Carbon capture

From post-combustion capture

To direct air capture

And carbon capture and usage





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PhD in Controls from Lund University, Sweden (2005)

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Why carbon capture?

- Atmospheric concentration of CO₂ has increased by 40% relative to pre-industrial levels
- One of the major drivers for climate change
- Governments worldwide are setting targets and implementing policies to reduce CO₂ emissions
- All decarbonization technology options needed



Improved energy efficiency



Carbon-free energy sources



Carbon capture & usage



What carbon capture?





How can system simulation help?





Modelon experience

- Point Source capture
 - Post combustion capture, amine scrubbing
 - Oxyfuel
 - Integration & flexibility study
- Transport
 - Supercritical transfer pipeline
 - Normal operation & failure modes
- Direct Air Capture
 - Adsorption in catalytic beds
 - Energy requirement & controls
 - Absorption based
- CCUS
 - Techno-economical assessment
- Conventional fluegas treatment
 - SCR, scrubbers, bag filter

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Chemical Engineering

Absorption Unit

Research Article

Technology

International Journal of Greenhouse Gas Control Volume 82, March 2019, Pages 192-203

Integrating carbon capture into an industrial

with hourly and seasonal load changes

J. Åkesson 🔀 C. D. Laird, G. Lavedan, K. Prölß, H. Tummescheit, S. Velut, Y. Zhu

combined-heat-and-power plant: performance

Guillermo Martinez Castilla 🖄 🖾, Maximilian Biermann, Rubén M. Montañés, Fredrik Normann, Filip Johnsson

Nonlinear Model Predictive Control of a CO₂ Post-Combustion

First published: 27 February 2012 | https://doi.org/10.1002/ceat.201100480 | Citations: 36



Available online at www.sciencedirect.com

Energy Procedia

www.elsevier.com/locate/procedia

GHGT-10

Energy Procedia 4 (2011) 3040-3047

Dynamic simulation of a carbon dioxide transfer pipeline for analysis of normal operation and failure modes

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ical simulations have been performed for CO₂ transfer through a fictive but realistic transport pipeline in evaluate the risk of phase transition during flow transients and pipe cooling. The simulation results provide understanding of transport phenomena during transport of CO₂ from the capture point to the storage point of n capture and storage (CCS) process. Two models were developed; one to describe pressure and flow es within the transport pipeline and the other to simulate transient cooling and the generation and tion of pressure waves in the pipeline. Together these models were used to determine pressure and flow isor trip. Pipe cooling as well as during operation modes of load change, start-up, shut-down, and sor trip. Pipe cooling us solud to result in the slow formation of two-phase flow. Quick shut-down and ange led to the occurrence of two phase flow which was restricted to the vertical section of pipeline nipe) her controlline to flow through the final could valve. Durick duridom created pressure

Effects of CO₂-Absorption Control Strategies on the Dynamic Performance of a Supercritical Pulverized-Coal-Fired Power Plant

Stefanía Ó. Garðarsdóttir*†💿, Rubén M. Montañés‡, Fredrik Normann†, Lars O. Nord‡, and Filip Johnsson†



Flexibility study of a NGCC with post combustion CO2 capture

Objective

Assess the transient performance of a commercial-scale natural gas combined cycle power plant with post-combustion CO2 capture.

Results

- Validated model of the full system using Thermal Power Library and the Separation Process Library add-on
- Assessed impact of decentralized control structures on load following capability of the plant
- Controlled L/G ratio turned out to be the best choice for
 - Stable power output at part load and during load changes
 Stable CO2 capture flow
- hodelon_



Norwegian University of Science and Technology



OUTLINE

- Post-combustion CO₂ capture: modelling & integration
- Direct Air Capture
- Feasibility assessment of CCUS technologies
- Conclusion



Post-combustion CCS

- Flue-gas enters the absorption column
- CO₂ is bound to amine-based solvent, clean gas to ambience
- Carbon rich solvent enters desorber column
- Heat provided by steam from power plant
- CO₂ leaves desorber in gaseous form
- Capture rate ~90%
- Capture cost: "4MJ/kg CO2
- Nearly pure CO₂ can be compressed & stored



Petra Nova Carbon Capture in Texas, United States



Modelling approach





System example & validation



Experimental data from Esbjerg plant, R. Faber et al, Energy Procedia 4 (2011)

odelon

Validation – Technology Centre Mongstad (Norway)

- World's largest center for testing and improving CO₂ capture technologies
- Amine plant for CO₂ capture 80 ton CO₂/day
- Solvent: 30 % wt MEA
- Slipstream of flue gas from NGCC CHP plant



dolon

Montañés, R.M.; Flø, N.E.; Nord, L.O. Dynamic Process Model Validation and Control of the Amine Plant at CO₂ Technology Centre Mongstad. Energies 2017, 10, 1527.



