GHGT-16, Lyon, 25.10.2022

Techno-economic Evaluation of Oxyfuel CO_2 Capture in Two European Cement Plants

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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.

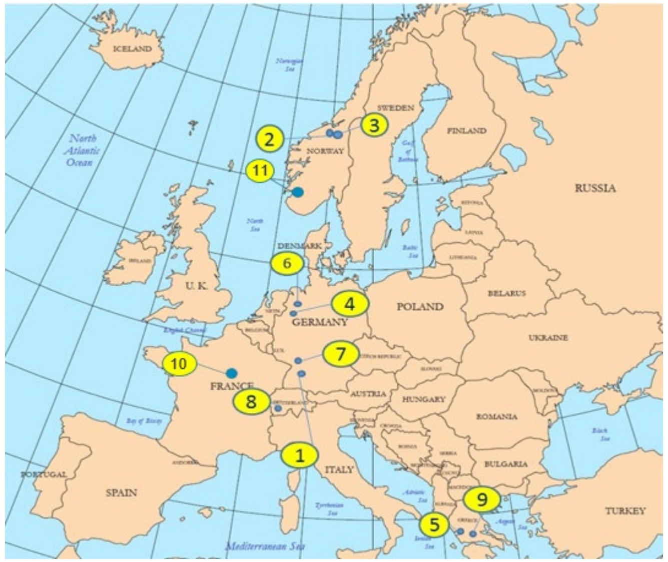
The AC^{2}OCem project

- 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



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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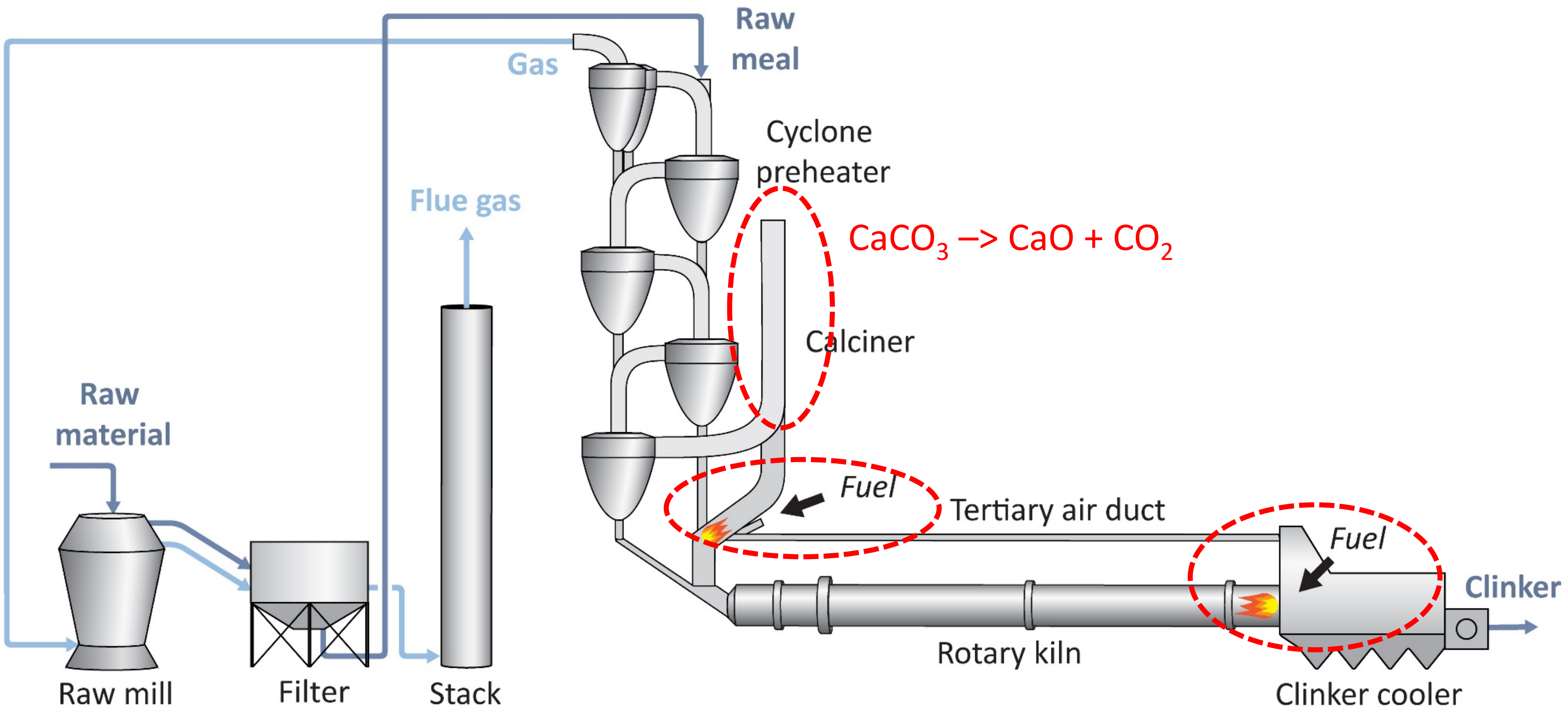
Cement production



