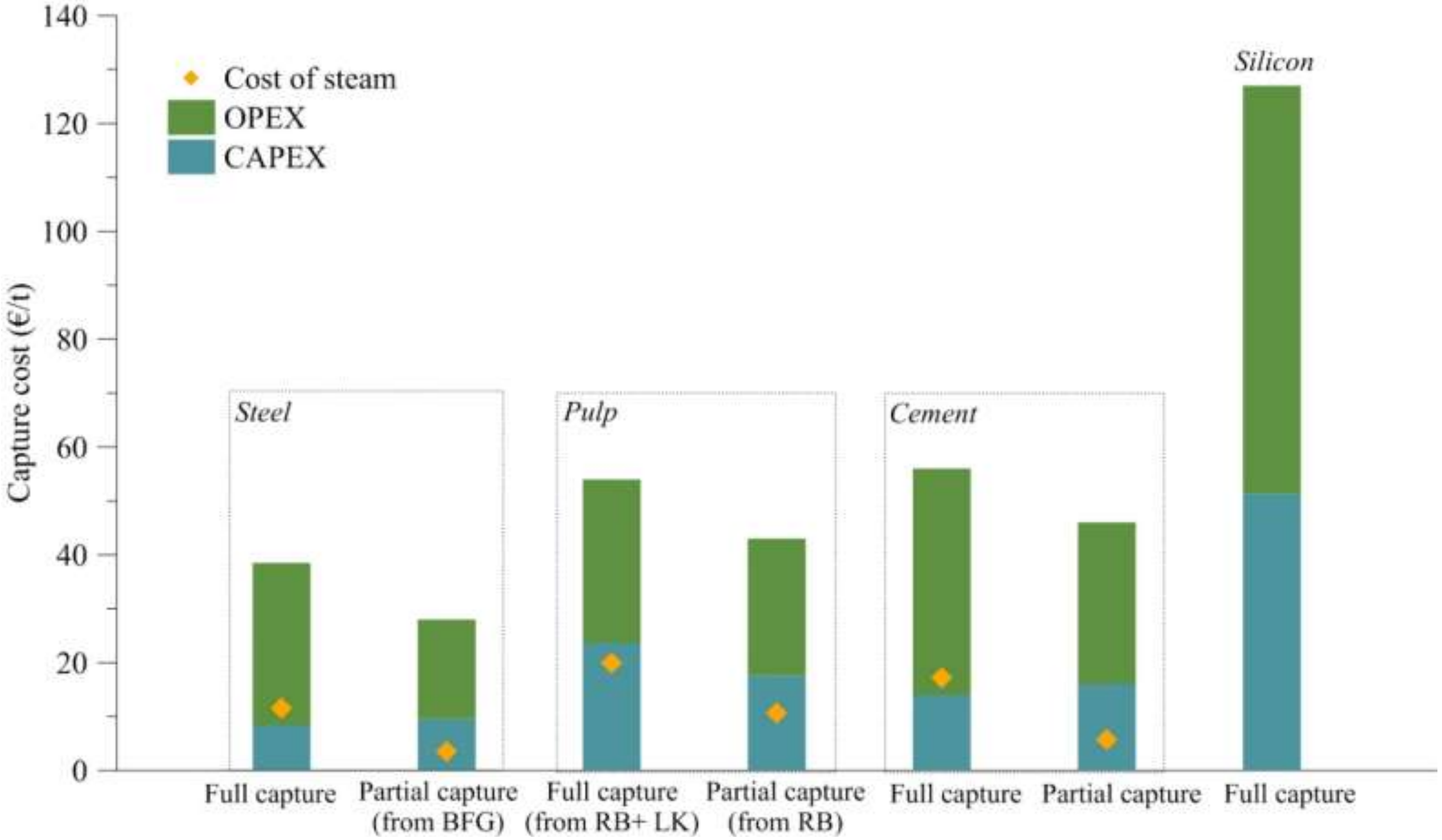
Partial capture

- The partial capture concept is defined as capture of only parts of the available CO_2 emissions on a plant