R.M. Montañés, S.Ó. Garðarsdóttir, F. Normann, F. Johnsson, L.O. Nord, Demonstrating load-change transient performance of a commercial scale natural gas combined cycle power plant with post combustion CO₂ capture, International Journal of Greenhouse Gas Control, 2017, 63, pp. 158-174



Accelerating integration studies

- For smooth integration studies, end-users need to
 - easily adapt the capture plant size
 - change the solvent type & properties
 - do parametric study
- Ongoing work at Modelon to
 - Initialize model from a previous result
 - Efficiently run parametric study
 - Scale-up/down capture plant
 - Support other solvent & chemistry



Working with large models

Being able to initialize large models from a previous simulation result is critical for 3 reasons

- Robustness bad initialization can lead to simulation problems
- Performance significant time is normally spent in the initial transient
- Relevance initial transient is normally not of interest

A custom function has been derived to start from a previous simulation result. Possible to combine with multi-execution. Apply output filter!

Model	Before	After	Speed-up
CO ₂ capture plant	30 s	~7 s	4
Combined cycle power plant	3,5 min	0,5 min	7







MJ/kgCO2





Scale-up of power plant & capture plant

2023.X

- Pressure & temperature levels roughly constant
- Find parameters with linear impact on power output
 - Heat transfer area
 - Nominal flow rates
 - Length (e.g. drum)
- Introduction of top-level scaling parameter





Supporting different solvents & chemistry

2023.X

Scrubber model has been used in different contexts

Application	Solvent	Solute
Point source carbon capture	MEA	CO2
Flue gas treatment	NaOH	SO2, HCl
Direct Air Capture	КОН	CO2

Ongoing work to unify the implementations and cover more use cases in the CCS context



Direct Air Capture

• Catalytic beds (released)

• Absorbers (ongoing work)







2022.1 content



Pressure and temperature swing

ThermalPower.Experiments.AdsorptionCycleCO2FromAir

Energy, CO2 & H2O balance for a cyclic DAC process

- Adsorption:
 - Air flows through bed
 - Ambient temperature & pressure
- Desorption:
 - Vacuum
 - Heating with liquid
 - Steam to heat up and flush remaining CO2

Patent WO 2016/005226 A1 "Steam assisted Vacuum Desorption Process for Carbon Dioxide Capture"



Carbon Capture & Usage – Feasibility Assessment

- Still skepticism around technology
- Uncertainty around cost & benefit
- Need for tool for techno-economic assessment
- Many different use cases
- Systematic approach desired



Carbon capture components

2022.2 & 2023.1

- Microgrid package extended with
 - Computation of CO₂ production wherever hydrocarbon combustion occurs
 - CCS component parameterized by
 - Cost
 - Efficiency
 - Energy requirement
 - CCUS component
 - Similar parametrization as CCS
 - Additional H₂ and CH₄ ports
 - Carbon tax for all emitted CO₂





Economy models

• CapEx and OpEx added to all components

• Automatic summation of the cost

- Allows technology assessment w.r.t. various KPIs
 - CapEx, OpEx, Total cost of ownership, Net Present Value, pay-back time



2022.2

content

Technology selection towards carbon neutrality

- Case study with a Japanese car manufacturing company
- Paper at upcoming Asian Modelica Conference
- Total Cost of Ownership minimization, targeting carbon neutrality
- Technology options
 - *1. CCS vs. CCUS vs. carbon tax* to deal with the emissions from the combustion processes
 - 2. Import versus on-site generation for hydrogen and power
 - 3. Conventional burner versus heat pump for drying process





CONCLUSION

• Carbon capture and utilization has been identified as key technology to achieve climate goals

- Modelon is working on different fronts to support the adoption of the technology
 - Feasibility assessment initial and promising work
 - Post-combustion carbon capture well-proven models, ongoing effort for a higher applicability & user-friendliness
 - Direct Air Capture several ongoing projects