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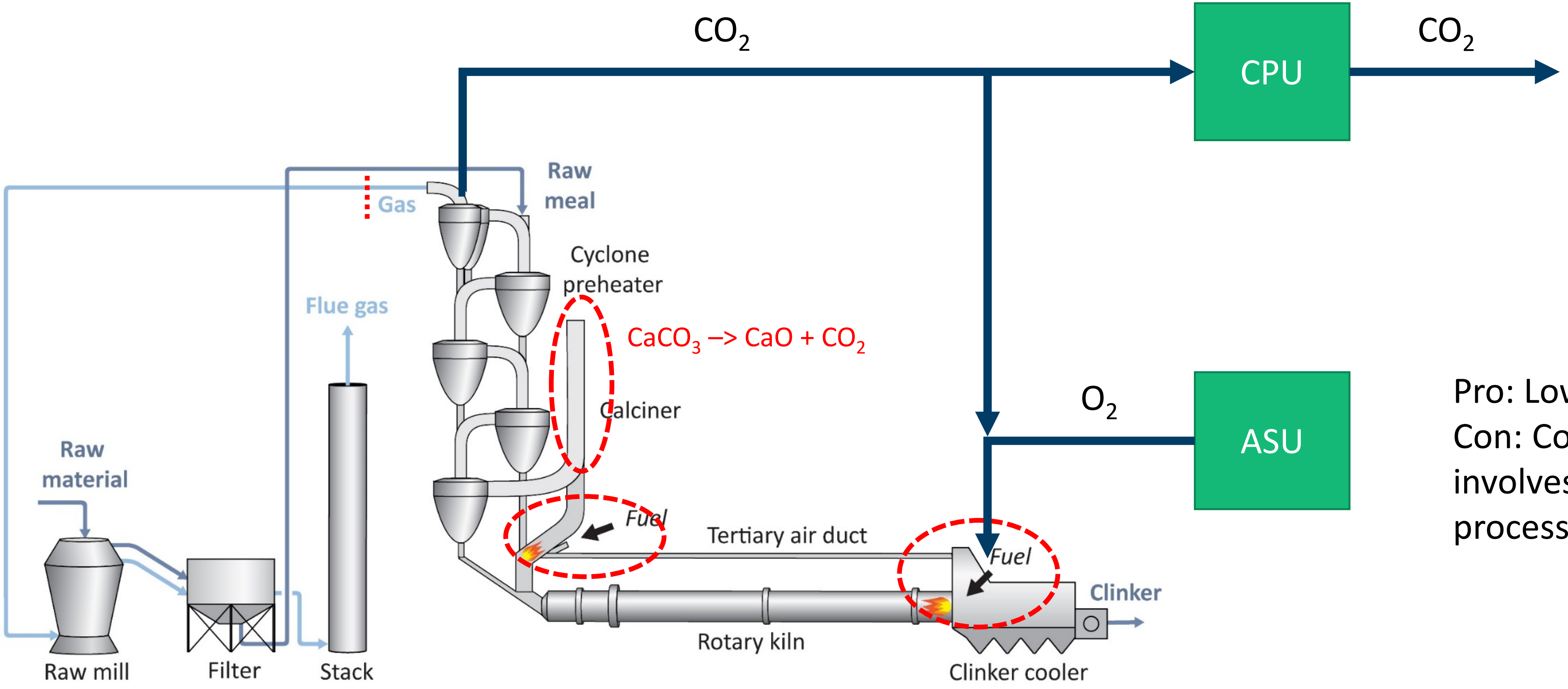
Oxyfuel cement production



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 CO_2/MWh (Statista)

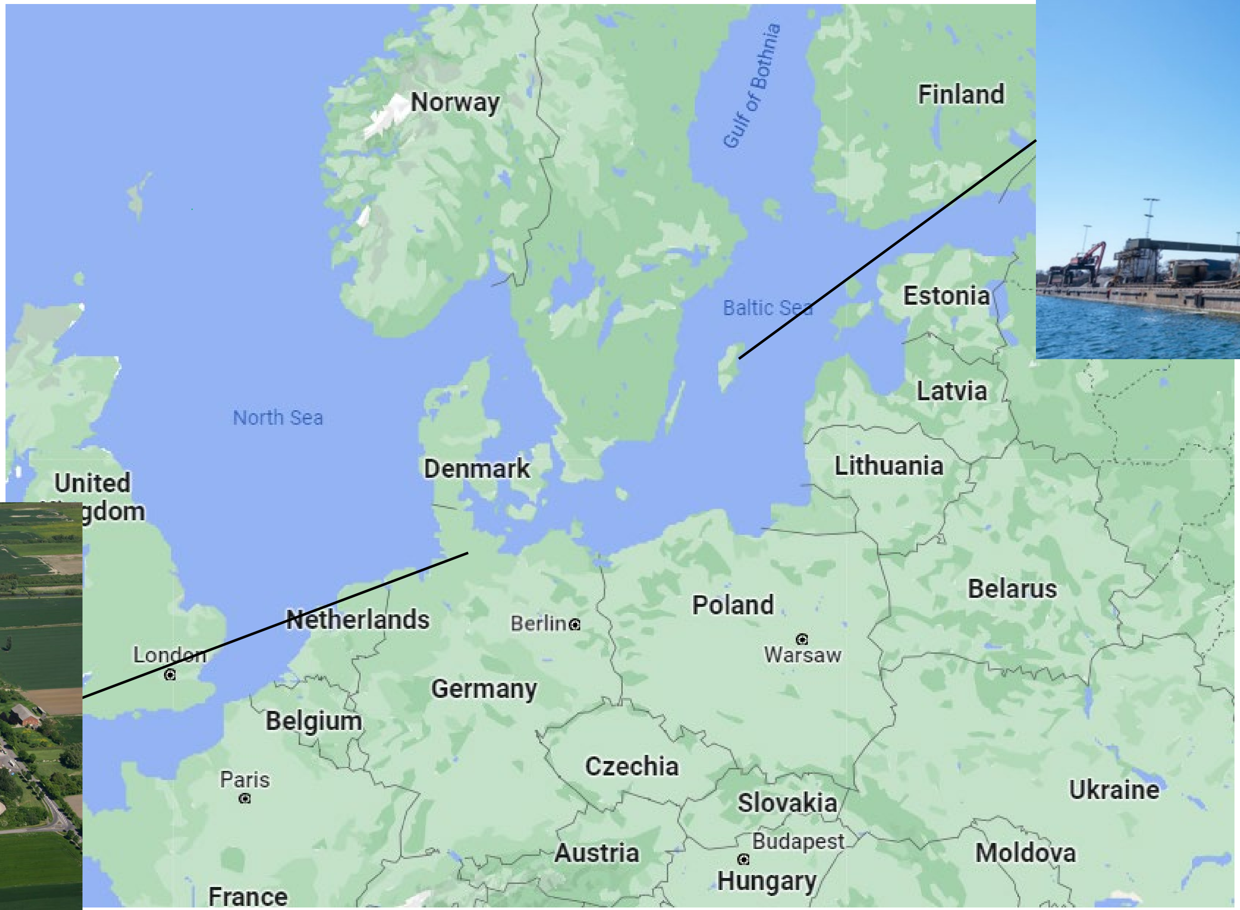

Figure: Google maps

Slite (Sweden)
HeidelbergCement
5600 tonne clinker/day
2-3% raw material moisture

Swedish el mix 2019:
44 €/MWh (Eurostat)
344 kg CO_2/MWh (Statista)

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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 CO_2 avoided without transport and storage:

