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Techno-economic Evaluation of Oxyfuel CO₂ Capture in Two European Cement Plants

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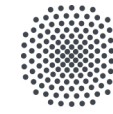
^aSINTEF Energy Research, ^bHeidelbergMaterials, ^cVDZ Technology gGmbH, ^dAir Liquide,

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The AC²OCem project

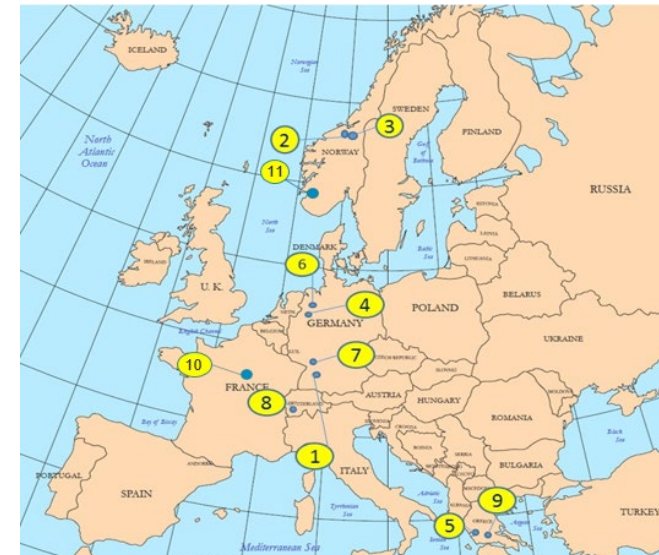
- ACT-project
- 11 European partners
- Coordinator: University of Stuttgart
- 2019 – 2023
- 4.3 M€
- Demo tests, theoretical and analytical studies
 - > expedite large scale implementation of 1st generation oxyfuel for retrofit
 - > promote a novel oxyfuel concept for new-built plants



University of Stuttgart
Germany



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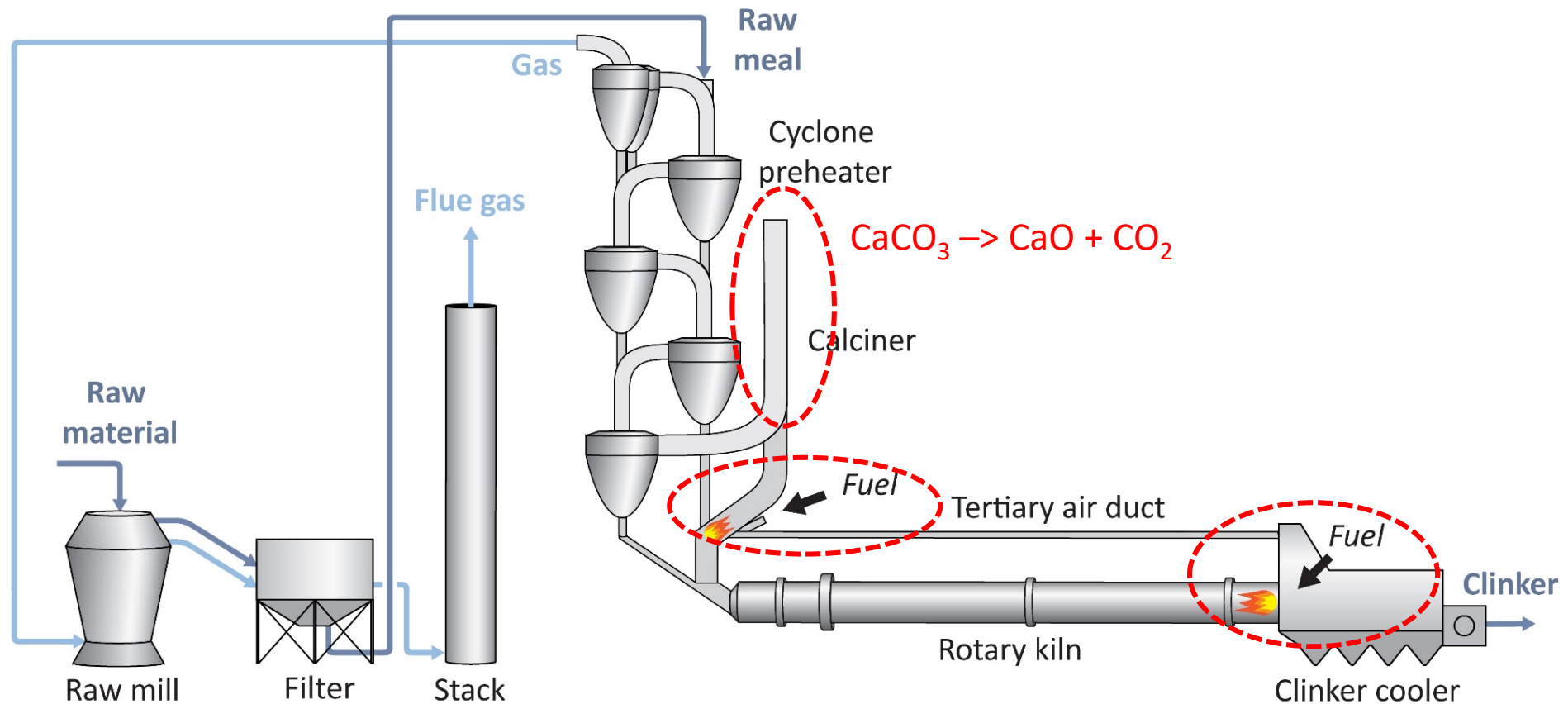


1. Universität Stuttgart, Germany
2. SINTEF Energy Research, Norway
3. Norwegian University of Science and Technology, Norway
4. VDZ Technology gGmbH, Germany
5. Center of Research and Technology CERTH, Greece
6. thyssenkrupp Industrial Solutions AG, Germany
7. HeidelbergCement AG, Germany
8. Holcim, Switzerland
9. TITAN Cement Company S A, Greece
10. Air Liquide, France
11. Total Norge AS, Norway