- Examples where partial capture could be considered;
  - Plants that have excess unused energy or an energy system that constantly or depending on market conditions may produce a part of the heat needed for carbon capture at low-cost
  - For plants with multiple stacks, targeting the most suitable stack(s) instead of total site emission
  - Plants where carbon capture is cost-efficient in combination with other mitigation measures

Overall results



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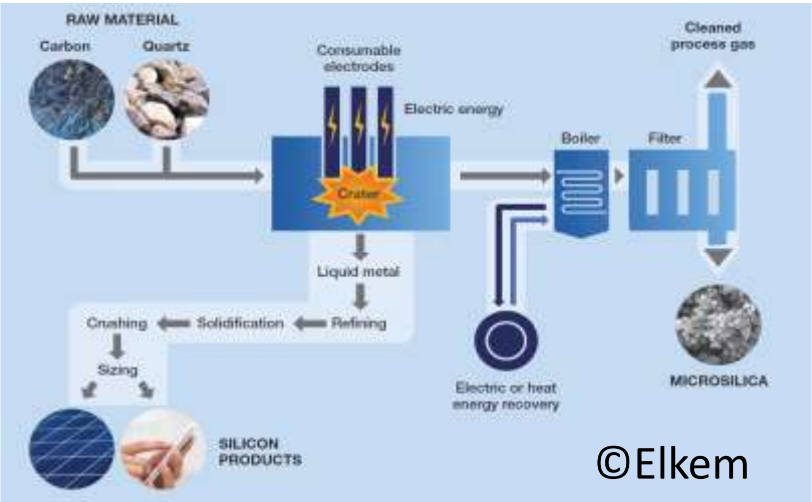
The silicon industry

- Silicon production is an energy intensive industry
- Consumes electricity and carbon-based raw materials
- Norwegian silicon has one of the lowest CO_2 emissions per ton product, mainly due to efficient process and hydro power
- Pathways are explored to reduce emissions: CCS, process development, waste heat utilisation, and bio-based carbon sources

Silicon production

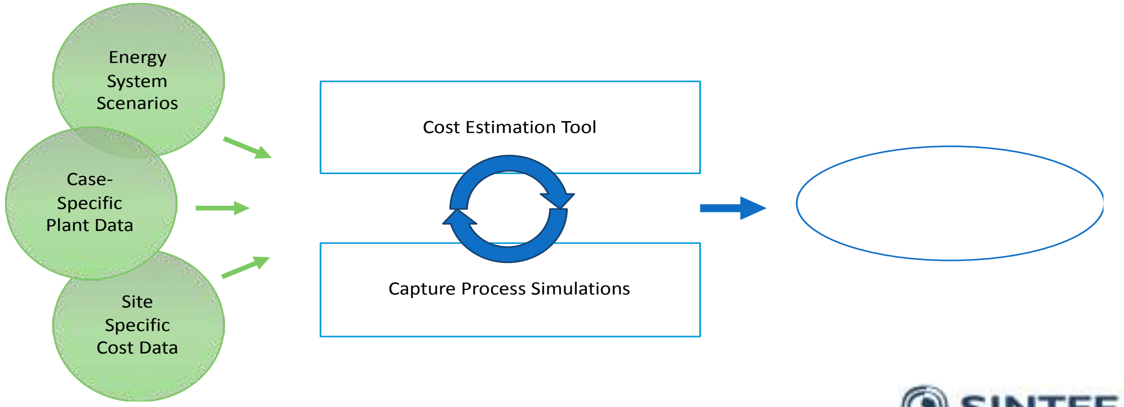


- Two plants: Si and FeSi alloy
- Electric arc furnaces where quartz is reduced by carbon $SiO_2 + 2C = Si + 2CO$
- With the current process, all CO is oxidized above the charge level
- The off-gas leaves the furnace at 400 - 700°C
  - Energy recovery is installed at some plants today