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

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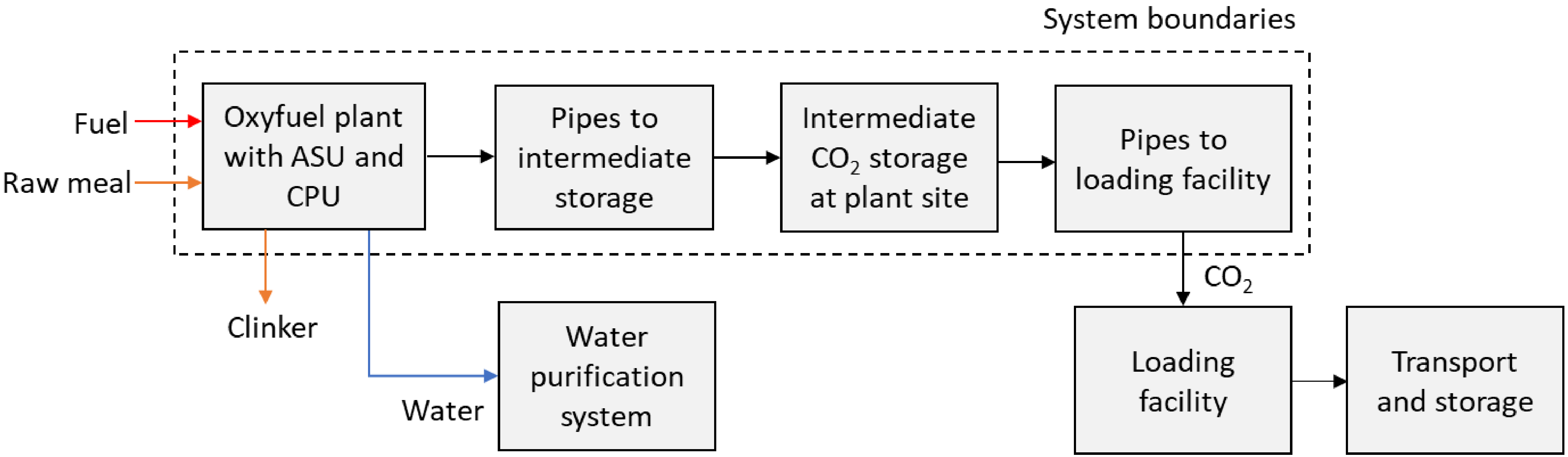
System boundaries



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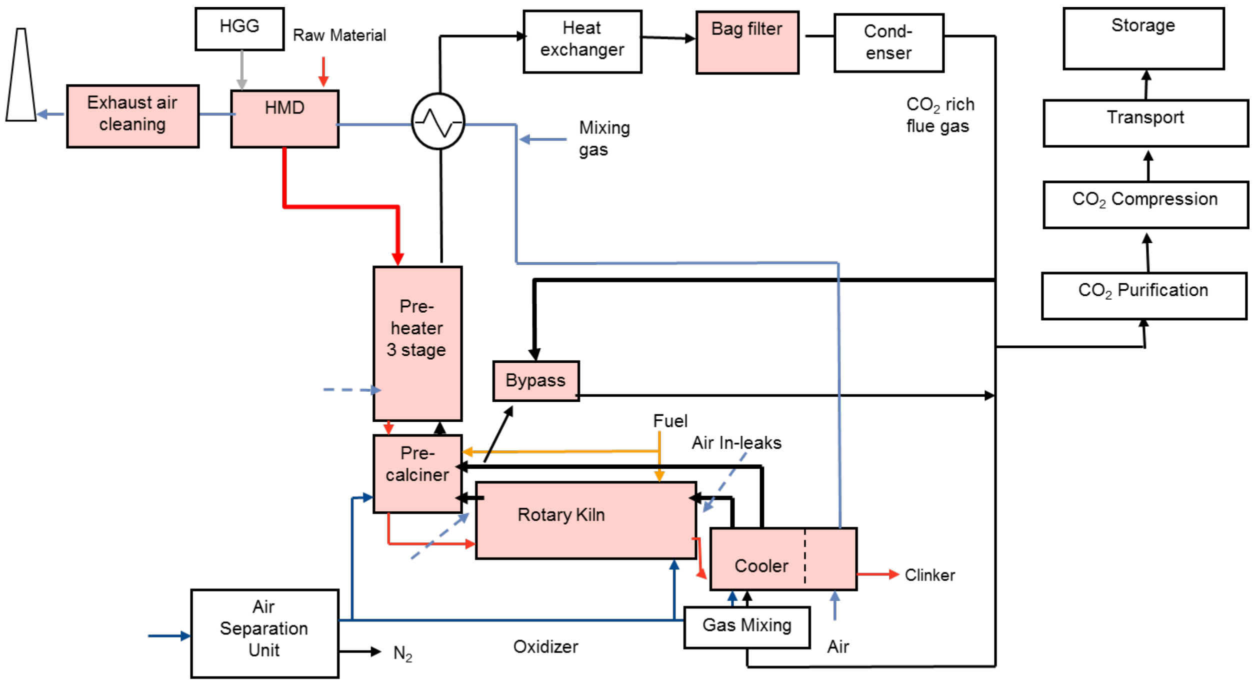
Main economic parameters

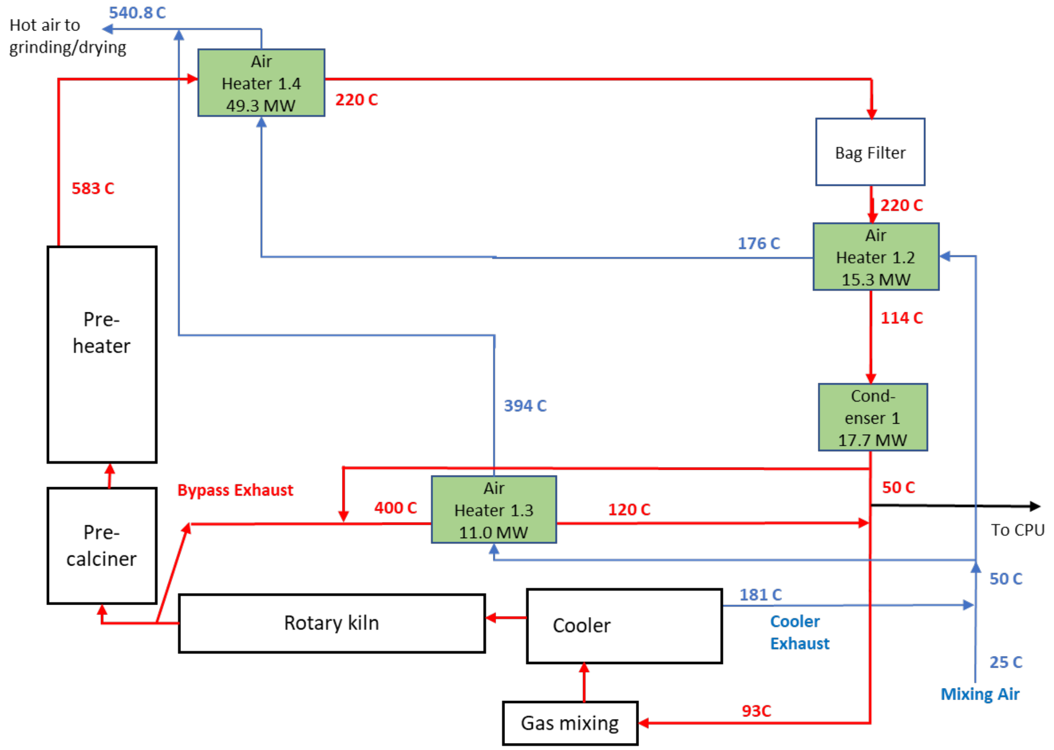
Economic parameter	Value
Cost year	2019
Discount rate	8%
Years of construction	1
Lifetime	25

Process simulation

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



SINTEF heat integration for design of heat exchanger networks



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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.

