DARTS - thermodynamics workshop

TU Delft

CALYSTO: an integrated approach for CO_2 transport and storage into depleted gas reservoirs

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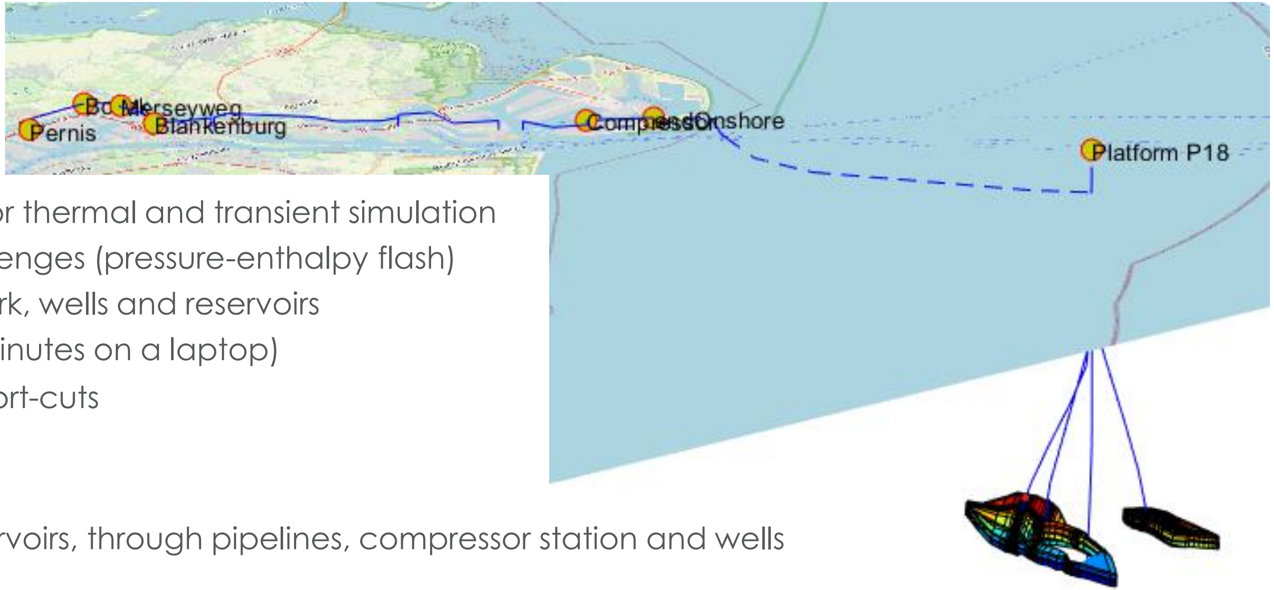
AGENDA

- CALYSTO in a nutshell
- CALYSTO thermodynamical description
- Impact of CO_2 composition on PORTHOS project
- Conclusions

CALYSTO in a nutshell

- CCS projects need integrated simulation tools
  - EBN has developed its own "in-house" modeling tool devoted to CO_2 injection in depleted gas reservoirs
  - CALYSTO (**CA**rbon **L**ow enthalp**Y** **S**torage **To**ol)

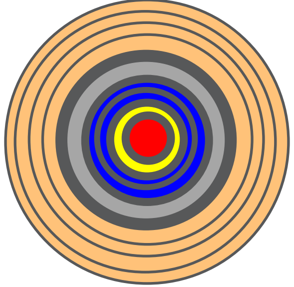


- Specificities
  - Physic based model allowing for thermal and transient simulation
  - Applied to CO_2 modeling challenges (pressure-enthalpy flash)
  - Fully coupling of surface network, wells and reservoirs
  - Simulations must be fast (few minutes on a laptop)

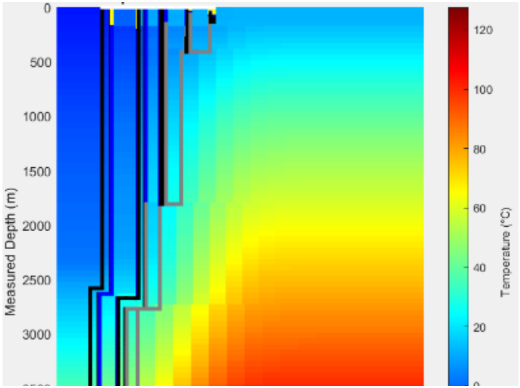
  → implies simplifications and short-cuts