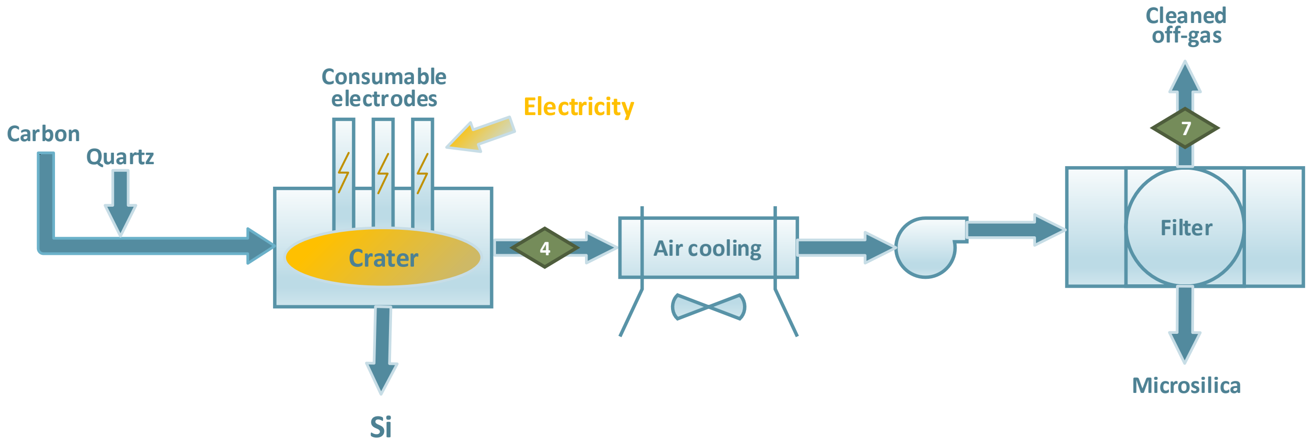
Method and assumptions

- Techno-economic analysis
- MEA-based rich solvent split flow configuration
- Aspen In-plant Cost Estimator combined with an in-house developed cost factor model
- Only plant emissions considered
- NOAK basis

Parameter	Unit	Value
Electricity price	EUR/kWh	0.055
Cooling water	EUR/m^3	0.02
Steam	EUR/t	16.67
Personnel – operators (1 person per shift)	kEUR/an	663.2
Personnel – engineers (1 person)	kEUR/an	157.9
Maintenance (% of CAPEX)	%	4
Operating hours	h	**8 760**
Rate of return	%	7.5
Number of years		25
Reference year		2015



REC Solar



- The plant produced close to 10 kt Si in 2015 from one furnace for use in solar panels
- Corresponding CO_2 emission
  - 43 kt from fossil energy sources,
  - and 12 kt from bio based sources
- Does not utilise waste heat today

- Small plant and low CO_2 concentration

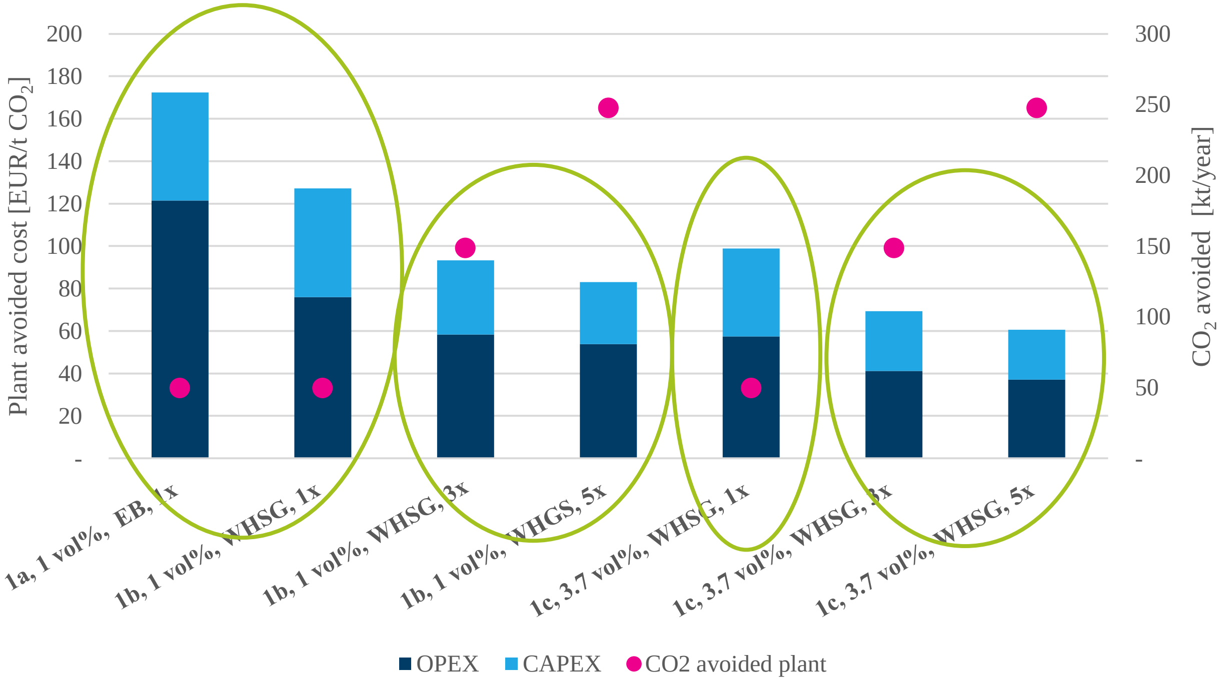
Parameter	Unit	Stream 4	Stream 7
CO_2	**Vol%**	**3.7**	**1.0**
H_2O	Vol%	1.0	7.4
N_2	Vol%	77.2	74.1
O_2	Vol%	18.1	17.5