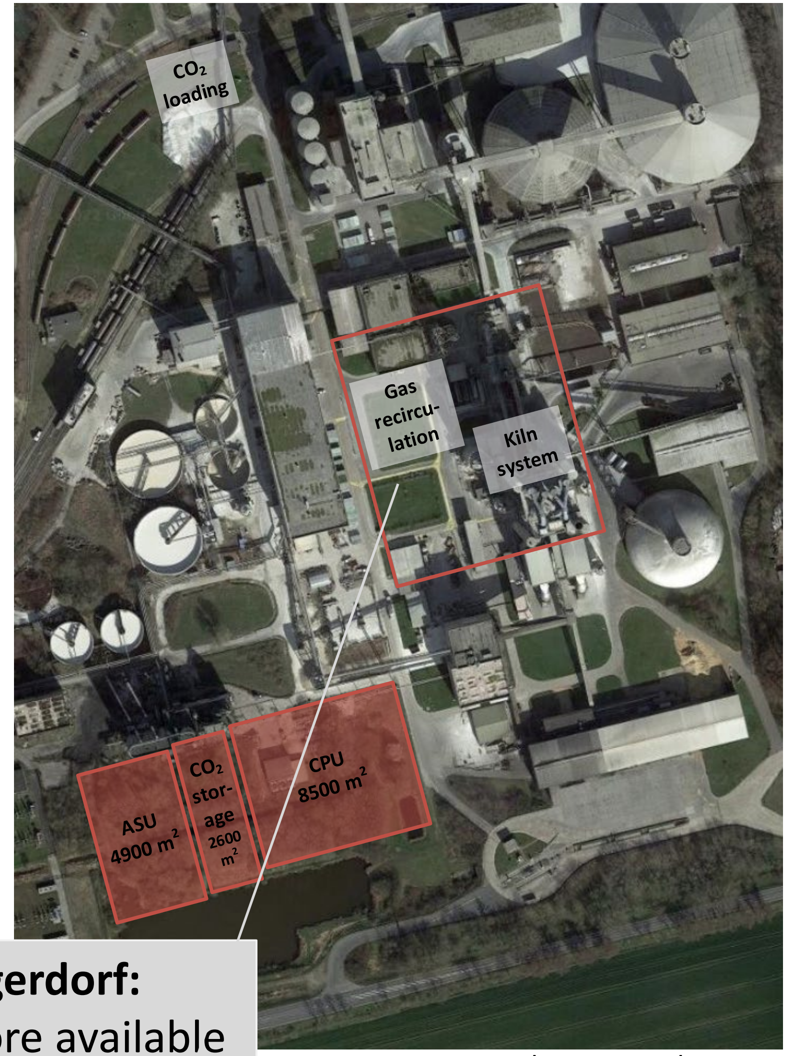

Photo: Google maps

Lägerdorf:
More available space close to kiln line.

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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 CO_2 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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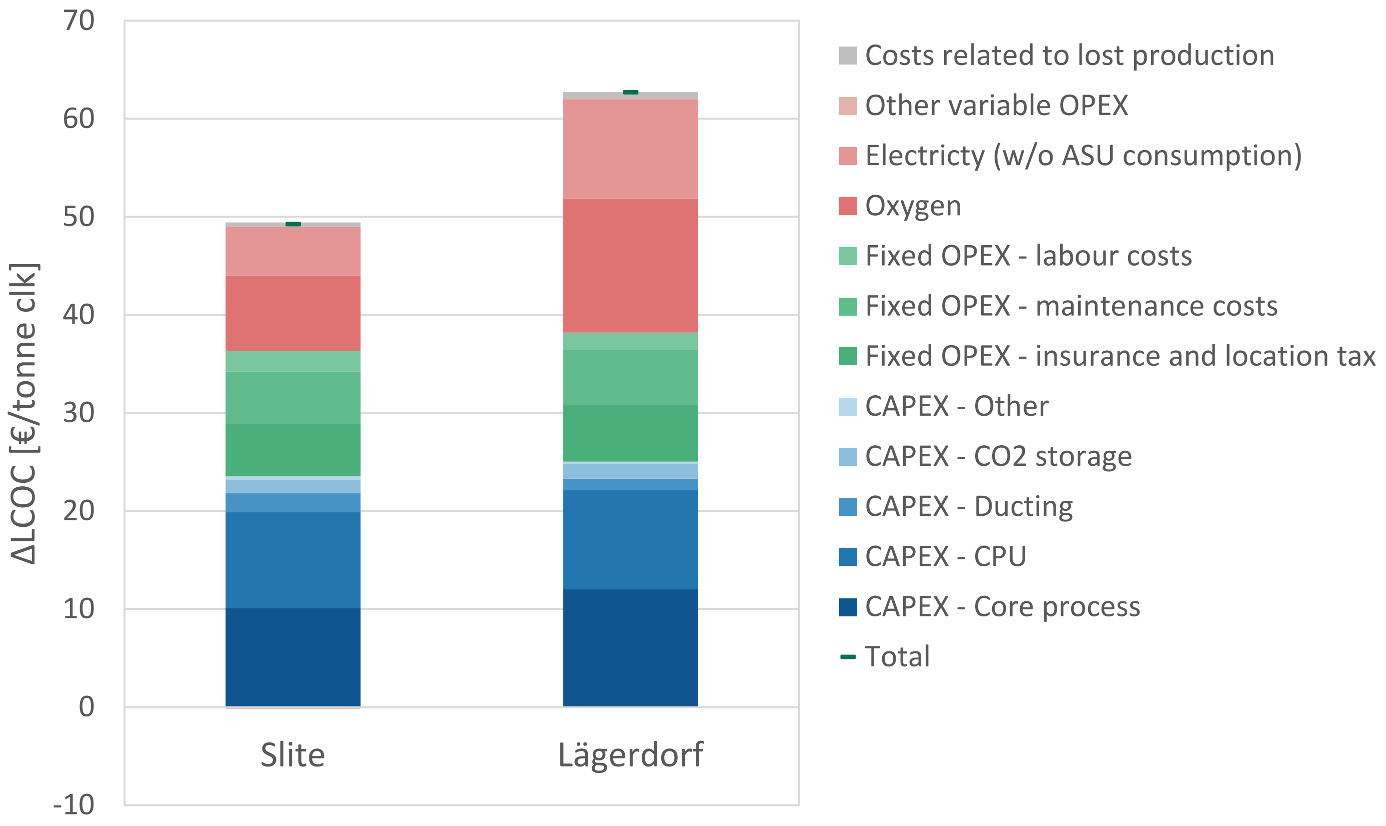
Increased levelized cost of clinker (ΔLCOC)