- Overall PORTHOS model
  - From emitters down to P18 reservoirs, through pipelines, compressor station and wells

CALYSTO in a nutshell



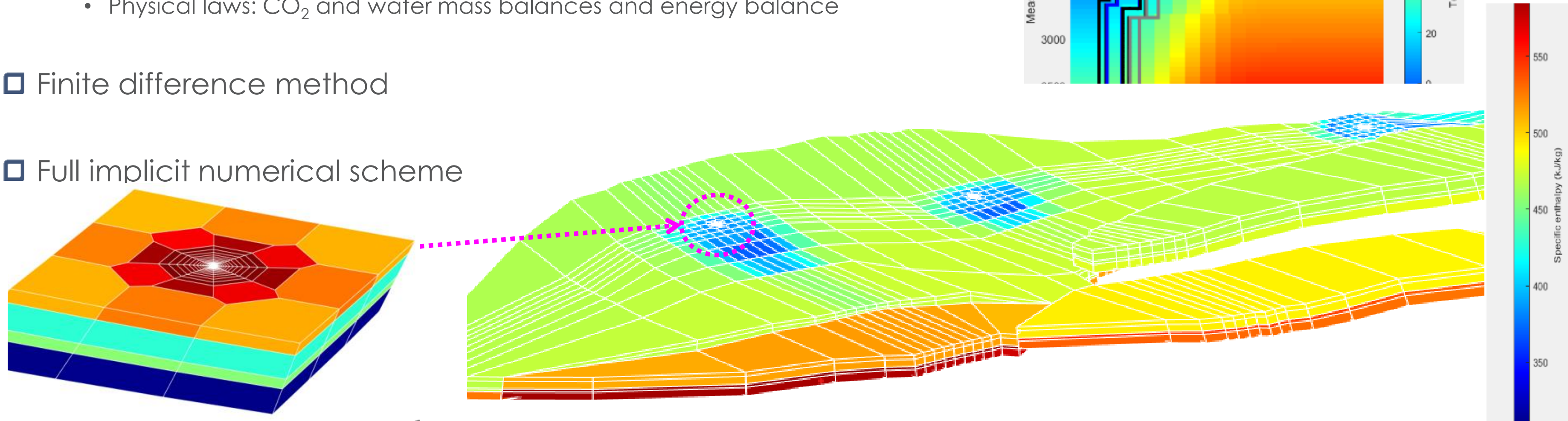
- Fully coupled network, wells and reservoir(s) model



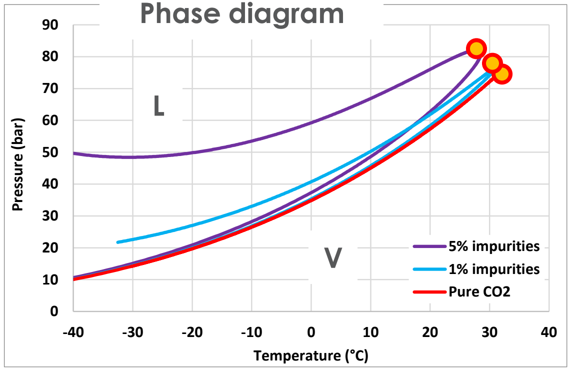
- Physics based model
  - Pipe/well description
    - Physical laws: mass, momentum and energy balance
    - External layers (pipe insulation/well completion) and soil/rocks
  - Reservoir description
    - 3D unstructured grid trying to describe near wellbore and far field evolution
    - Physical laws: CO_2 and water mass balances and energy balance