★ Excess energy sufficient to capture 90% of the produced CO_2

REC Solar - results

- The effect of increased CO_2 concentration and plant size

Scenario	CO_2 capture details	Specific reboiler duty, SRD	Steam supply/need
1a	1 vol% CO_2, 90% capture rate	3.53 MJ/kg CO_2 captured	Electric boiler, 1x – 5.6 MW
1b	1 vol% CO_2, 90% capture rate	3.53 MJ/kg CO_2 captured	WHSG, 1x – 5.6 MW 3x – 16.8 MW 5x – 28.0 MW
1c	3.7 vol% CO_2, 90% capture rate	3.34 MJ/kg CO_2 captured	WHSG, 1x – 5.6 MW 3x – 15.9 MW 5x – 26.5 MW



- 1x – 55 kt CO_2, captured ~50 kt
- 3x – 165 kt CO_2, captured ~149 kt
- 5x – 275 kt CO_2, captured ~248 kt

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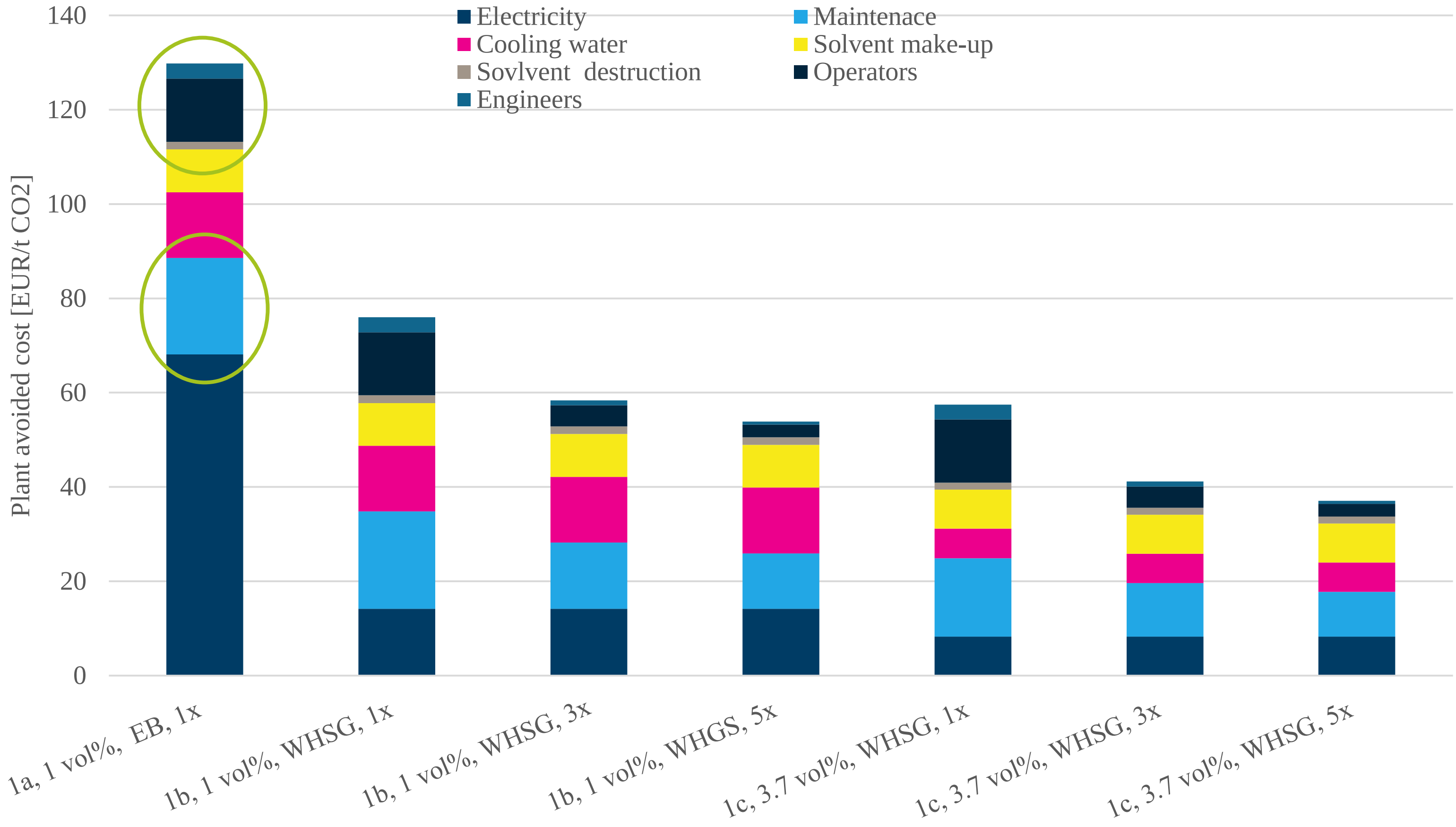
REC Solar – OPEX details



- Maintenance and personnel cost contribute disproportionally for the small plant
- Regardless of plant size
  - 1 operator per shift
  - 1 engineer

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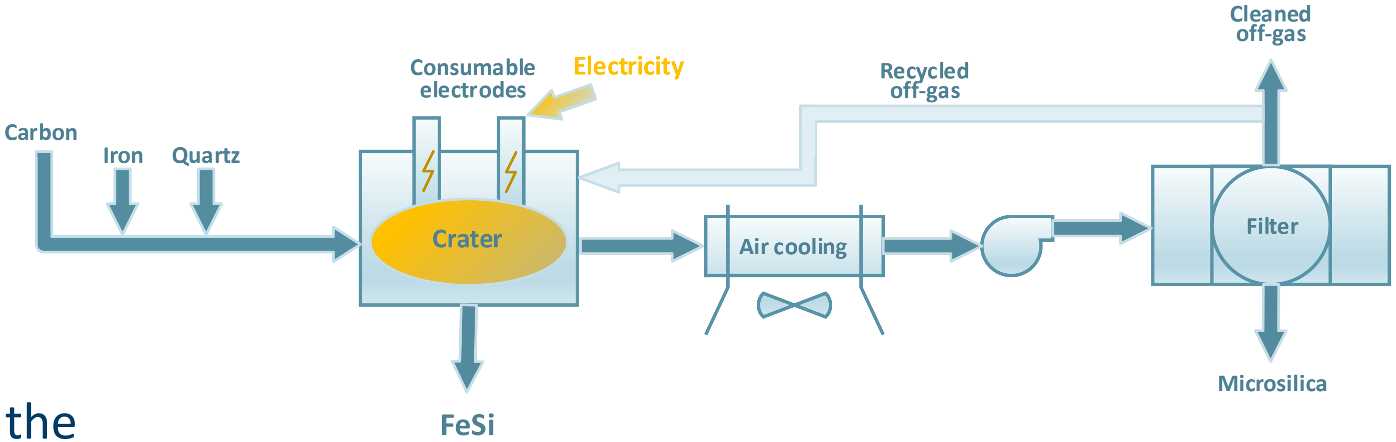
Generic plant