- 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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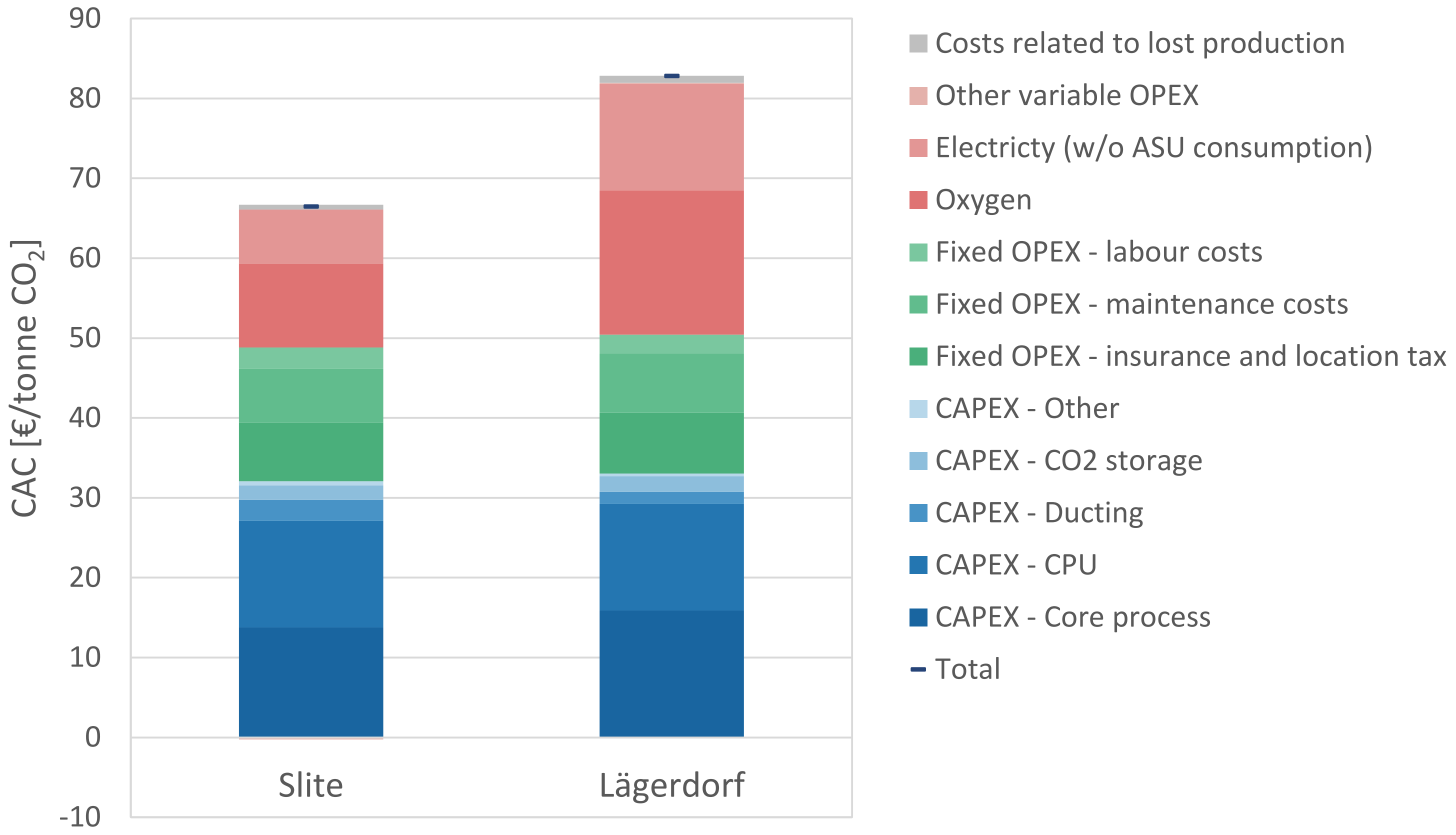
Cost of avoided CO_2 (CAC)



- Direct and indirect emissions are considered
- Lägerdorf higher CO_2 avoided than Slite due to a different process