- Finite difference method

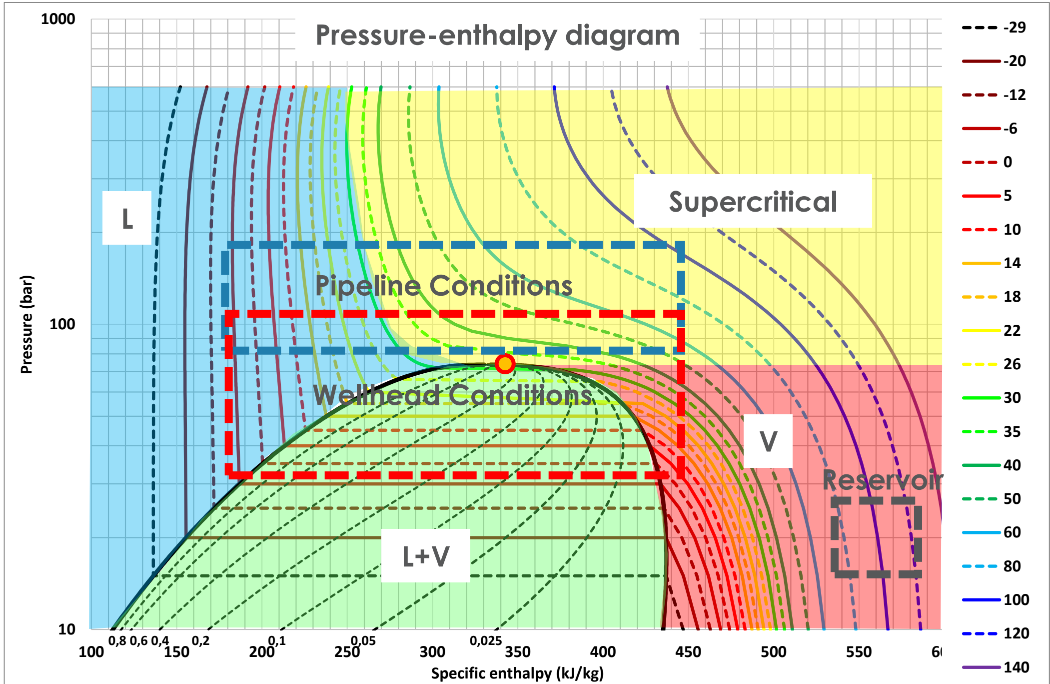
- Full implicit numerical scheme



CALYSTO in a nutshell



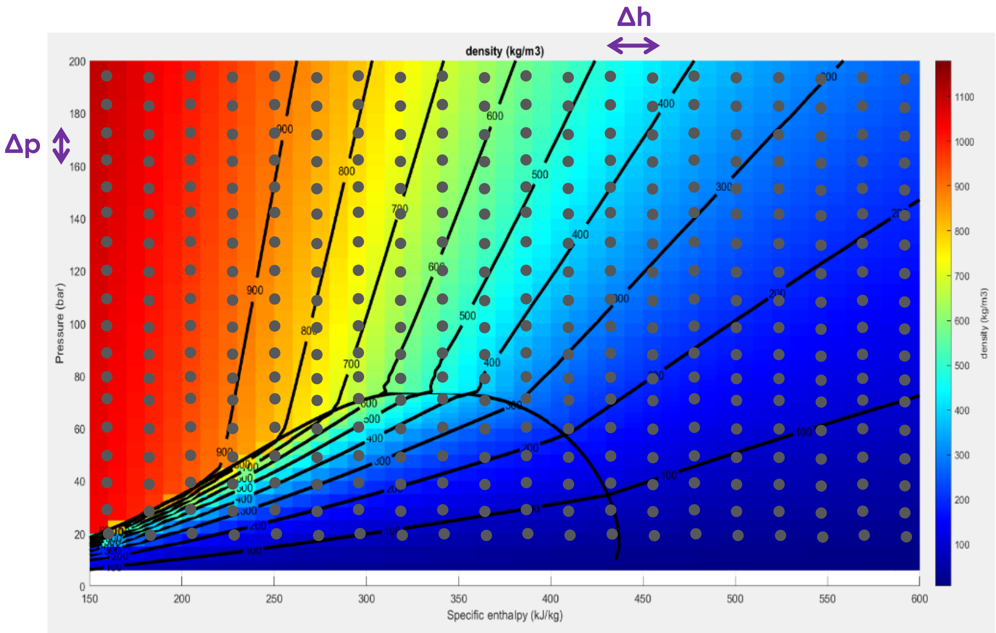
- CO$_2$ PVT
  - Phase envelope is narrow (even not existing for pure CO$_2$) in P-T diagram
  - Thermodynamical conditions in CO$_2$ projects are wide → the fluid might change phase
  - Thermal exchanges are key to model CO$_2$ behavior
  - Specific EOS must be used