- Two furnaces producing FeSi primarily for the iron and steel industry
- Annual CO_2 emission ~ 250 kt
- Furnace off-gas recycling to increase CO_2 concentration is being explored

Parameter	Unit	Traditional furnace off-gas, from one furnace*	Off-gas recycling off-gas, from one furnace	One traditional and one off-gas recycling furnace
CO_2	vol%	**4.4**	**15.1**	**6.8**
H_2O	vol%	4.3	11.8	6.4
N_2	vol%	74.9	67.1	72.8
O_2	vol%	16.4	6.0	14.0

★ Excess energy sufficient to capture 90% of the produced CO_2

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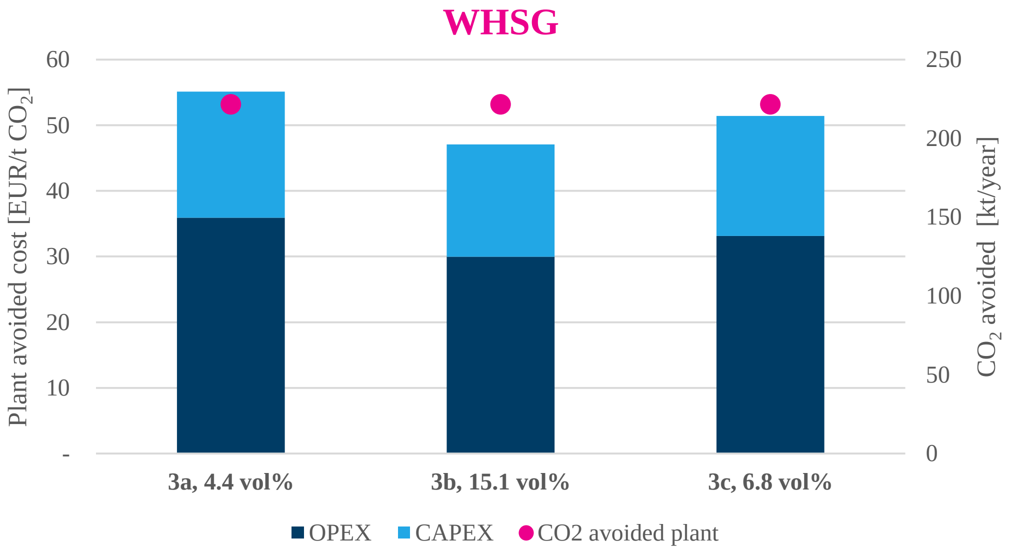
Generic plant - results

- Effect of flue gas recycling
- The feasibility and cost of modifying the plant is not considered

Scenario	CO_2 capture details	Specific reboiler duty, SRD	Steam supply/need
3a (ref.)	Two furnaces no recycling, 4.4 vol% CO_2, 90% capture rate	3.34 MJ/kg CO_2 captured	**WHSG**, 23.6 MW
3b	Two furnaces recycling in both, 15.1 vol% CO_2, 90% capture rate	3.15 MJ/kg CO_2 captured	**WHSG**, 22.3 MW
3c	Two furnaces only one with recycle, 6.8 vol% CO_2, 90% capture rate	3.26 MJ/kg CO_2 captured	**WHSG**, 23.0 MW



Silicon - partial capture

The investigated plants had sufficient energy to capture 90%

- Alternative use of the excess heat is for district heating
- Partial capture - seasonal capture
- Assumptions
  - Waste heat for district heating is only sold during the winter months (six months of the year)
  - That the waste heat can be used "free of charge" for CO_2 capture during the summer months
  - Full-sized capture plant is built (capacity to capture 90% of the CO_2 produced at the given time)
  - The value of the steam as district heating was set to 16.67 €/t
  - All year capture includes a loss of revenue from sales of district heating during winter