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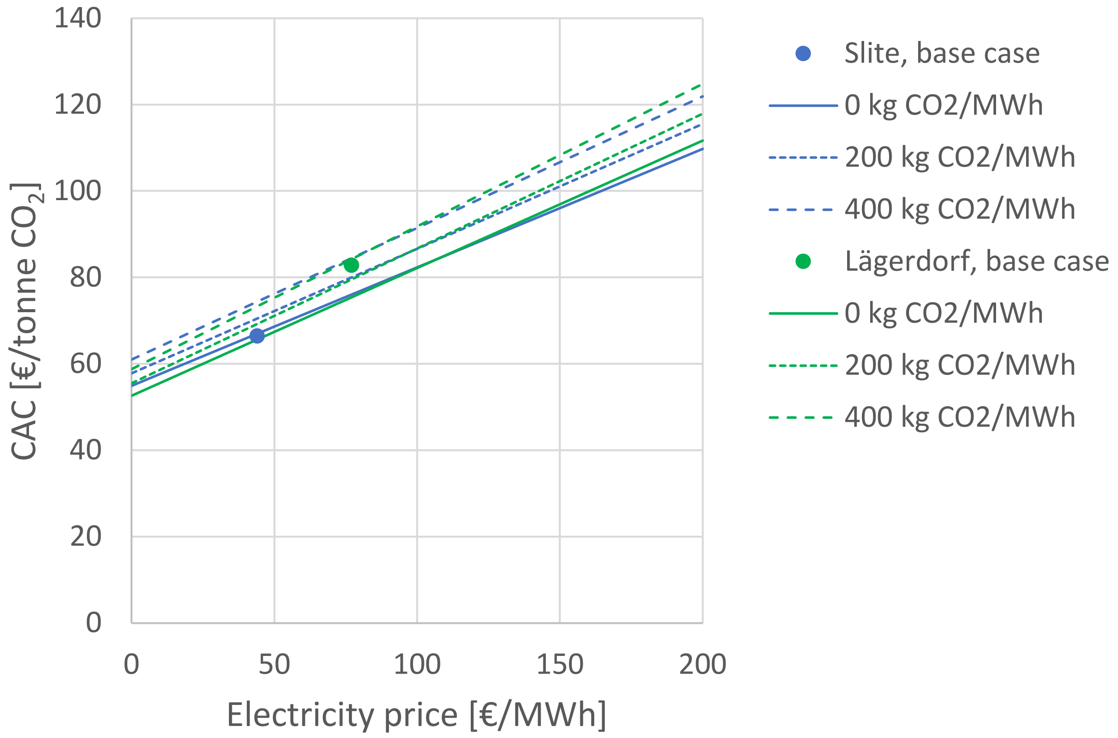
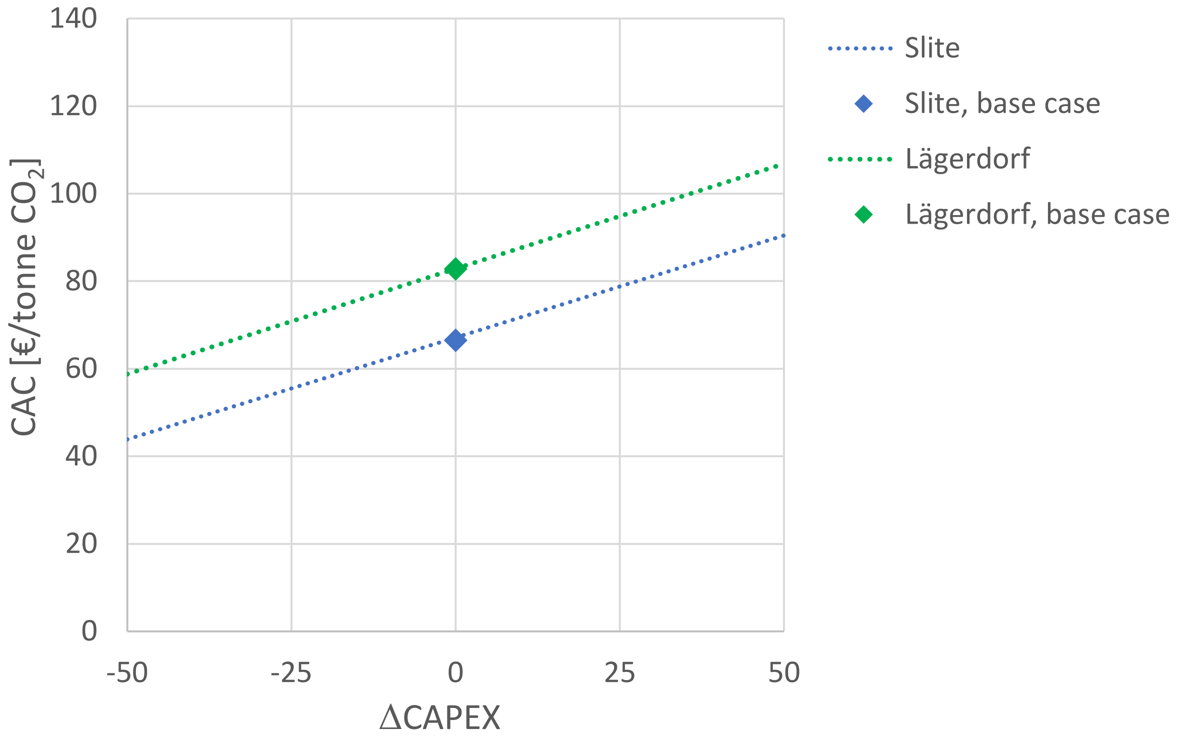
Sensitivity analysis (I)

CAC sensitivity to electricity price and CO_2 intensity
(includes impact of electricity price on oxygen cost)



CAC sensitivity to CAPEX



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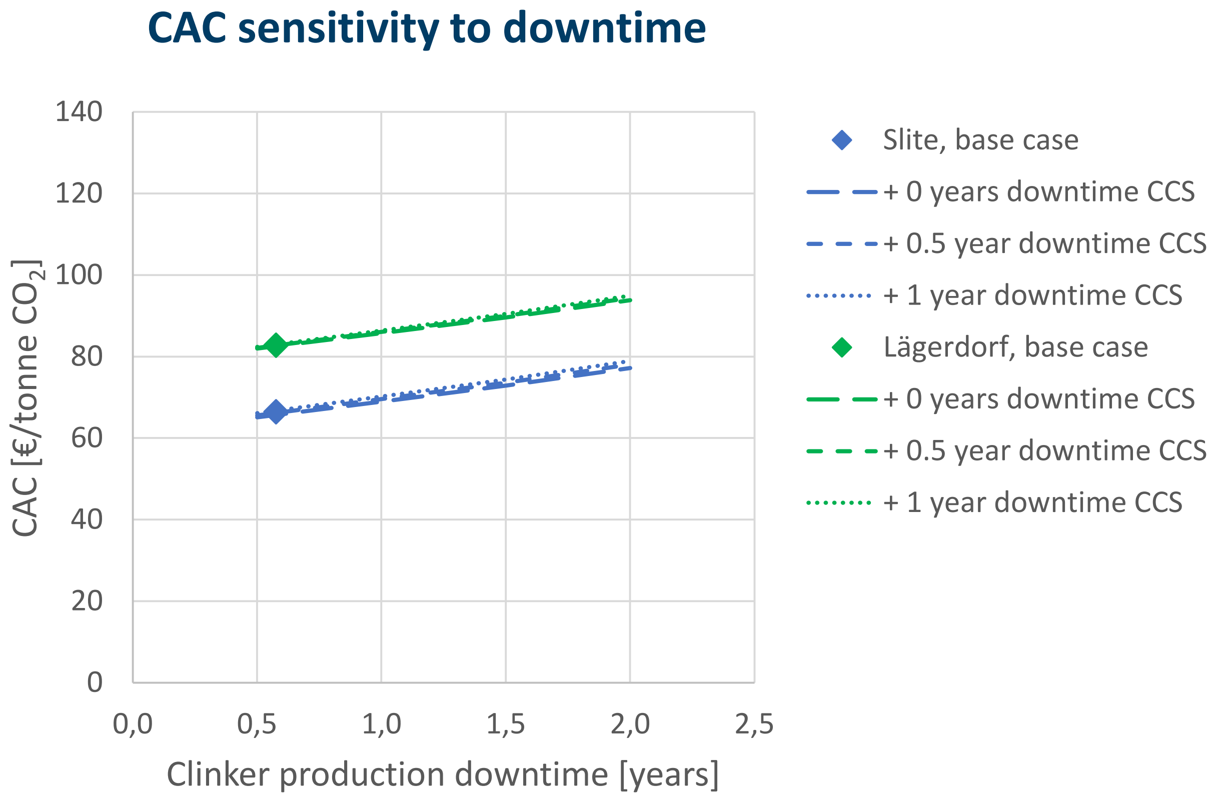
Sensitivity analysis (II)



- Downtime is a major uncertainty
  - Clinker production downtime
  - CO_2 capture downtime with clinker production
- Lost production of clinker has largest impact on CAC