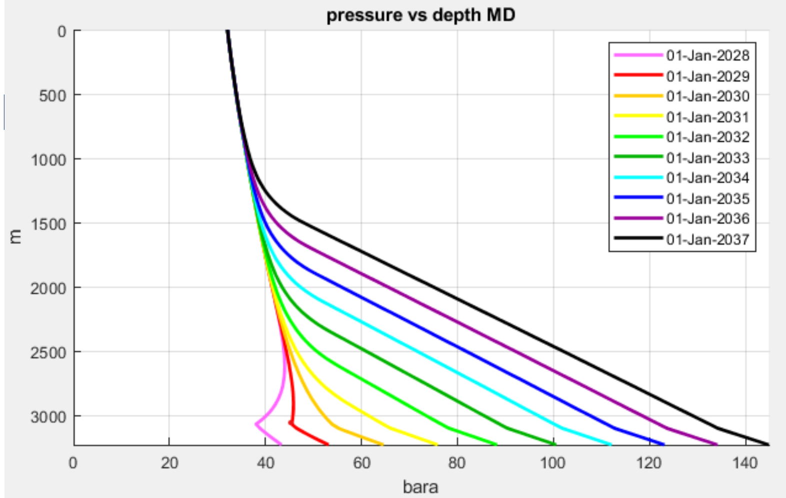
- In classical reservoir simulators, p and T are primary variables… but unsuitable for CO$_2$ projects because it's impossible to model 2-phase conditions
  - enthalpy must replace temperature as primary variable
  - equations must be written using p-h (pressure – enthalpy) variables

CALYSTO thermodynamical description

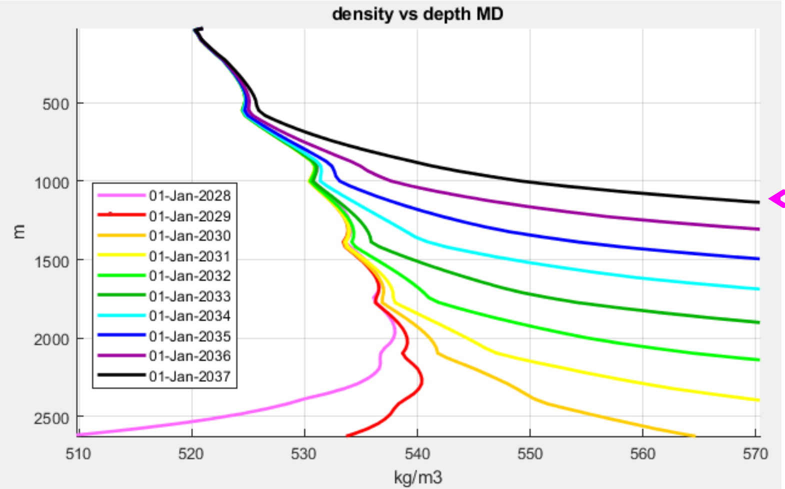
- PVT flash
  - Instead of computing the EOS for each cell at each timestep (which is very time consuming), thermodynamical properties (ρ, μ…) are *interpolated* between values stored in *predefined* tables
  - These tables are vs p and h (not p and T): $\rho(p,h)$, $\mathrm{T}(p,h)$, $\mu(p,h)$
  - Δp = 1 bar (close to critical point) up to 20 bar (far from critical point)
  - Δh = 5 kJ/kg (in 2 phase domain), Δh = 10 kJ/kg (in single phase)
  - EOS
    - Span and Wagner for pure CO_2
    - GERG 2008 for CO_2 mixture

