Carbon capture

From post-combustion capture

To direct air capture

And carbon capture and usage

Modelon

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PhD in Controls from Lund University, Sweden (2005)

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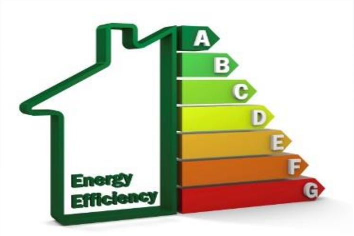
Why carbon capture?

- Atmospheric concentration of CO_2 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 CO_2 emissions
- All decarbonization technology options needed

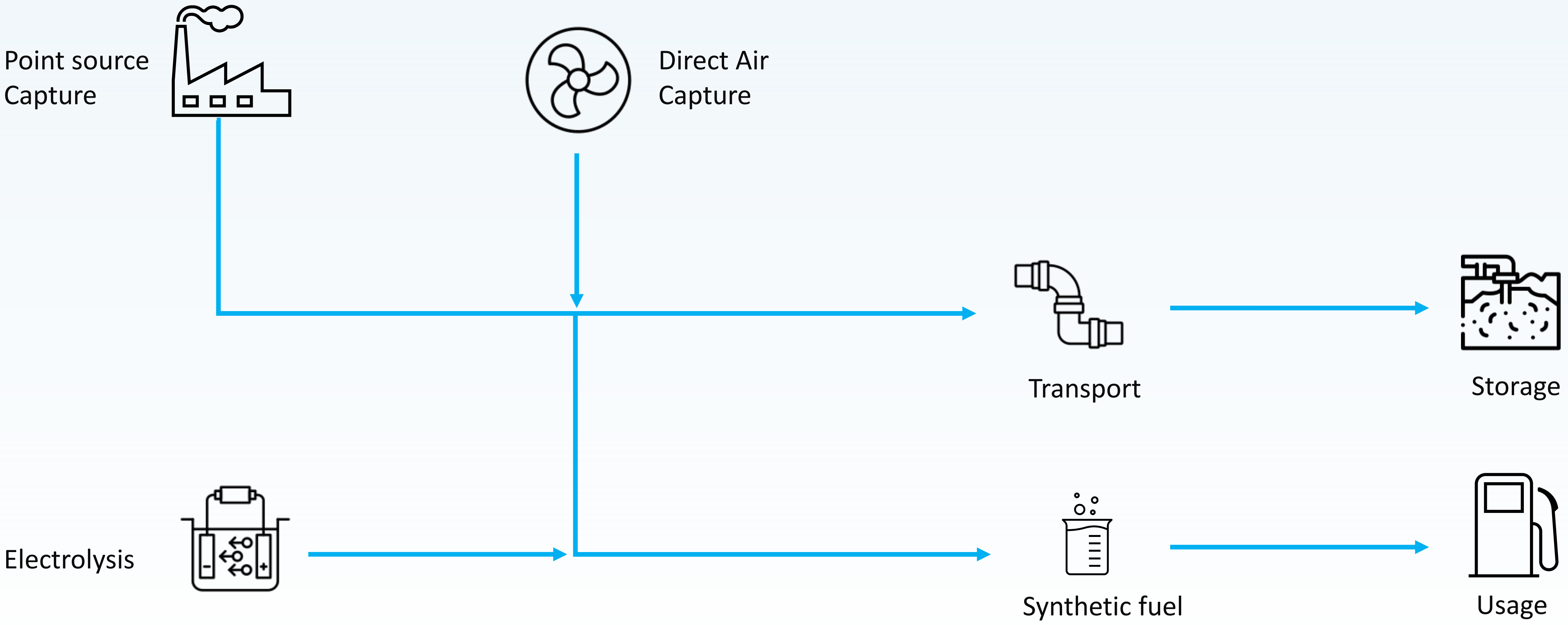


Improved energy efficiency

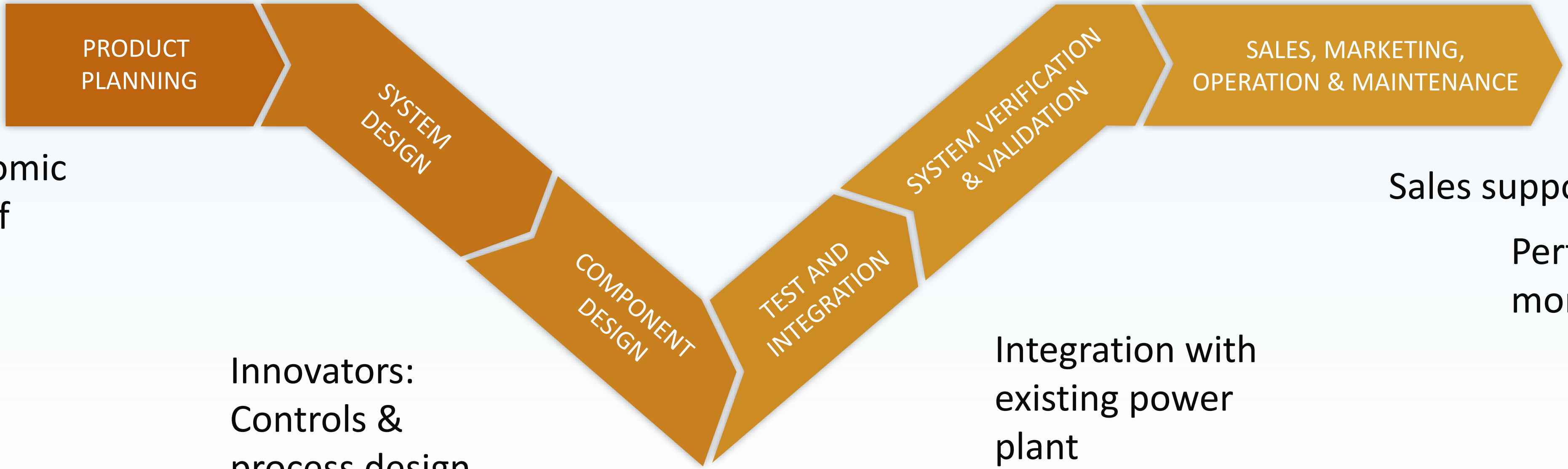
Carbon-free energy sources

Carbon capture & usage

What carbon capture?