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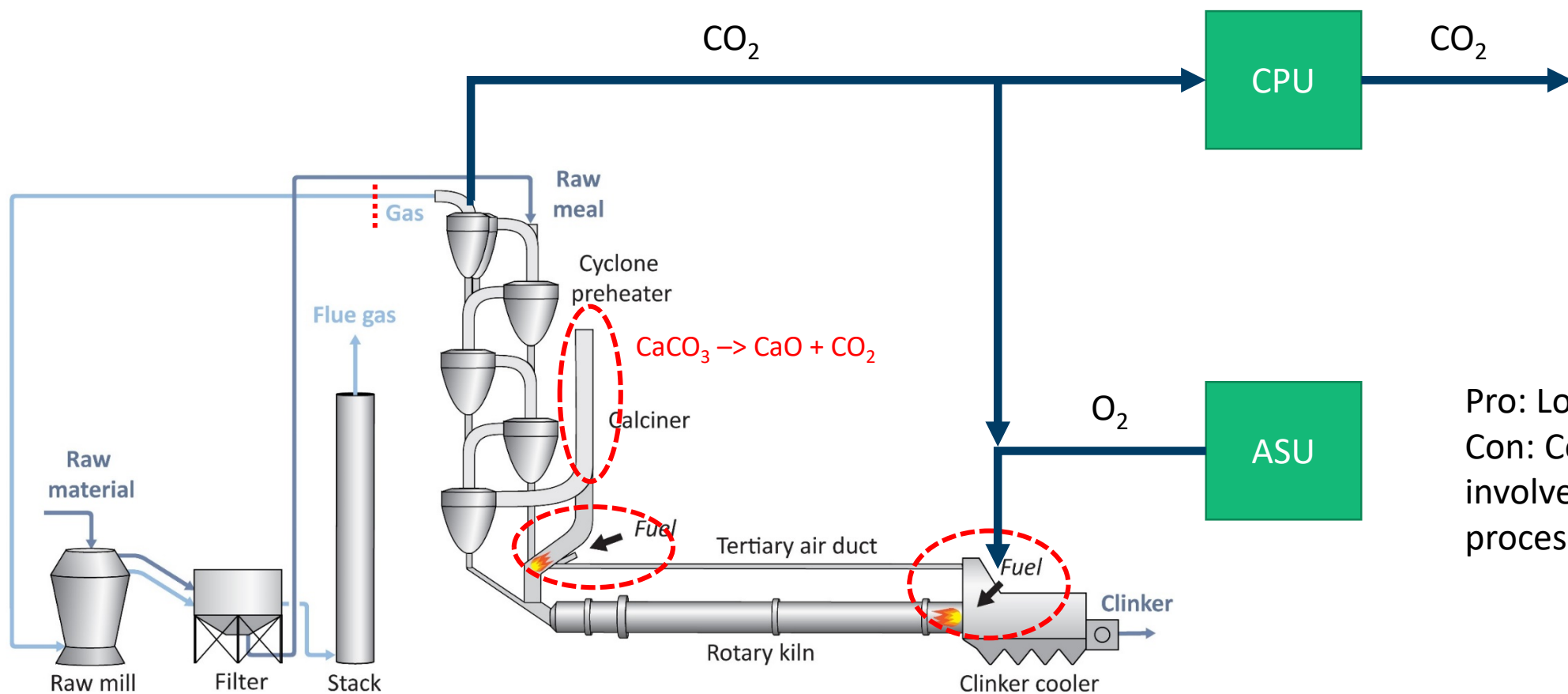
Cement production





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Oxyfuel cement production



Pro: Low OPEX
Con: Complex and involves the core process



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Plants investigated for retrofit

Lägerdorf (Germany)

Holcim

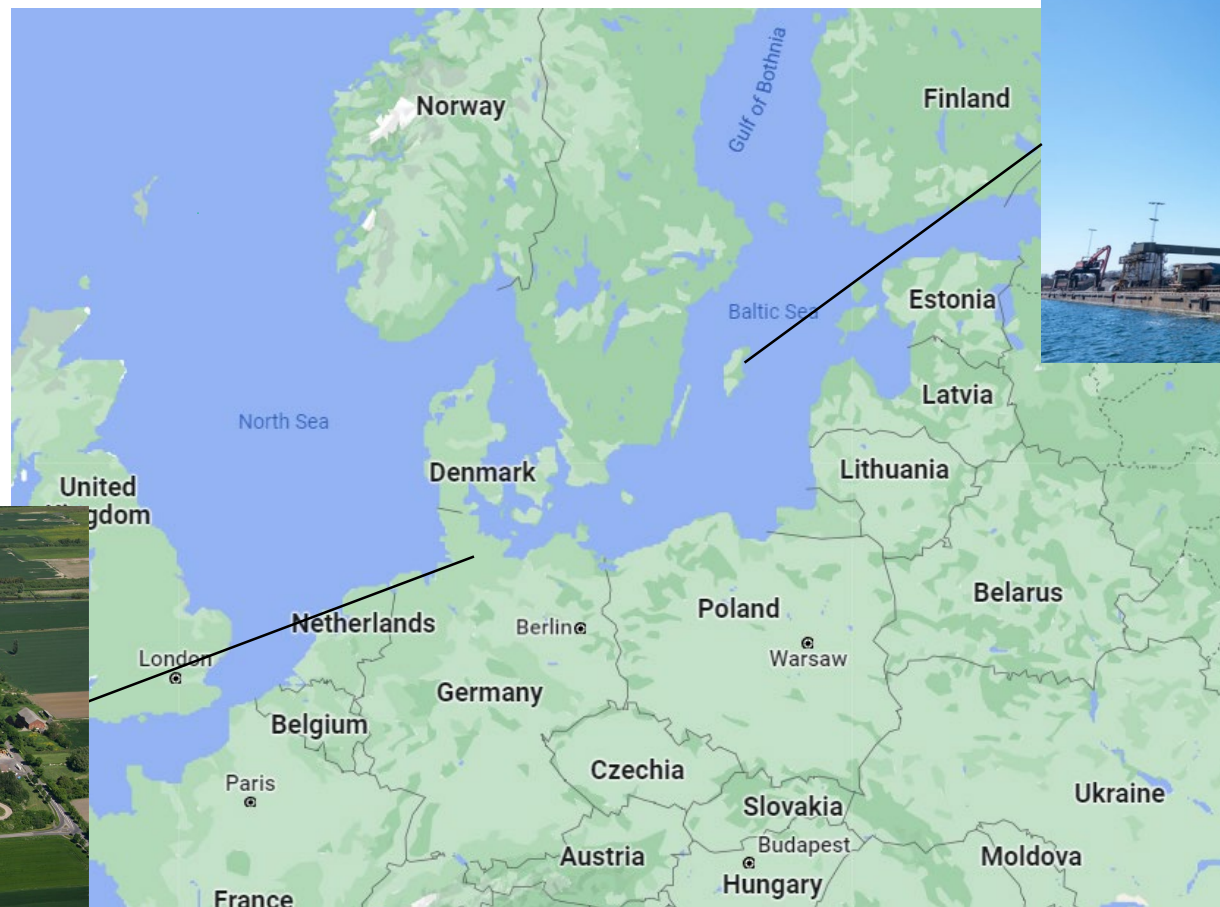
4400 tonne clinker/day

20% raw material moisture

German el mix 2019:

77 €/MWh (Eurostat)

10 kg CO₂/MWh (Statista)



Slite (Sweden)

HeidelbergCement

5600 tonne clinker/day

2-3% raw material moisture

Swedish el mix 2019:

44 €/MWh (Eurostat)

344 kg CO₂/MWh (Statista)

Figure: Google maps



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Key performance indicators

Increased levelized cost of clinker:

$$\Delta LCOC = LCOC_{CCS} - LCOC_{ref} = \left(\frac{\sum_{t=1}^n (CAPEX_t + OPEX_t)(1+r)^{-t}}{\sum_{t=1}^n A_{cli,t}(1+r)^{-t}} \right)_{CCS} - \left(\frac{\sum_{t=1}^n (CAPEX_t + OPEX_t)(1+r)^{-t}}{\sum_{t=1}^n A_{cli,t}(1+r)^{-t}} \right)_{ref}$$

