Techno-economic evaluation of five technologies for CO$_2$ capture from cement production

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Introduction

• Motivation
  7-9% of global anthropogenic CO₂ emissions from the cement industry – CCS only viable option

• H2020 project CEMCAP
  Prepare the ground for large-scale implementation of CO₂ capture in the European cement industry
  → Understanding costs and reducing uncertainties important!
CEMCAP technologies

- Oxyfuel process
- Chilled ammonia process
- Membrane-assisted CO$_2$ liquefaction
- Calcium looping (CaL)
  - Tail-end
  - Integrated entrained flow
- Reference: MEA
Approach

• CEMCAP framework
• Reference cement kiln

• Key performance indicators
  • Specific equivalent primary energy consumption per CO₂ avoided (SPECCA)
  • Cost of clinker
  • Cost of CO₂ avoided

• Several conditions studied
  • Base case (90% capture, pipeline, steam from NG boiler)
  • Alternative cases: Low air leak, optional capture, ship transport, steam import, etc.
  • Sensitivity analysis
MEA absorption

- **Base case**
  - SPECCA: 7.1 MJ/kg\textsubscript{CO2}
  - Cost of clinker: +72%
  - Cost of CO\textsubscript{2} avoided: 80 €/t\textsubscript{CO2}
- **Cost of steam critical**
Oxyfuel process

- **Base case**
  - SPECCA: 1.6 MJ/kg\(\text{CO}_2\)
  - Cost of clinker: +49%
  - Cost of CO\(_2\) avoided: 42 €/t\(_{\text{CO}_2}\)
- **Low CAPEX and OPEX**
Chilled ammonia process

- Base case
  - SPECCA: 3.8 MJ/kgCO₂
  - Cost of clinker: +68%
  - Cost of CO₂ avoided: 66 €/tCO₂
- Lower steam and power demand than MEA
- IP protection for improved process ongoing
Membrane-assisted CO₂ liquefaction

- Base case
  - SPECCA: 3.2 MJ/kgCO₂
  - Cost of clinker: +92%
  - Cost of CO₂ avoided: 84 €/tCO₂

- Power consumption and CAPEX
- Membrane performance critical
- Low maturity → high contingency
Calcium looping – tail-end

• Base case
  • SPECCA: 4.1 MJ/kg CO₂
  • Cost of clinker: +66%
  • Cost of CO₂ avoided: 52 €/t CO₂

• Coal consumption

• Power import/export

• Dependent on integration level (IL)
Calcium looping – integrated EF

- Base case
  - SPECCA: 3.2 MJ/kg CO₂
  - Cost of clinker: +73%
  - Cost of CO₂ avoided: 59 €/t CO₂

- Lower coal demand than CaL tail-end
- Less heat recovery/power generation
- Low maturity → high contingency
Base case overview

![Graph showing cost of CO₂ avoided for different processes (MEA, Oxyfuel, CAP, MAL, tail-end, and Integrated EF). The vertical axis represents the cost of CO₂ avoided in €/tCO₂, and the horizontal axis lists the processes. Each bar is divided into segments indicating the cost contributions from steam, electricity consumption/generation, coal, raw material, other variable cost, fixed operating costs, investment, and total cost of CO₂ avoided.](Image)
Sensitivity analysis

SPECCA – electricity mix

Cost of clinker – carbon tax

CO₂ avoided – steam cost

CO₂ avoided – electricity price

Steam cost [€/MWh]

Electricity price [€/MWh]
Conclusions

- Methodology for cost evaluation developed
- Results sensitive to assumptions
- More integrated technologies more promising from cost perspective
- Other important aspects should be considered together with costs
- Final evaluation must be taken for the specific plant

Final report:
D4.6 CEMCAP comparative techno-economic analysis of CO₂ capture in cement plants

To be shared in:
https://zenodo.org/communities/cemcap/
CEMCAP Partners

Cement Producers

- Italcementi
- NORCEM
- HeidelbergCement

Technology providers

- GE
- IKI
- thyssenkrupp

R&D providers

- SINTEF
- ECRA
- TNO
- ETH Zürich
- University of Stuttgart
- Politecnico Milano
- CSIC
- vdz.

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CAPEX

- Bottom-up approach
- Standard process equipment
  - Aspen Process Economic Analyser®
  - Thermoflex
- Non-standard equipment
  - Estimates from industry partners
  - Literature
- Annualized CAPEX
OPEX

- Total opex
  - Variable opex
    - Total consumables
      - Fuel
      - Electricity
      - Raw material
    - Other variable O&M
    - Insur. and loc. tax
      - 0.02*TPC per year
  - Fixed opex
    - Maintenance cost (M)
      - 0.025*TPC per year
    - Labour
      - Maintenance labour
        - 0.4*M
      - Other maintenance cost
        - 0.6*M
      - Operating (O)
      - Adm and support
        - 0.3*(O + 0.4*M)