How can system simulation help?



Techno-economic assessment of DAC/CC(U)S

Innovators: Controls & process design

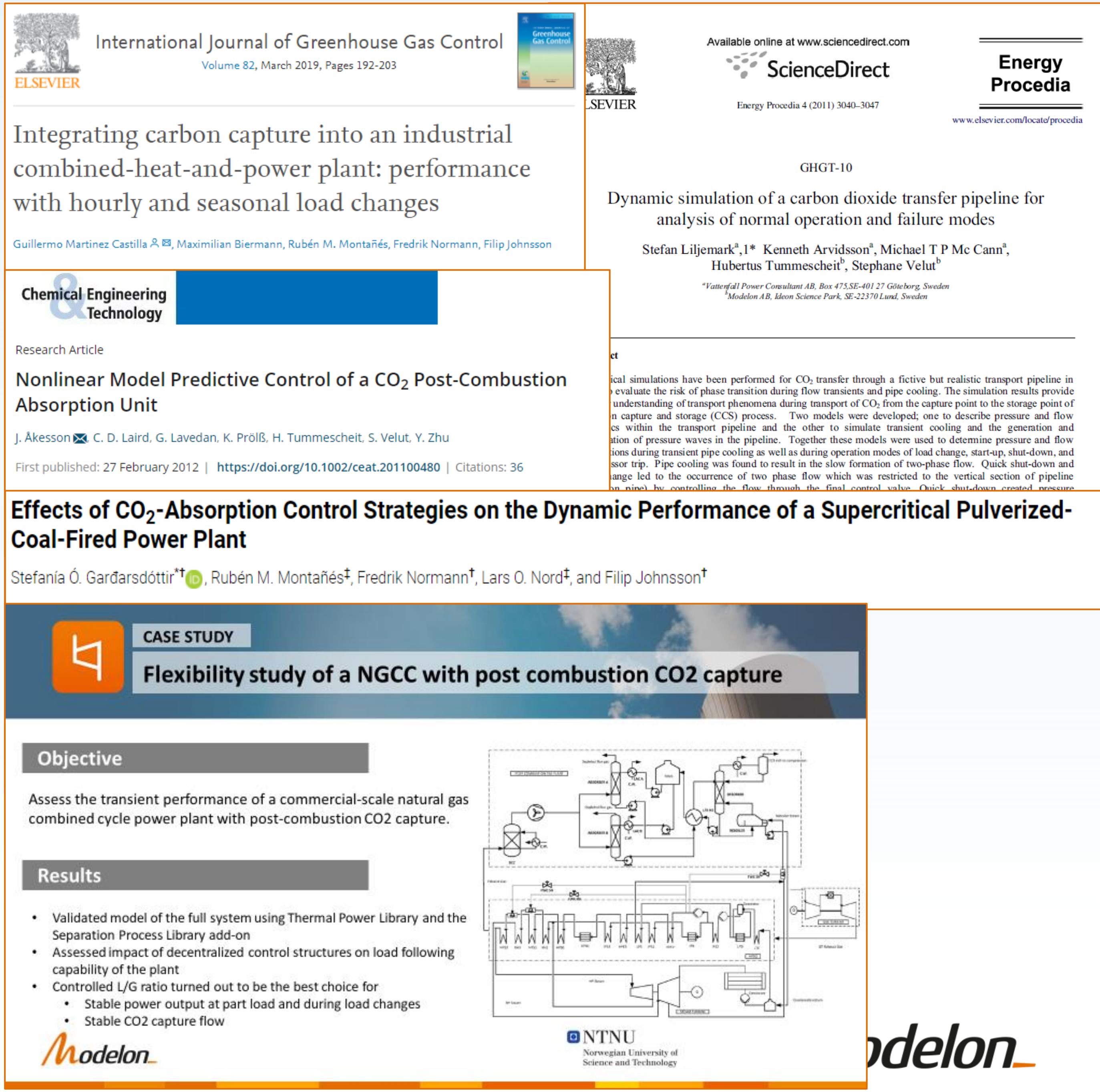
Integration with existing power plant

Sales support

Performance monitoring

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



OUTLINE

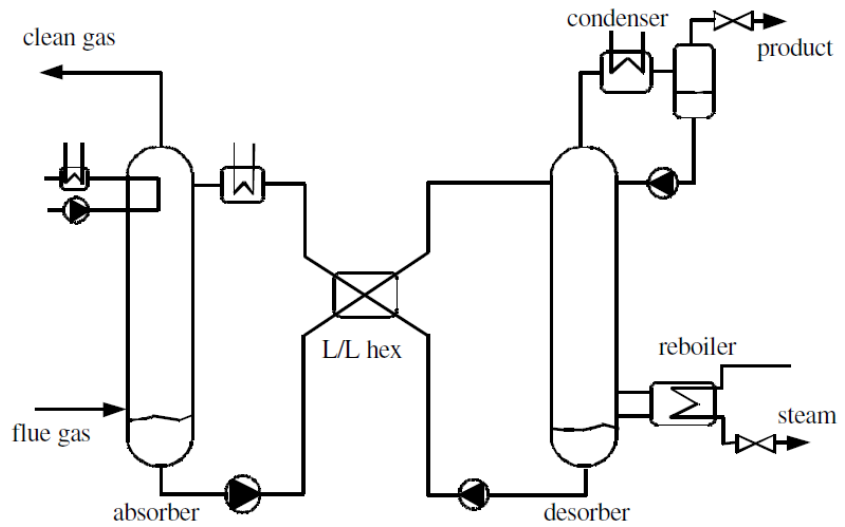
- Post-combustion CO_2 capture: modelling & integration
- Direct Air Capture
- Feasibility assessment of CCUS technologies
- Conclusion