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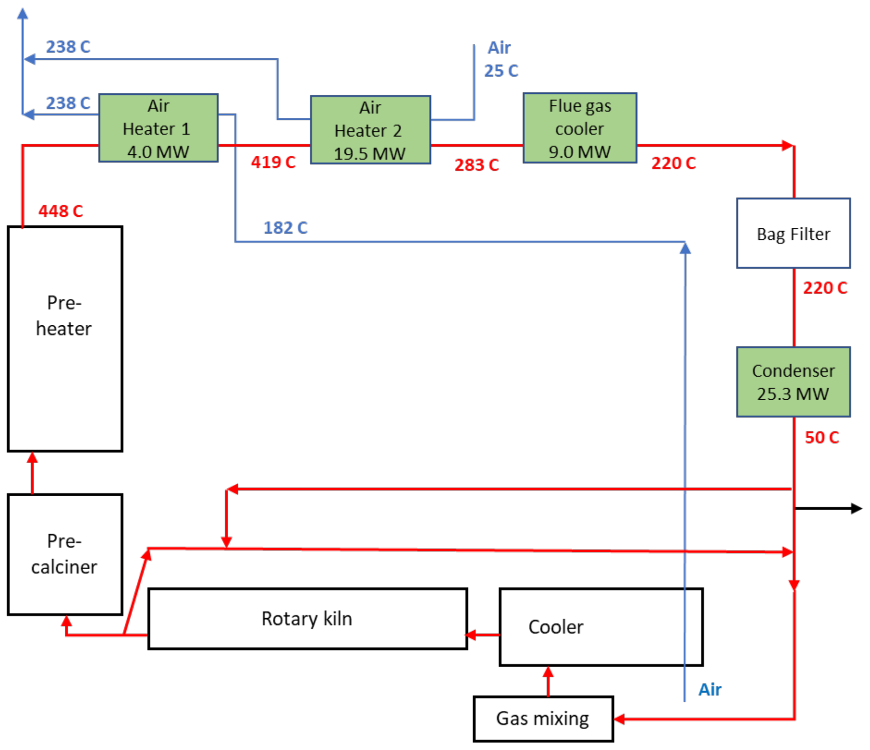
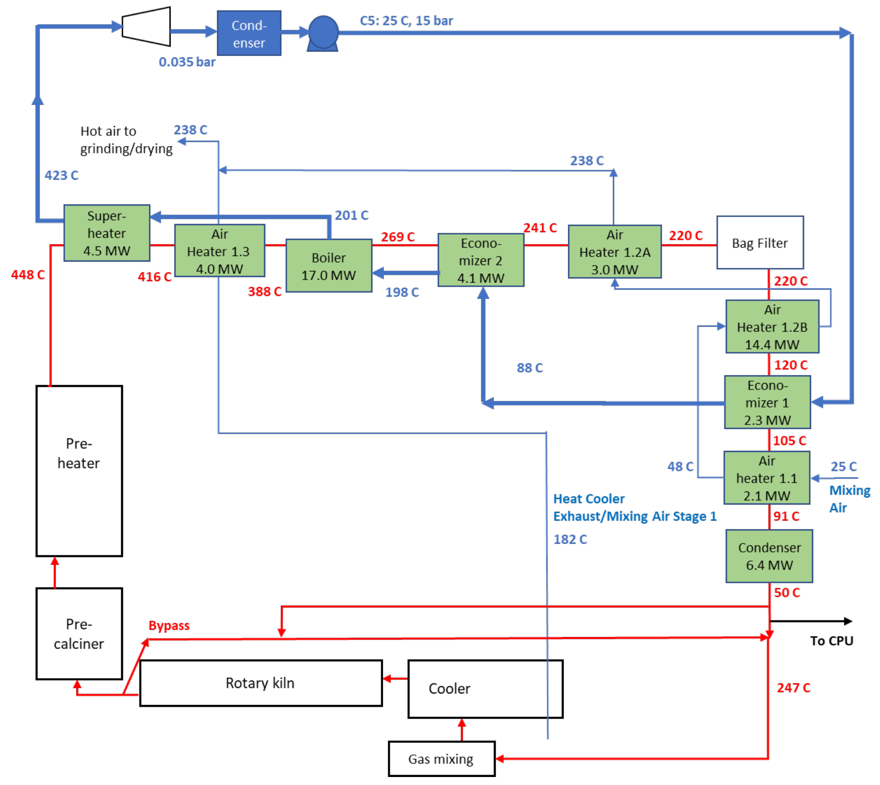
Investigation of power cycle at Slite

Without steam cycle



With steam cycle, 8.7 MW power



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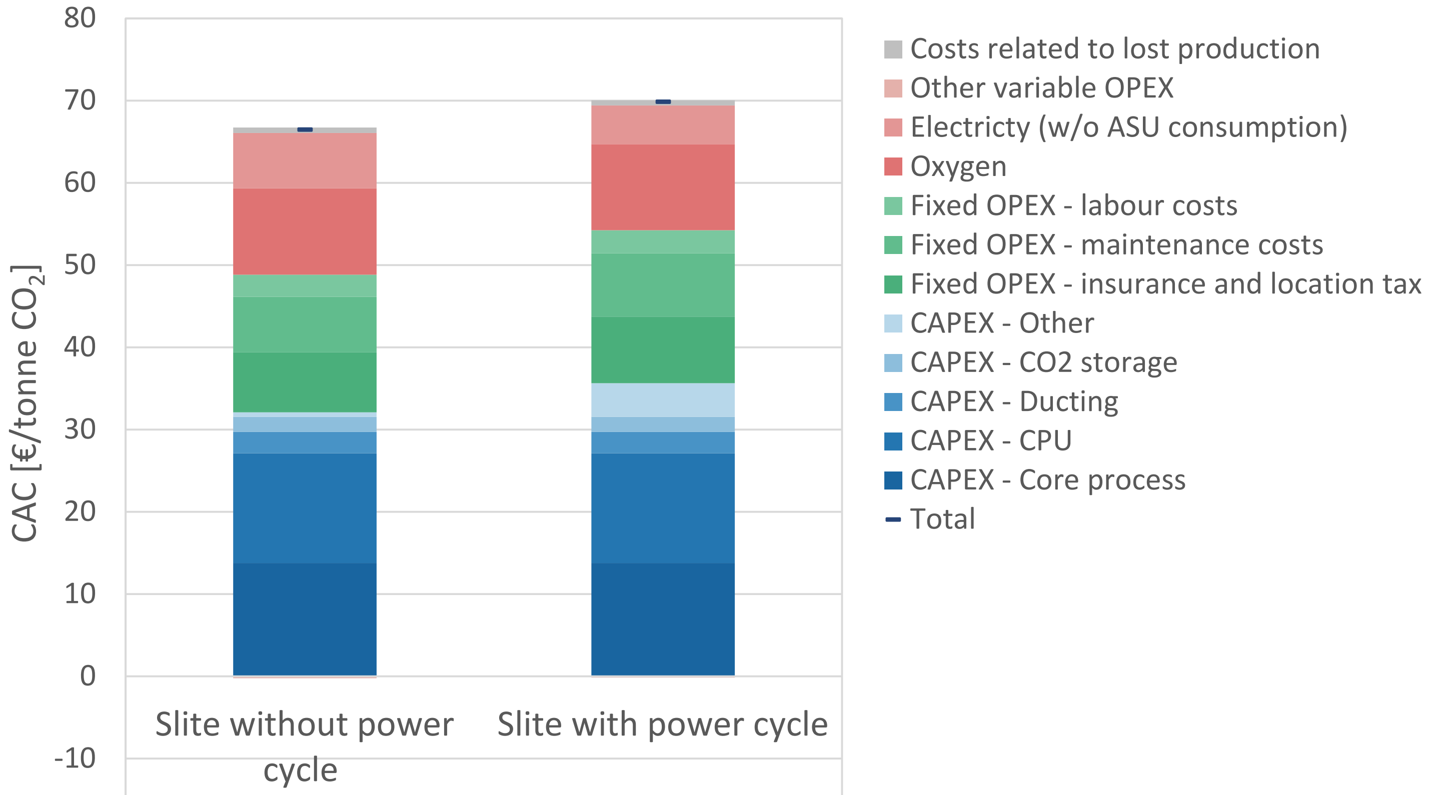
Slite heat to power cycle