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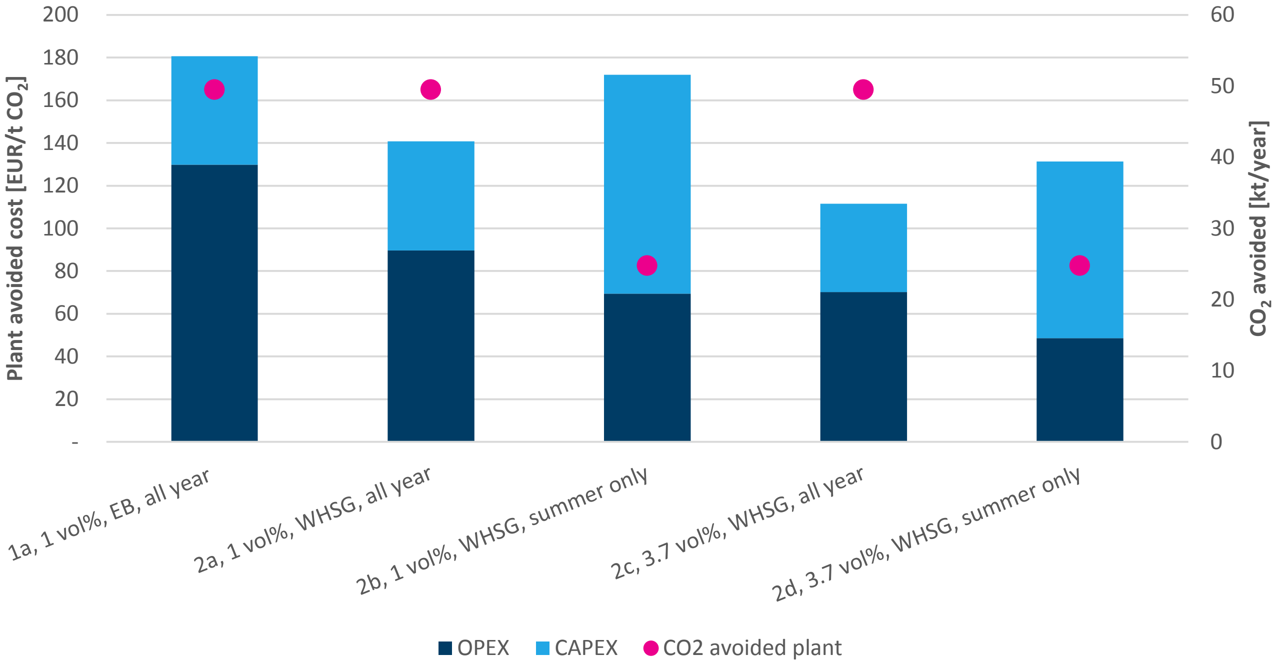
Seasonal capture – results



Summer only capture results in a change from OPEX to CAPEX as main contributors for the cost

Final remarks (1)

The overall conclusion:
Utilise waste heat for CO_2 capture

- REC Solar
  - The low CO_2 concentration and small source makes CO_2 capture costly
  - A relatively small increase in CO_2 concentration, ~ 4 vol%, is beneficial as expected,
  - the same is found for increased plant size

- Generic plant
  - Current CO_2 concentration ~4 vol% CO_2, flue gas recycling can increase it to ~ 15 vol%
  - The higher concentration makes CO_2 capture less costly, but needs to be weighted against the changes needed in the process
  - Higher concentrations may also make other capture technologies attractive

Final remarks (2)

- Seasonal/partial capture
  - Seasonal capture could under the right circumstances be considered
  - The results are highly dependent on the value of district heating
  - A further investigation into the possibility of combining heat for CO_2 capture and district heating is recommended
  - Should be assessed for plants larger in size and/or with a higher CO_2 concentration

Webinar – June 25th

- Ragnhild Skagestad, SINTEF Industry
  "The CO_2stCap project and overall results"
- Max Bierman, Chalmers
  "Scenario for near-term implementation of partial capture from blast furnace gases in Swedish steel industry"
- Anette Mathisen, SINTEF Industry
  "CO_2 capture opportunities in the Norwegian silicon industry"
- Jens Wolf, RISE Bioeconomy
  "Partial Capture of CO_2 From a Pulp Mill with Focus on Cost Reduction"

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The CO2st Cap project and overall results

Sign up to the webinar here:

Tue, Jun 25, 2019 2:00 PM - 3:00 PM CEST

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Project partners:

SINTEF, CHALMERS, USN, RISE, SWERIM

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