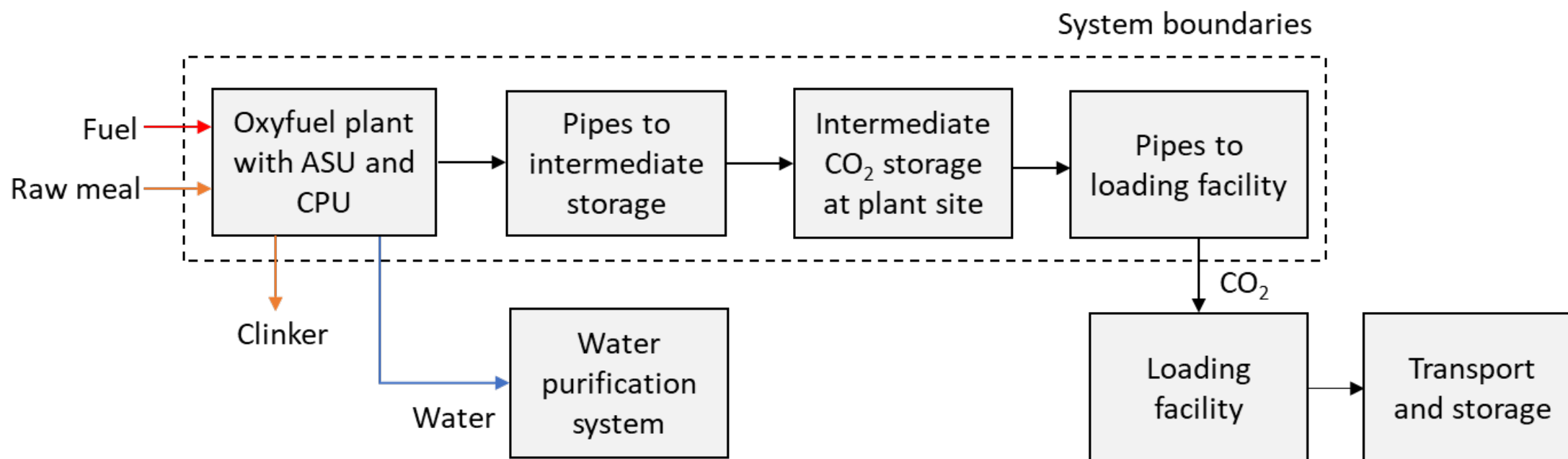
Cost of CO₂ avoided without transport and storage:

$$CAC = \frac{\Delta LCOC}{e_{clk,eq,ref} - e_{clk,eq,CCS}}$$



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System boundaries



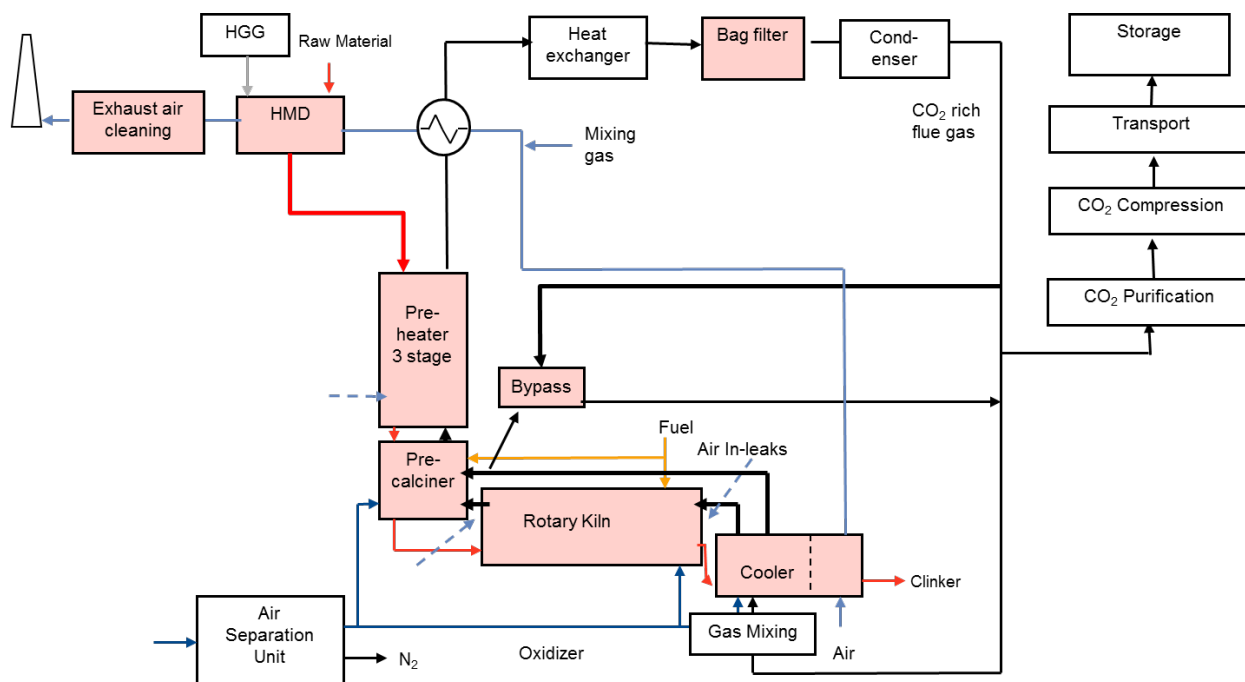


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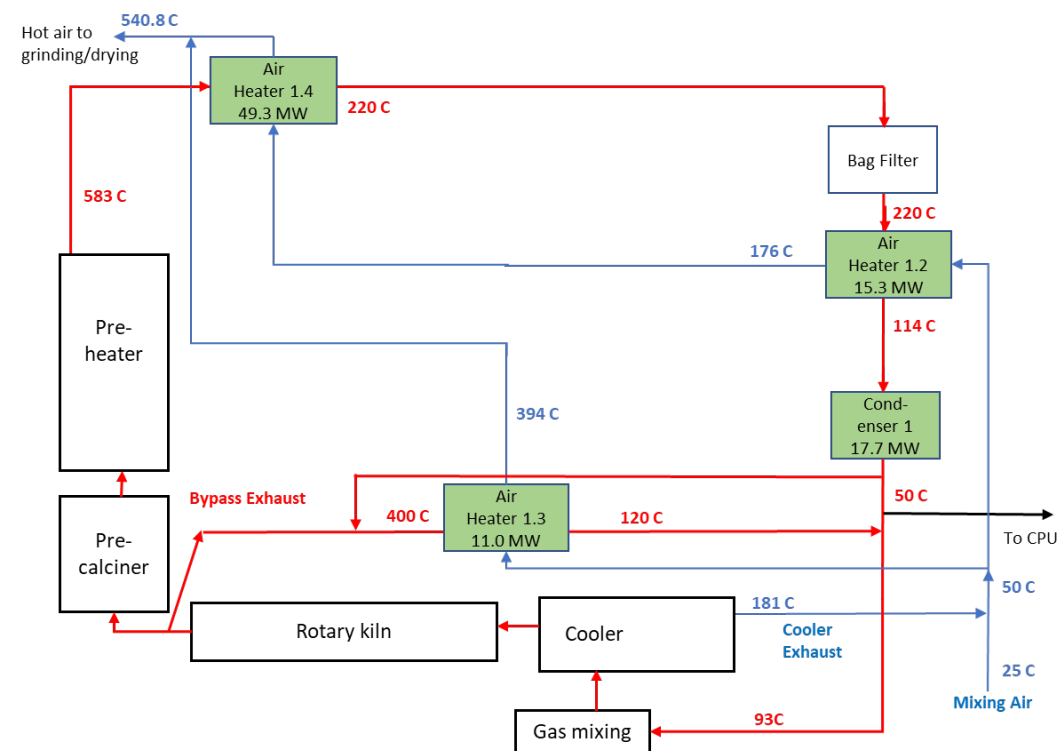
Main economic parameters

Economic parameter	Value
Cost year	2019
Discount rate	8%
Years of construction	1
Lifetime	25

VDZ simulation of core process with in-house cement plant model



SINTEF heat integration for design of heat exchanger networks



Disclaimer: All estimates presented in this presentation are based on literature data, publicly available data, and assumptions. Plant specific data have not been used in the calculations.