Post-combustion CCS

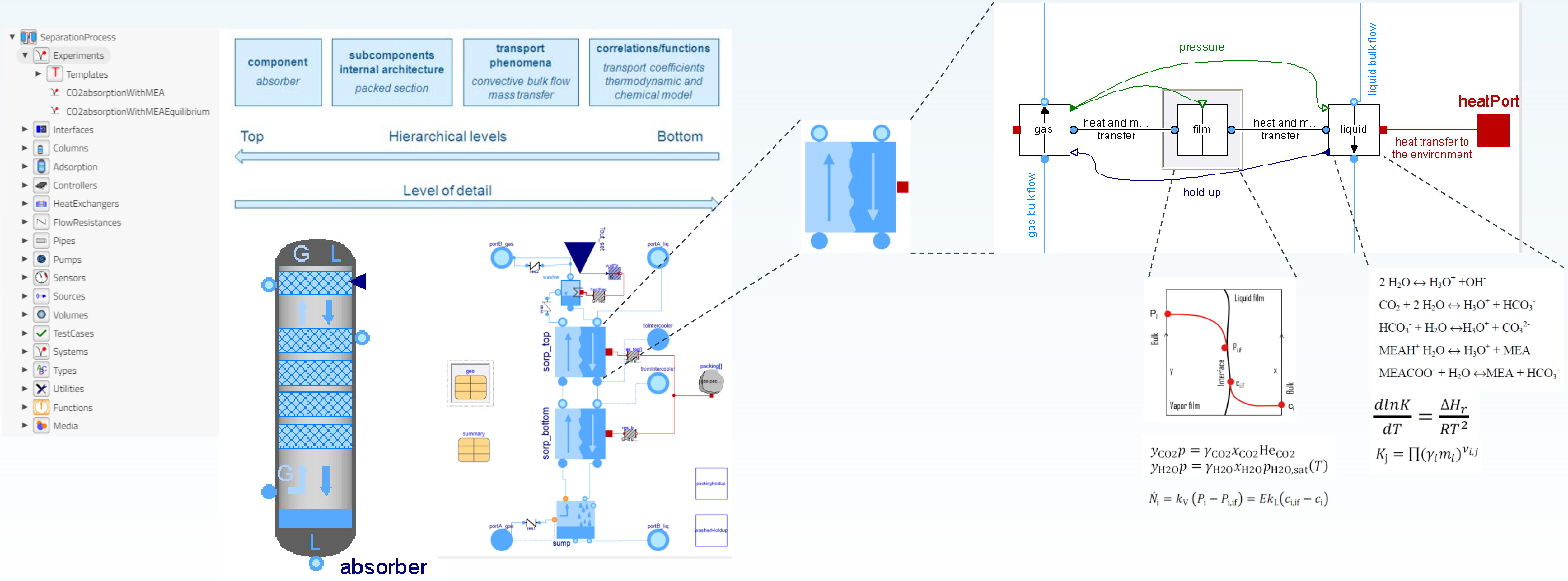
- Flue-gas enters the absorption column
- CO_2 is bound to amine-based solvent, clean gas to ambience
- Carbon rich solvent enters desorber column
- Heat provided by steam from power plant
- CO_2 leaves desorber in gaseous form

- Capture rate ~90%
- Capture cost: ¨4MJ/kg CO2
- Nearly pure CO_2 can be compressed & stored

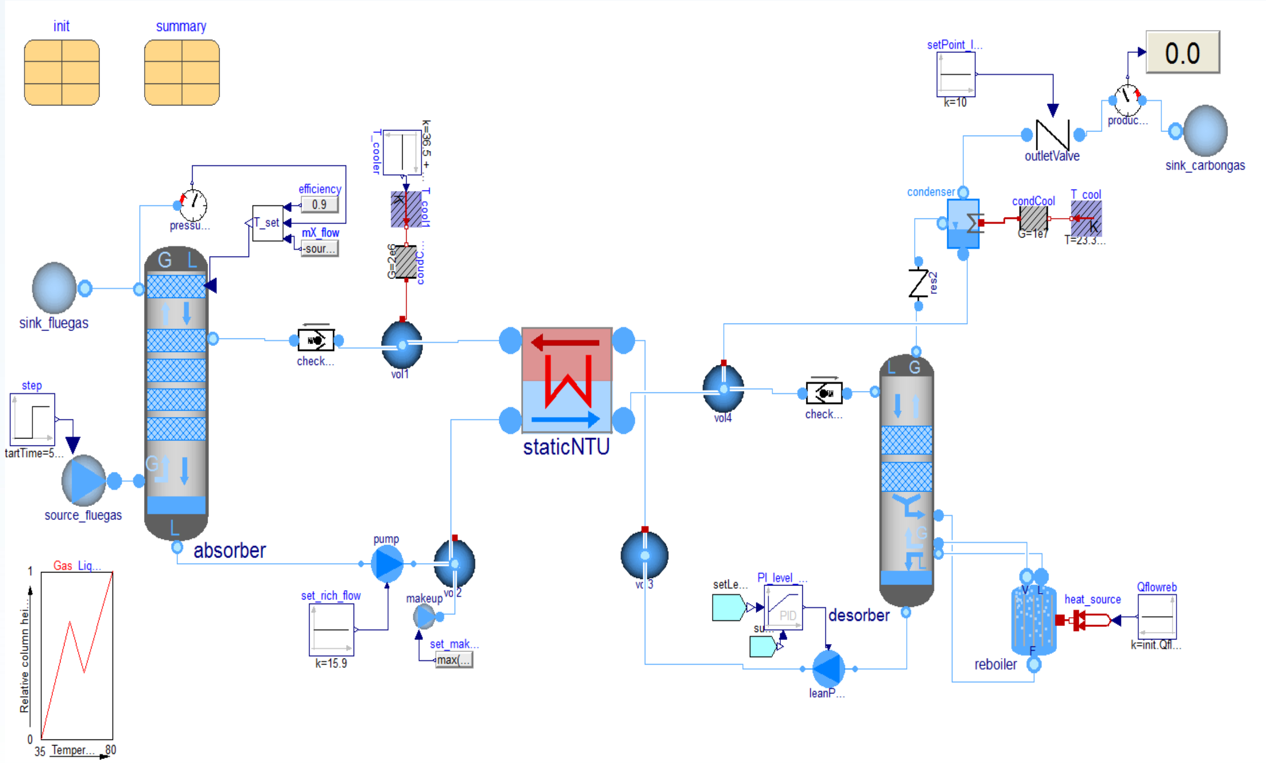
Petra Nova Carbon Capture in Texas, United States