- Increased CAPEX
- Reduced electricity cost
- Increased CO_2 avoided

- Base case: Sweden 2019
  - Electricity price: 44 €/MWh
  - CO_2 emission factor: 10 kg/MWh

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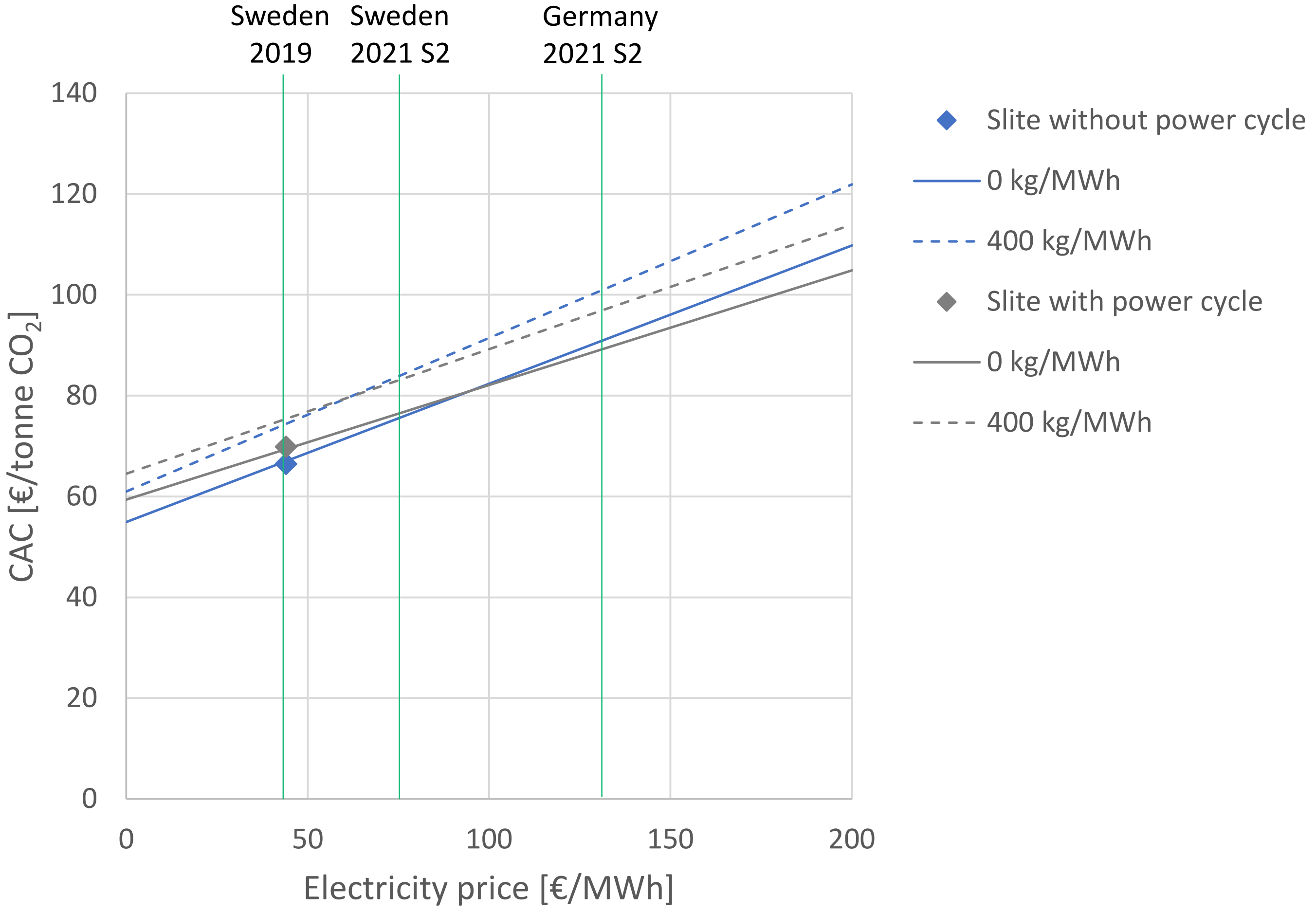
Slite heat to power cycle – sensitivity to grid conditions



- Base case: Sweden 2019
  - Electricity price: 44 €/MWh
  - CO_2 emission factor: 10 kg/MWh
- Germany 2019:
  - Electricity price: 77 €/MWh
  - CO_2 emission factor: 344 kg/MWh
- Sweden 2021 S2:
  - Electricity price: 72 €/MWh
- Germany 2021 S2:
  - Electricity price: 131 €/MWh

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 CO_2 buffer tanks are included
- Plant downtime included
- Higher O_2 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 CO_2 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

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Funding agencies

Accelerating CCS Technologies

AC^{2}OCem is funded through the ACT program (Accelerating CCS Technologies, Horizon2020 Project No 299663).

Financial contributions made from the,
•Research Council of Norway, (RCN), Norway
•Federal Ministry for Economic Affairs and Energy (BMWi), Germany
•Swiss Federal Office of Energy (SFOE), Switzerland
•General Secretariat for Research and Development (GSRT), Greece
•French Environment & Energy Management Agency (ADEME), France
are gratefully acknowledged.

ADEME
French Environment & Energy Management Agency

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

The Research Council of Norway

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Federal Office of Energy SFOE

ΕΣΠΑ 2014-2020
ανάπτυξη - εργασία - αλληλεγγύη
Partnership Agreement 2014 - 2020

GSRT
GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

European Union
European Structural and Investment Funds

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