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Space availability and location of equipment

Unit	Slite	Lägerdorf
Oxygen pipeline (Kiln system – ASU)	800 m	510 m
Flue gas pipeline (Gas recirculation – CPU)	700 m	220 m
Liquid CO ₂ pipeline (CO ₂ storage tanks – loading facility)	600 m	410 m



Photo: Google maps

Slite:

Limited space available close to kiln line. Existing old kiln must be removed.

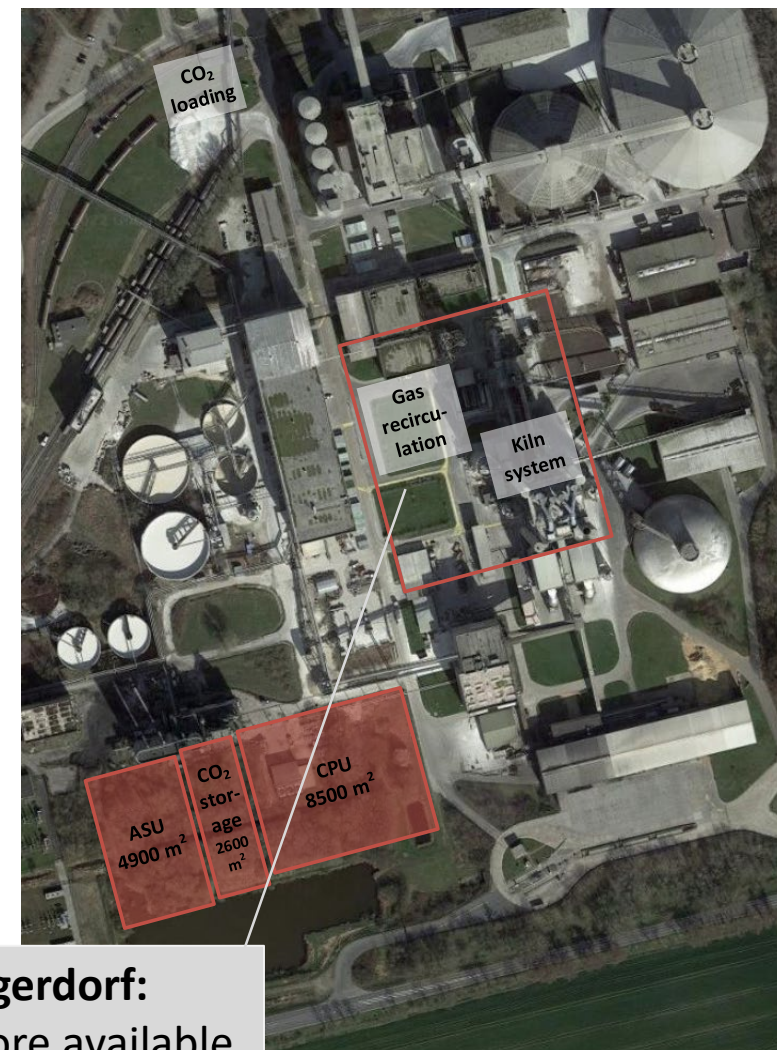


Photo: Google maps

Lägerdorf:

More available space close to kiln line.



CAPEX estimation

- ASU and CPU: AirLiquide
- Flue gas recycling and plant modifications: thyssenkrupp Industrial Solutions (high-level estimate based on project planning archive from previous projects)
- Additional heat recovery: SINTEF
- Ducting and CO₂ storage tanks: TotalEnergies
- Removal of existing equipment: HeidelbergCement and Holcim



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Plant utilisation

	Clinker production		CO ₂ capture	
	Utilisation factor	Operating hours	Utilisation factor	Operation hours
Normal operation	91%	8000 h	91%	8000 h
Year 1	50%	4380 h	0%	0 h
Year 2	80%	7008 h	65%	5694 h
Year 3	91%	8000 h	80%	7008 h

Normal operation: Assumed based on typical industry target (not real data from the specific plants)

Year 1-3:

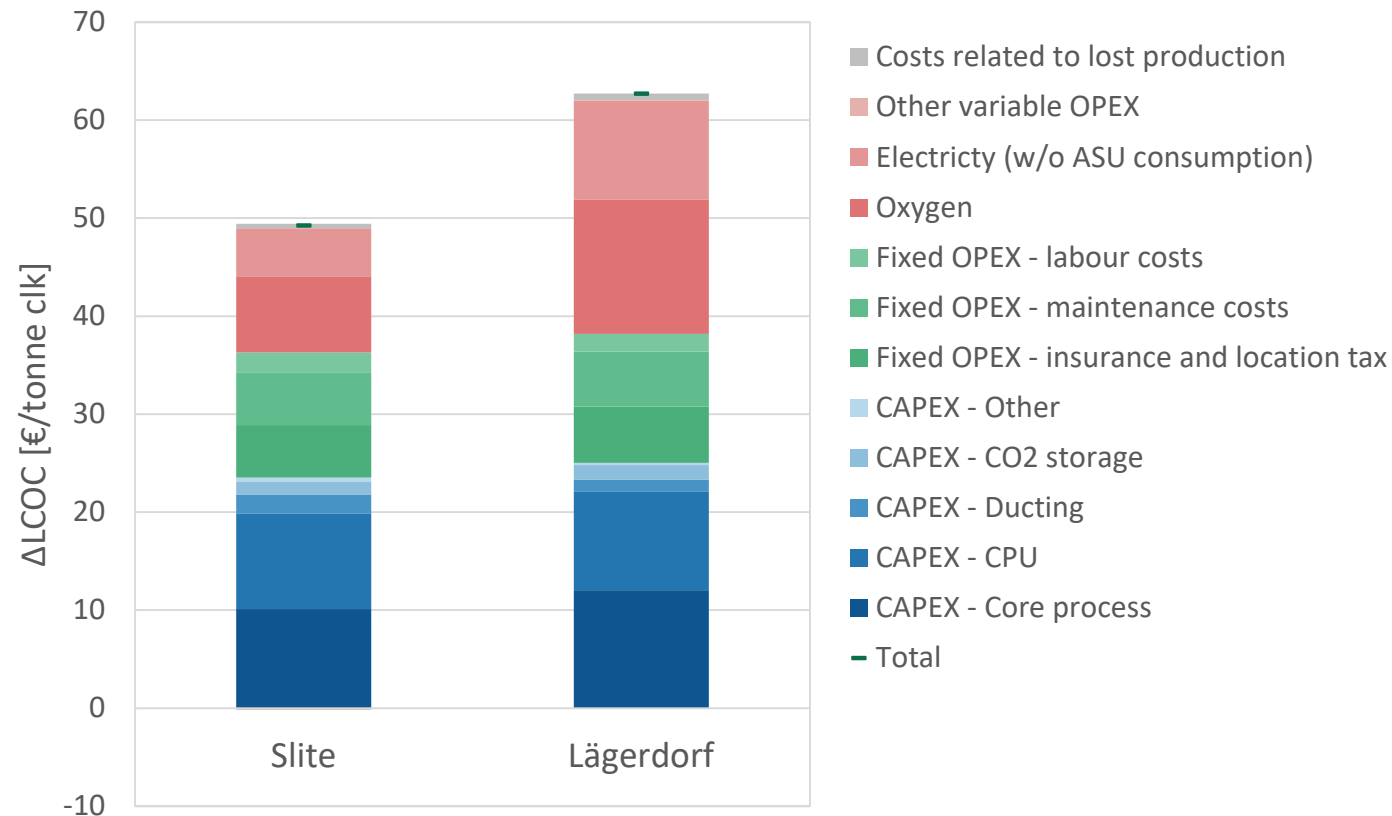
- Downtime necessary for plant modifications estimated by thyssenkrupp IS (6 months)
- Unforeseen downtime assumed