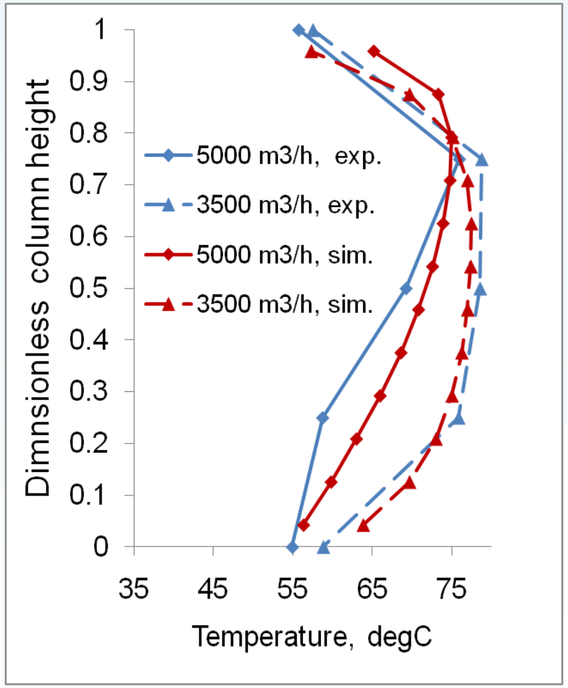


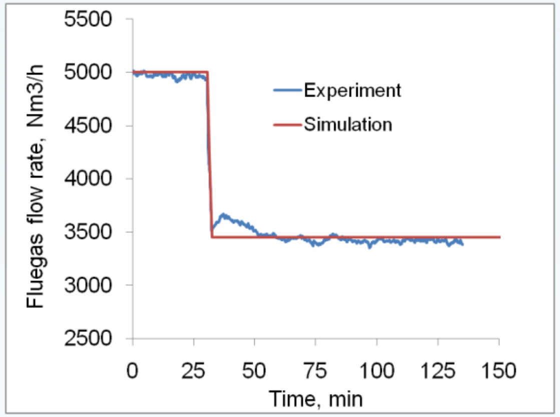
Modelling approach

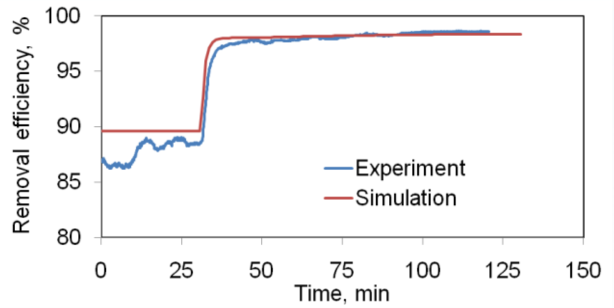


System example & validation









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

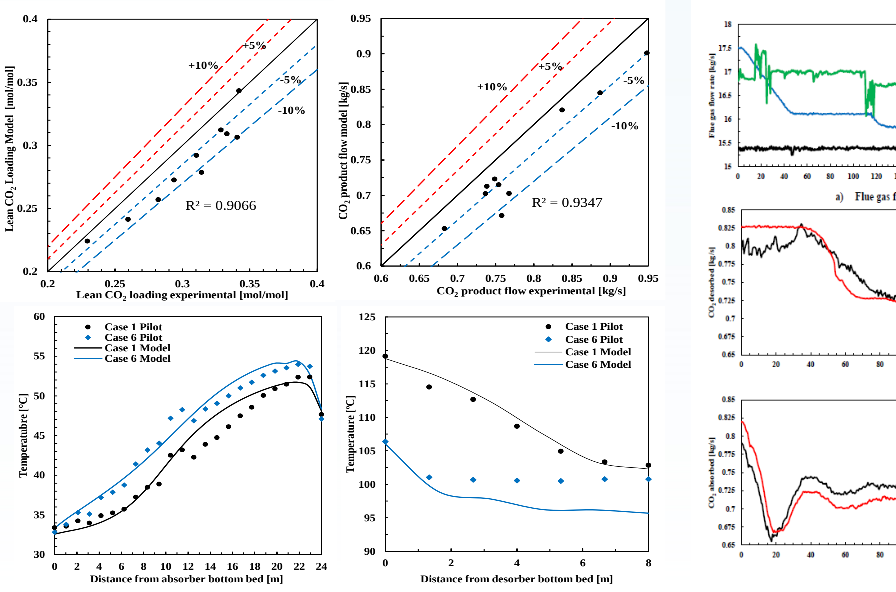
Validation – Technology Centre Mongstad (Norway)

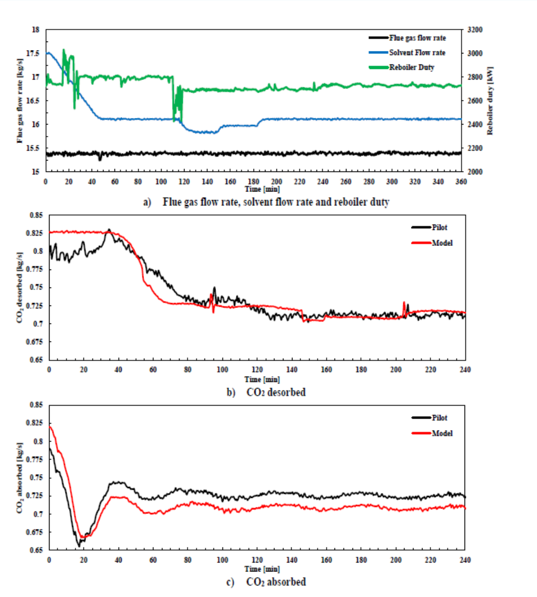
- World's largest center for testing and improving CO_2 capture technologies
- Amine plant for CO_2 capture 80 ton CO_2/day
- Solvent: 30 % wt MEA
- Slipstream of flue gas from NGCC CHP plant

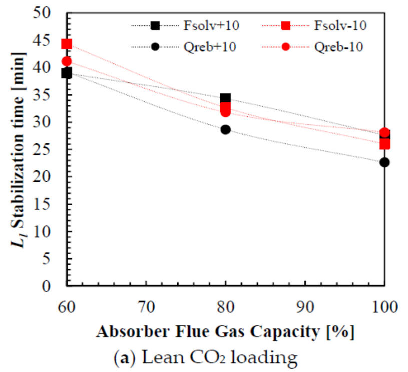
Installed amine-based Post combustion CO_2 capture process at TCM

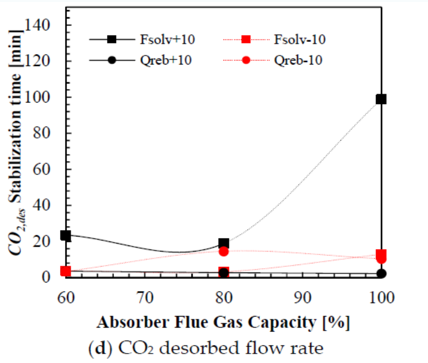
Source: http://www.climit.no/en/success-for-climit%E2%80%99s-largest-project

NTNU
Norwegian University of Science and Technology









Montañés, R.M.; Flø, N.E.; Nord, L.O. **Dynamic Process Model Validation and Control of the Amine Plant at CO_2 Technology Centre Mongstad**. *Energies* **2017**, *10*, 1527.

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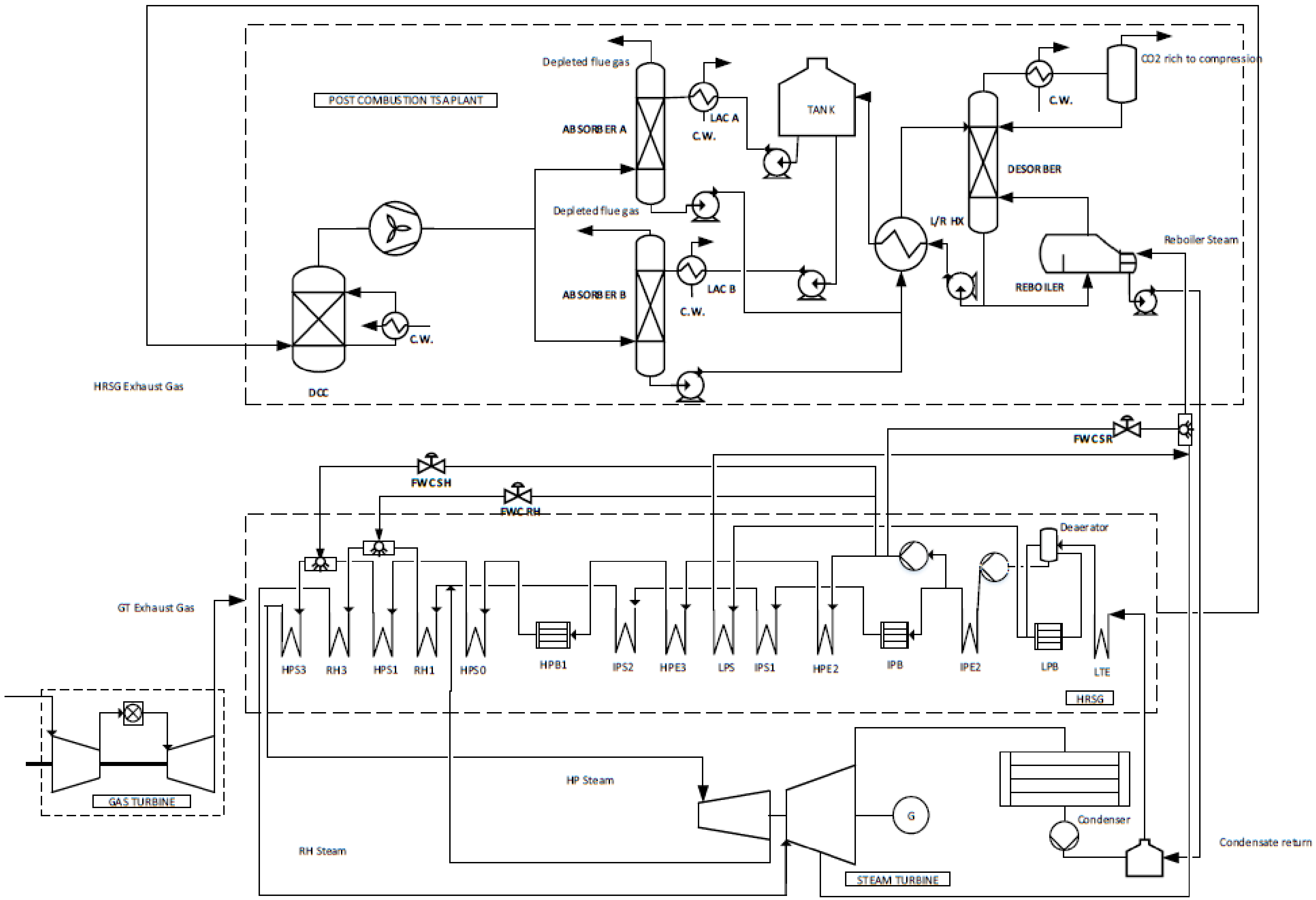
Integration study