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Increased levelized cost of clinker (ΔLCOC)

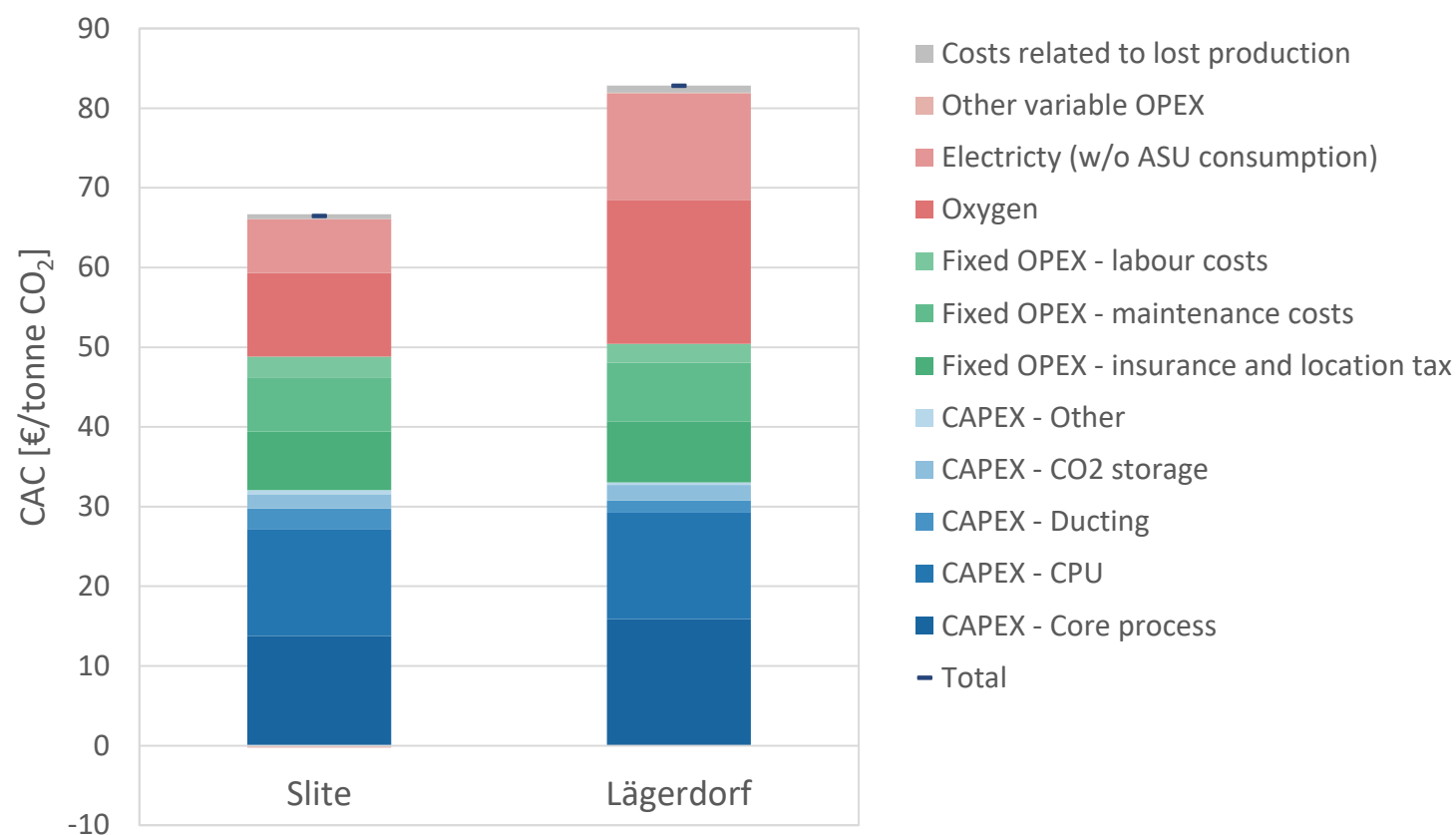


- Main cost drivers:
 - Core process CAPEX
 - CPU CAPEX
 - Oxygen (TCO)
 - Electricity
- Main plant differences:
 - Heat recovery required
 - Location factor
 - Space availability
 - Electricity and oxygen price



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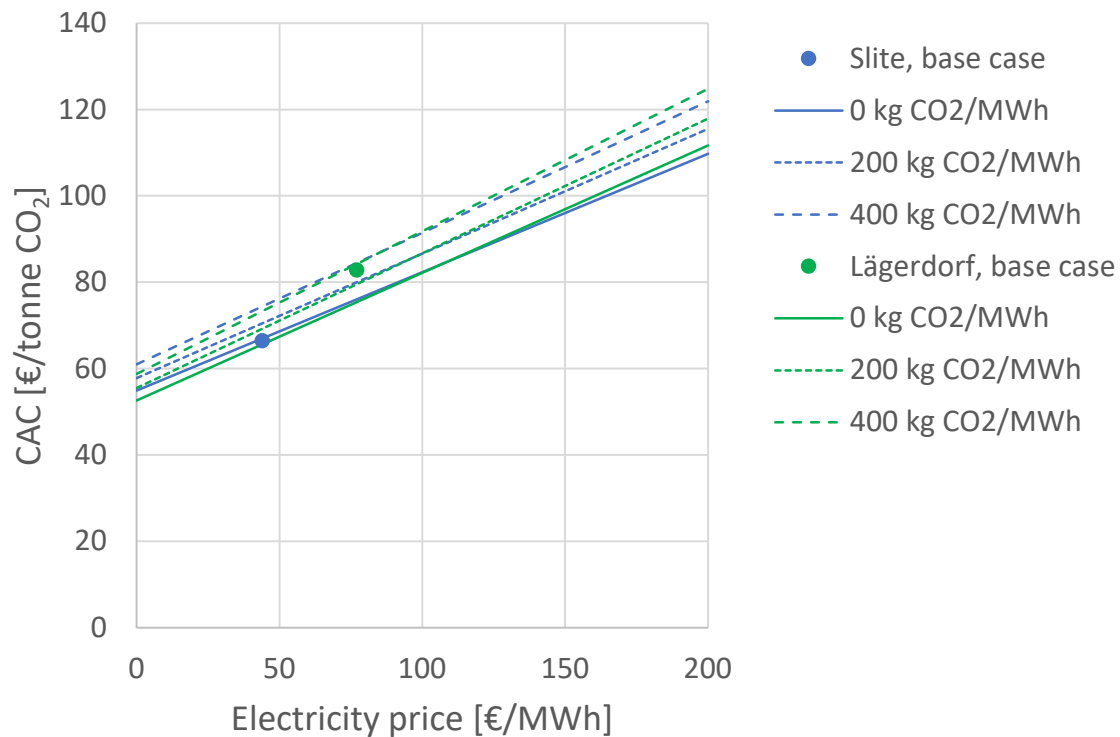
Cost of avoided CO₂ (CAC)



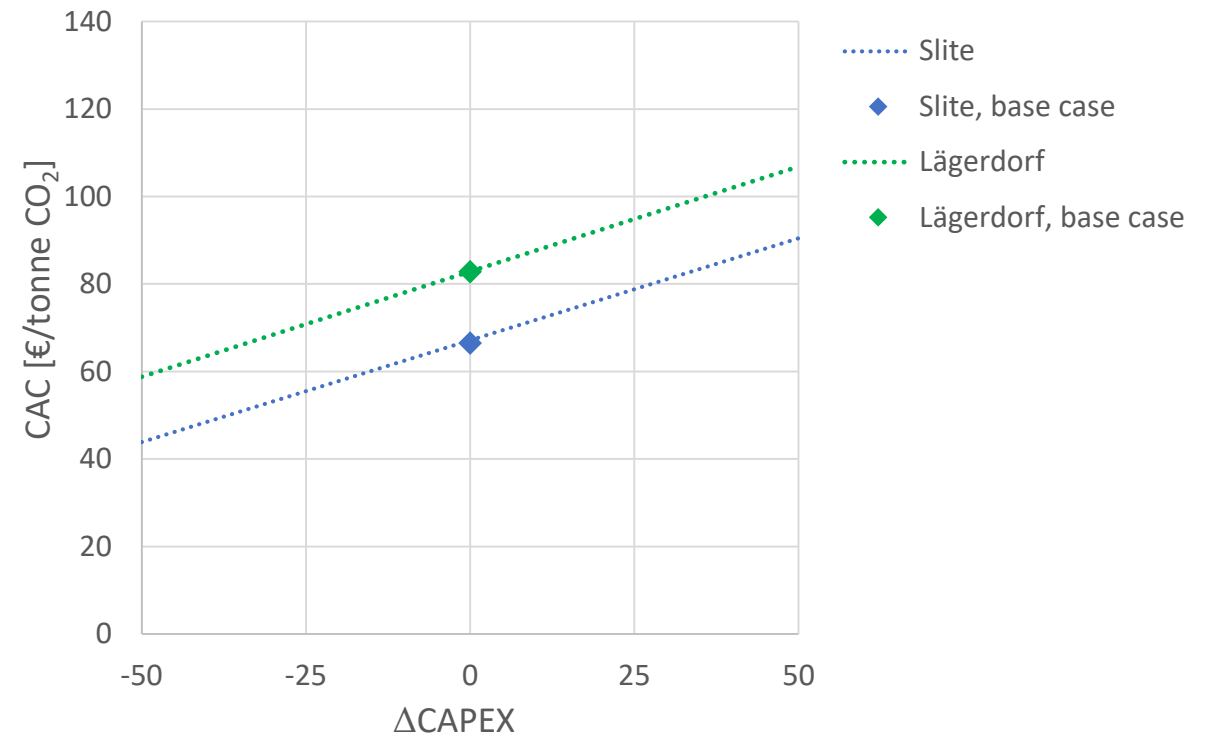
- Direct and indirect emissions are considered
- Lägerdorf higher CO₂ avoided than Slite due to a different process

Sensitivity analysis (I)

CAC sensitivity to electricity price and CO₂ intensity (includes impact of electricity price on oxygen cost)



CAC sensitivity to CAPEX



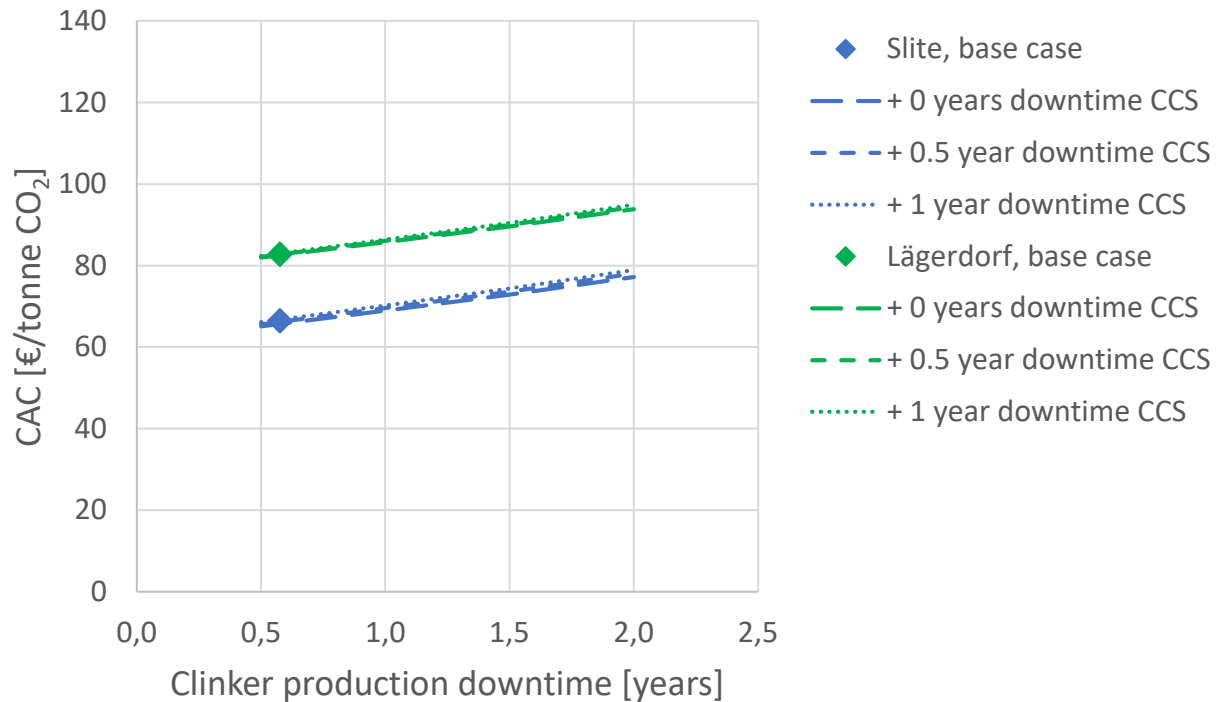
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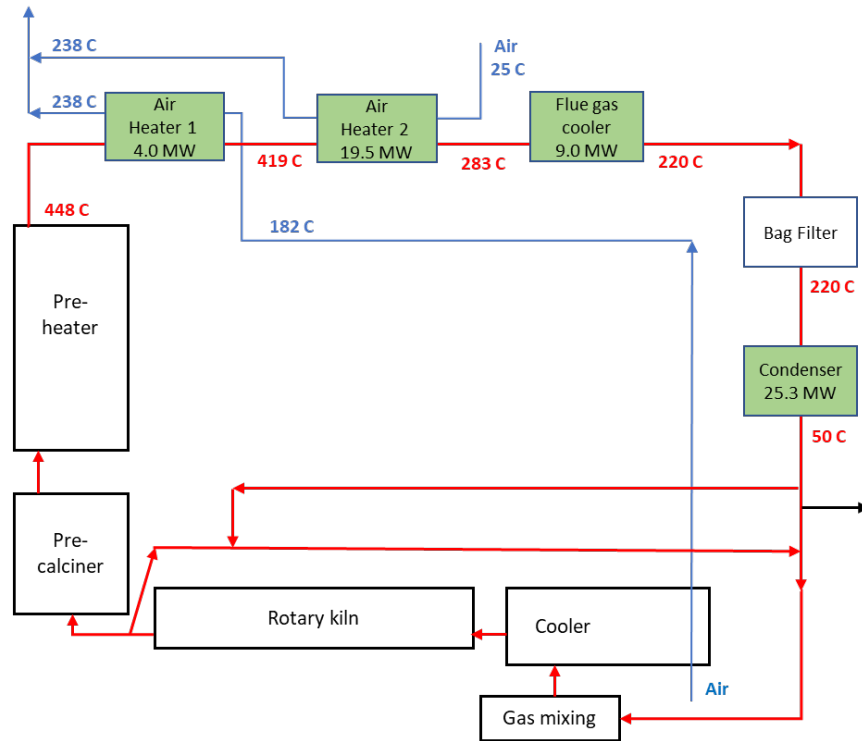
Sensitivity analysis (II)