i) Process configuration
Process integration between power plant and post-combustion system

ii) Dynamic process models
Detailed dynamic process models of power plant and PCC unit

iii) Dynamic process simulations
Simulation of linked process models



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 CO_2 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

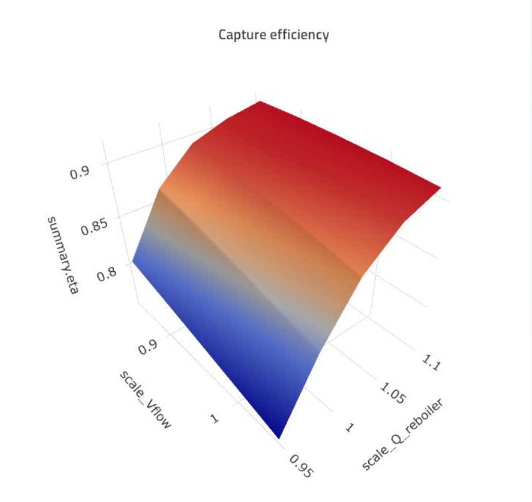
DEMO

2023.1

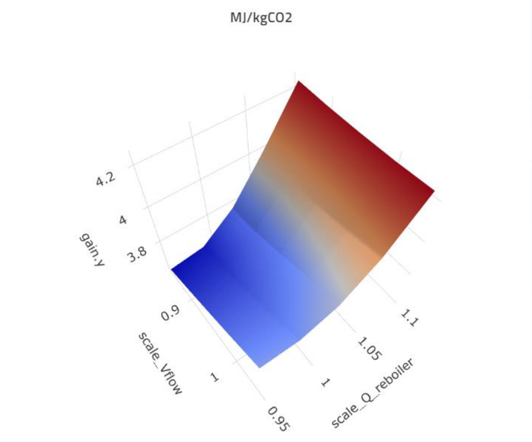
Working with large models

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

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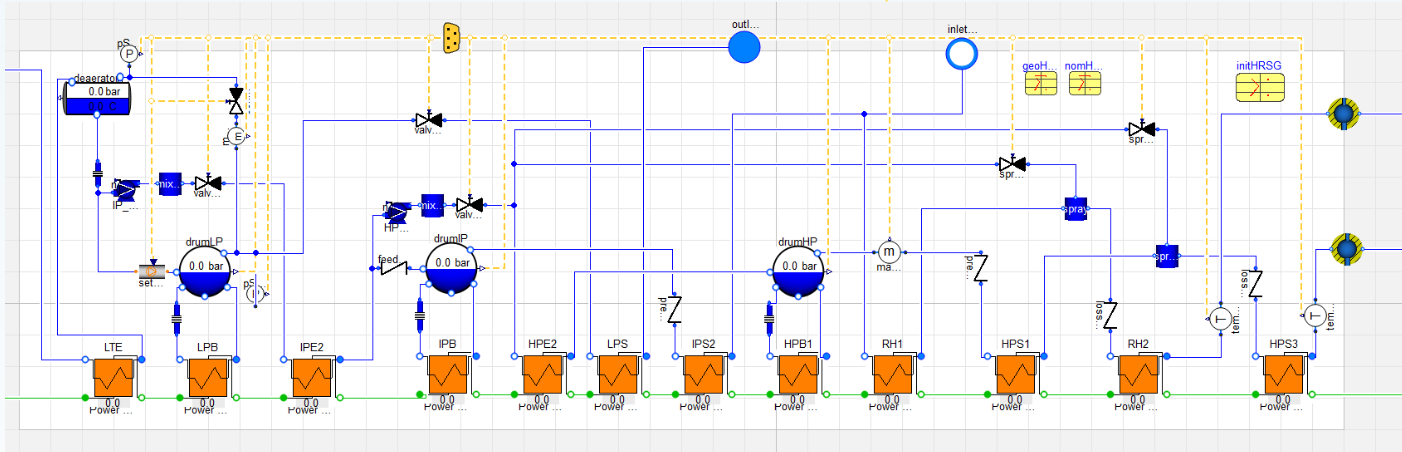
Scale-up of power plant & capture plant

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

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Scrubber model has been used in different contexts

Application	Solvent	Solute
Point source carbon capture	MEA	CO_2
Flue gas treatment	NaOH	SO_2, HCl
Direct Air Capture	KOH	CO_2

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

Direct Air Capture

- Catalytic beds (released)
- Absorbers (ongoing work)

Direct Air Capture package

2022.1
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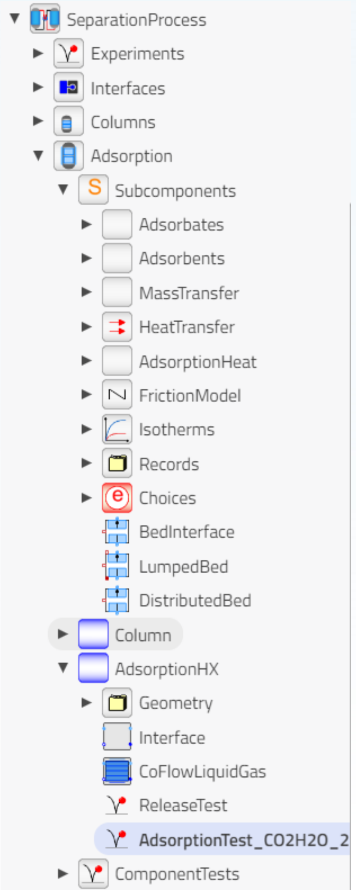
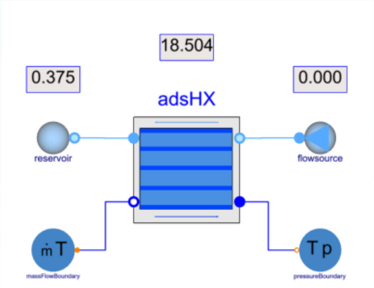
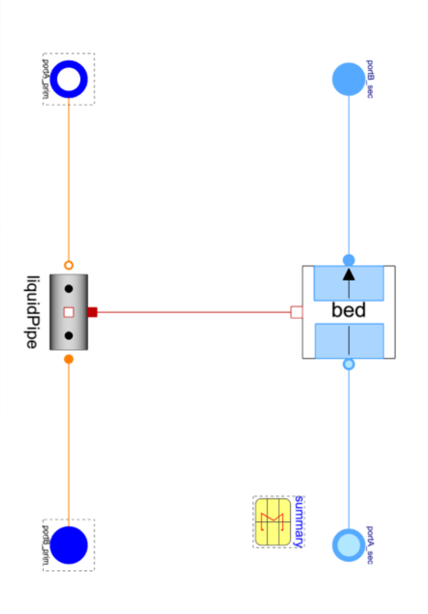
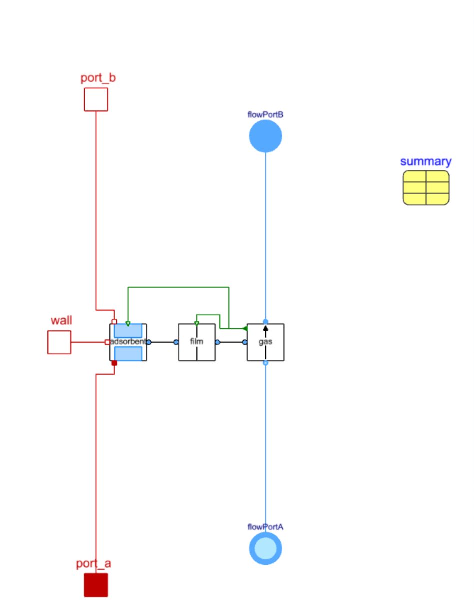




Adsorption heat exchanger



Cooling pipes & catalytic bed



Solid catalyst – film – gas volume

- Adsorbents
  - Activated carbon
  - Zeolite 13X
- Adsorbates: CO_2 (and H_2O)
- Various isotherms
  - Toth (single adsorbate)
  - IAS (multiple adsorbates)
  - RLBET (multiple adsorbates)
- Heat of adsorption