CAC sensitivity to downtime



- Downtime is a major uncertainty
 - Clinker production downtime
 - CO₂ capture downtime with clinker production
- Lost production of clinker has largest impact on CAC

Without steam cycle



The diagram illustrates the process flow of a cement plant with integrated CO₂ capture. Key components and their associated parameters are as follows:

- Pre-calciner:** Receives feed from the bottom left and sends material to the Rotary kiln.
- Rotary kiln:** Receives material from the Pre-calciner and sends it to the Cooler.
- Cooler:** Receives material from the Rotary kiln and sends it to the Gas mixing unit.
- Gas mixing:** Receives gas from the Cooler and sends it to the Heat Cooler.
- Heat Cooler:** Receives gas from the Gas mixing unit and sends it to the Exhaust/Mixing Air Stage 1.
- Exhaust/Mixing Air Stage 1:** Receives air from the Heat Cooler and sends it to the Air heater 1.1.
- Air heater 1.1:** Receives air from the Exhaust/Mixing Air Stage 1 and sends it to the Economizer 1.
- Economizer 1:** Receives air from the Air heater 1.1 and sends it to the Air heater 1.2B.
- Air heater 1.2B:** Receives air from the Economizer 1 and sends it to the Bag Filter.
- Bag Filter:** Receives air from the Air heater 1.2B and sends it to the Air heater 1.2A.
- Air heater 1.2A:** Receives air from the Bag Filter and sends it to the Economizer 2.
- Economizer 2:** Receives air from the Air heater 1.2A and sends it to the Boiler.
- Boiler:** Receives air from the Economizer 2 and sends it to the Air Heater 1.3.
- Air Heater 1.3:** Receives air from the Boiler and sends it to the Super-heater.
- Super-heater:** Receives air from the Air Heater 1.3 and sends it to the Pre-heater.
- Pre-heater:** Receives air from the Super-heater and sends it to the Pre-calciner.
- Condenser:** Receives air from the Pre-heater and sends it to the Condenser.
- Condenser:** Receives air from the Pre-heater and sends it to the Condenser.
- Condenser:** Receives air from the Pre-heater and sends it to the Condenser.

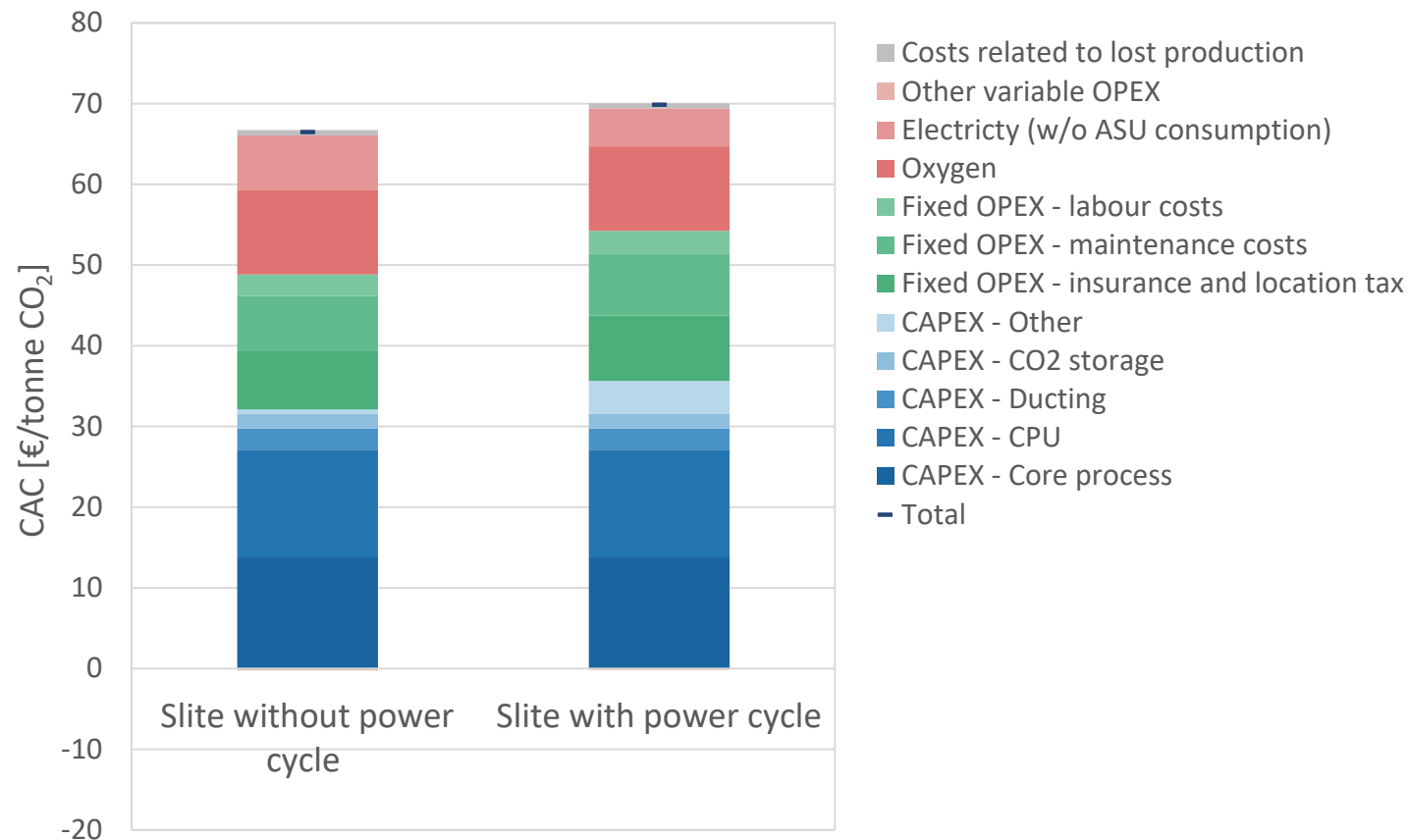
Temperatures and pressures are indicated at various points in the process flow, such as 423 C, 238 C, 201 C, 269 C, 198 C, 241 C, 220 C, 220 C, 120 C, 105 C, 91 C, 50 C, 247 C, 182 C, 88 C, 48 C, 25 C, 25 C, 15 bar, and 0.035 bar.