DEMO

Pressure and temperature swing

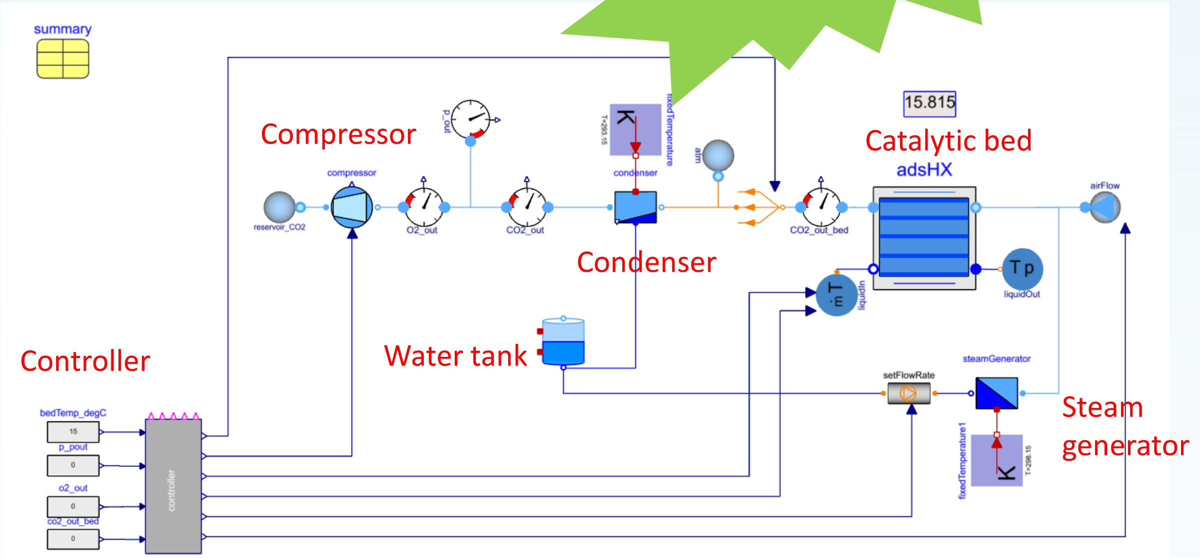
2022.1 content

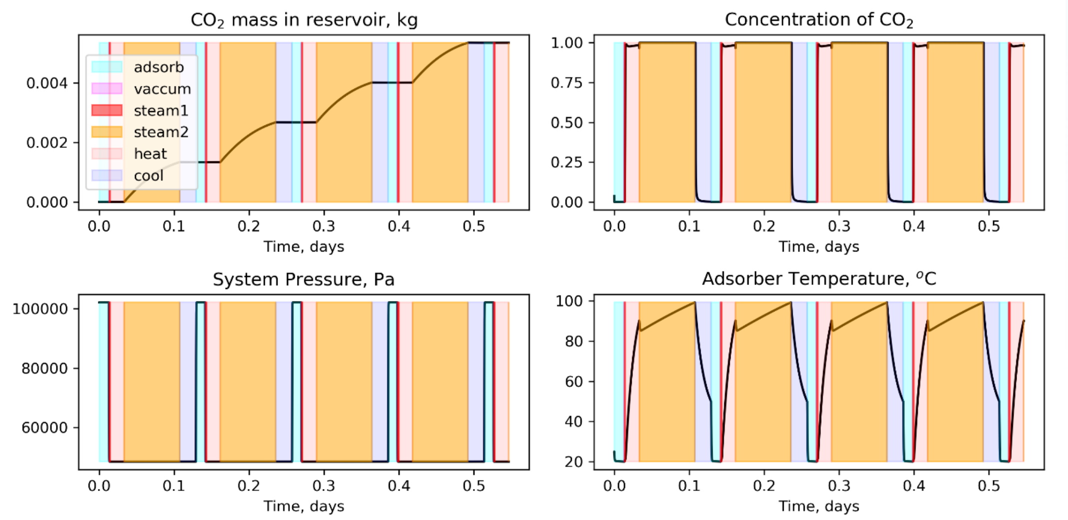
ThermalPower.Experiments.AdsorptionCycleCO2FromAir

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"





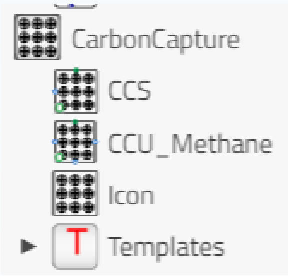
Carbon Capture & Usage – Feasibility Assessment

- 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 CO_2 production wherever hydrocarbon combustion occurs
  - CCS component parameterized by
    - Cost
    - Efficiency
    - Energy requirement
  - CCUS component
    - Similar parametrization as CCS
    - Additional H_2 and CH_4 ports
  - Carbon tax for all emitted CO_2



Economy models

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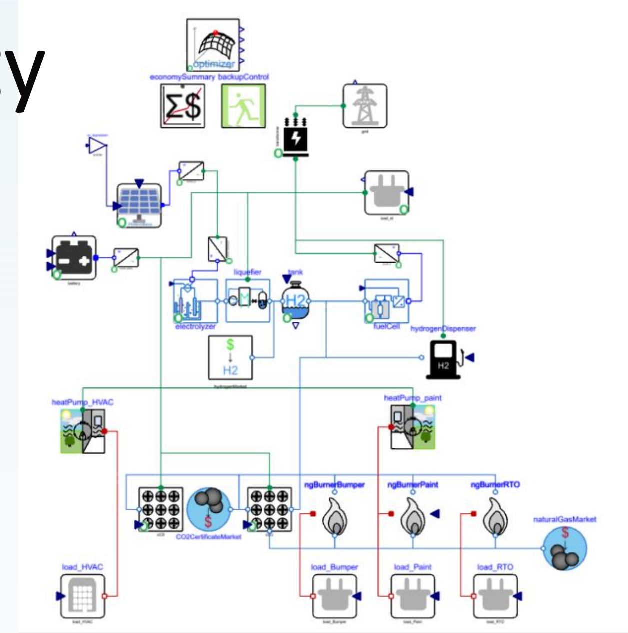
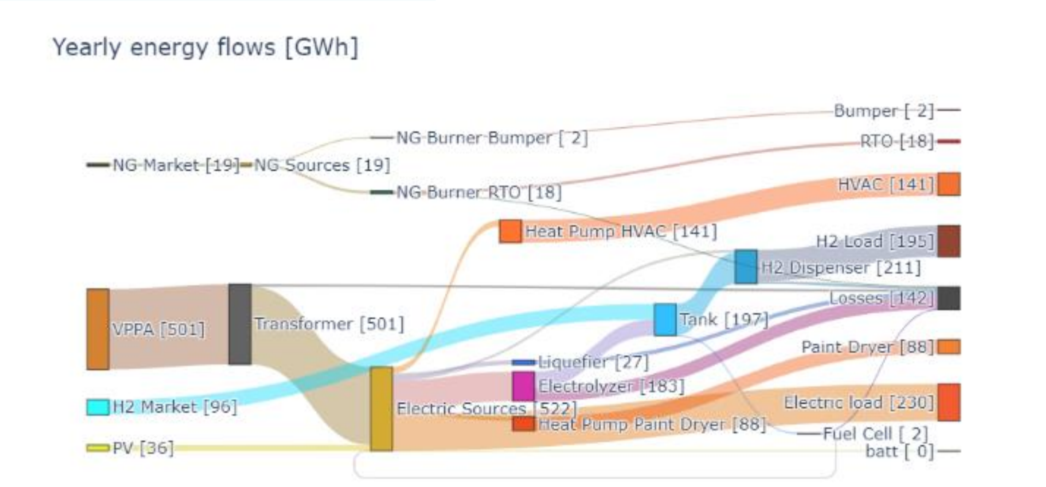
- CapEx and OpEx added to all components
- Automatic summation of the cost
- Allows technology assessment w.r.t. various KPIs
  - CapEx, OpEx, Total cost of ownership, Net Present Value, pay-back time

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