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Slite heat to power cycle

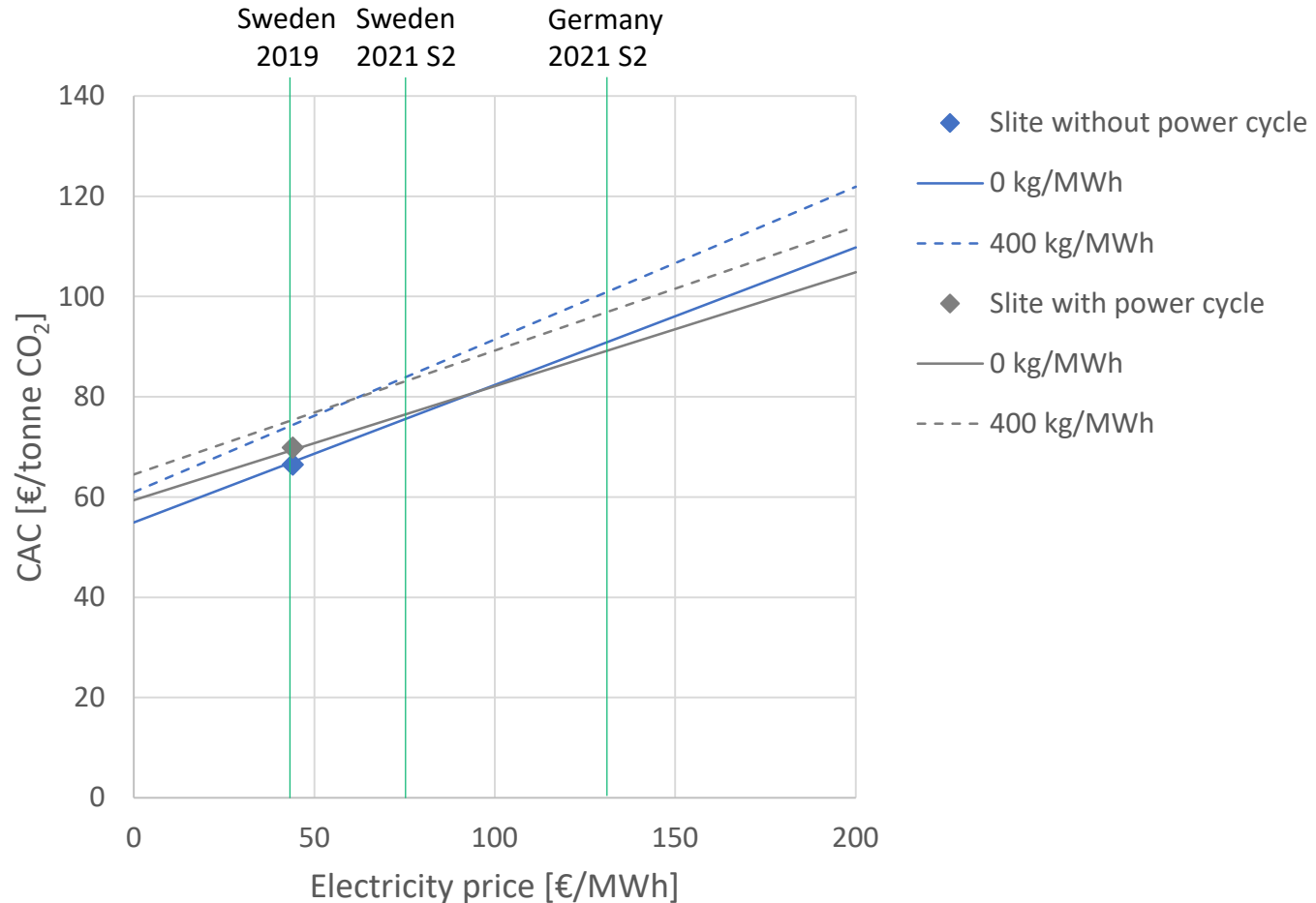


- Increased CAPEX
- Reduced electricity cost
- Increased CO₂ avoided
- Base case: Sweden 2019
 - Electricity price: 44 €/MWh
 - CO₂ emission factor: 10 kg/MWh



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Slite heat to power cycle – sensitivity to grid conditions



- Base case: Sweden 2019
 - Electricity price: 44 €/MWh
 - CO₂ emission factor: 10 kg/MWh
- Germany 2019:
 - Electricity price: 77 €/MWh
 - CO₂ emission factor: 344 kg/MWh
- Sweden 2021 S2:
 - Electricity price: 72 €/MWh
- Germany 2021 S2:
 - Electricity price: 131 €/MWh



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Comparison with previous studies

Estimate	Cost year	CAC [€/tonne CO ₂]
AC2OCem Slite	2019	67
AC2OCem Lägerdorf	2019	83
CEMCAP	2014	42
ECRA	2009	45

A combination of several factors gives significantly higher CAC than in previous studies

- Higher CAPEX
 - Real plants considered instead of hypothetical reference plant
 - Increased understanding on complexity of modifying existing plants (core process CAPEX)
 - Higher CPU CAPEX based on estimate by technology supplier
 - Extended scope: pipelines and CO₂ buffer tanks are included
- Plant downtime included
- Higher O₂ consumption in real plants compared to reference plant
- Slightly different evaluation frameworks in the three studies (e.g. contingency estimation)
- Other differences: Location factors, cost years, electricity cost and CO₂ footprint

Note: Due to differences in assumptions, scope, and evaluation framework, costs of other technologies evaluated in CEMCAP cannot be directly compared with AC2OCem oxyfuel costs.



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Conclusions

- The main cost drivers for the oxyfuel process are CAPEX and cost of electricity – both are sensitive to the specific plant investigated
- Integration of steam cycle may be profitable for plants with low raw material moisture and high electricity prices
- The estimated costs for the two real plants are significantly higher than for the hypothetical reference plant investigated in previous studies



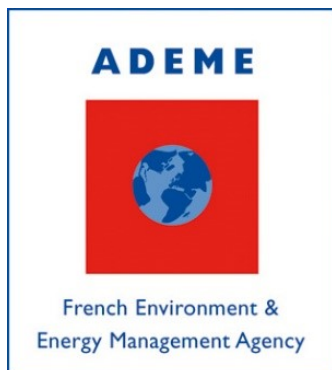
Funding agencies



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