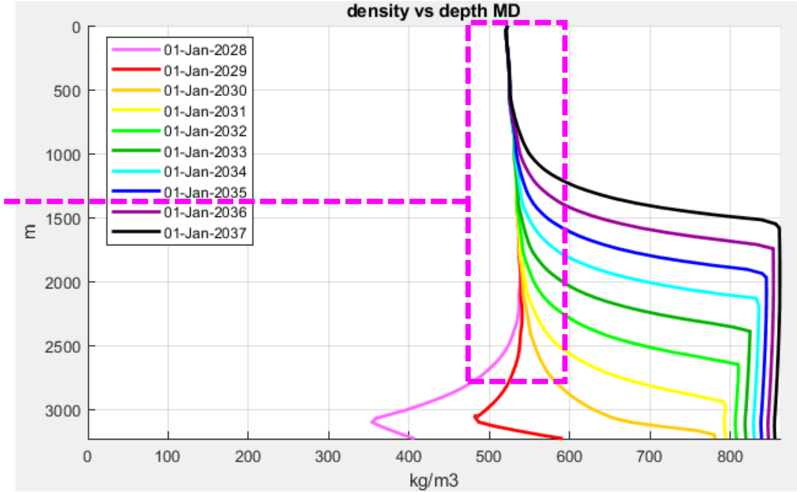


CALYSTO thermodynamical desc



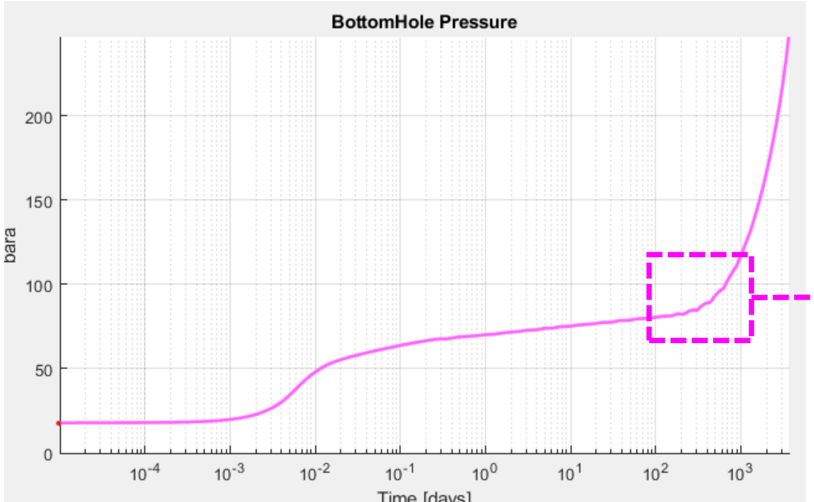
- ☐ Consequence on well profiles
  - Density profiles are not "perfect" due to linear interpolation
  - Same for the fluid velocity profiles
  - → CALYSTO's approach is not fully accurate, but it is fast
  - → Compromise between accuracy and computational efficiency

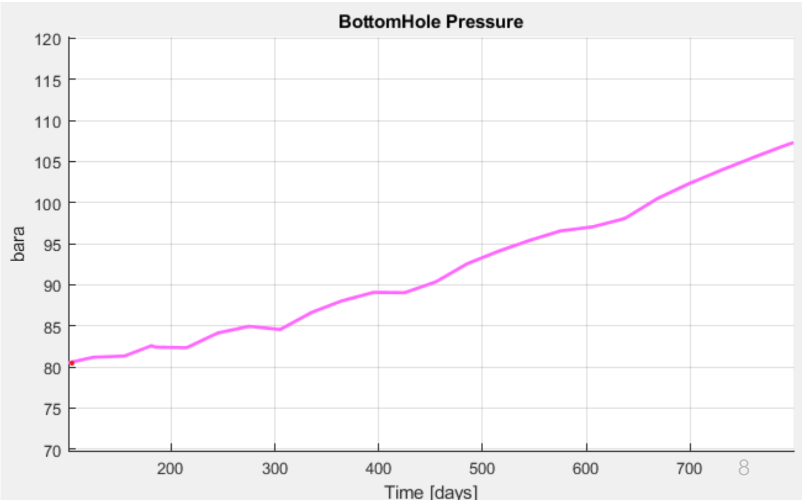




CALYSTO thermodynamical description

- Consequence on BHP evolution vs time (single layer reservoir)
  - BHP evolution also shows small "oscillations" due to linear interpolation of thermodynamical properties
    → CALYSTO's approach is not fully accurate, but it is fast
    → Compromise between accuracy and computational efficiency





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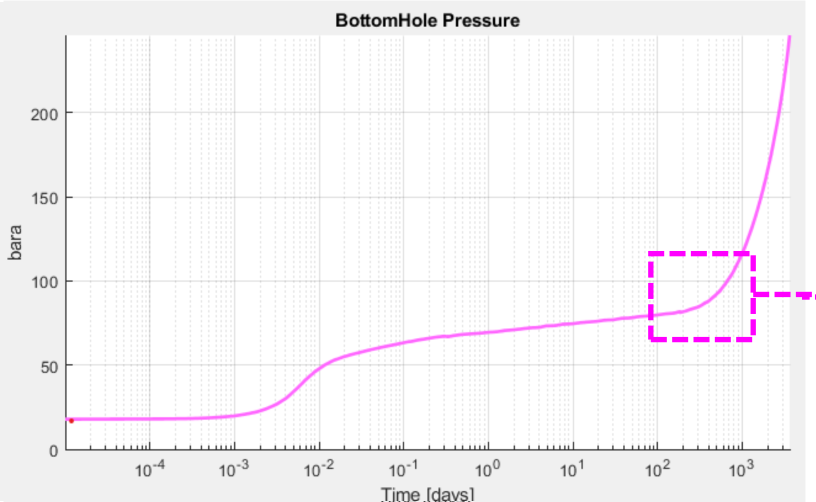
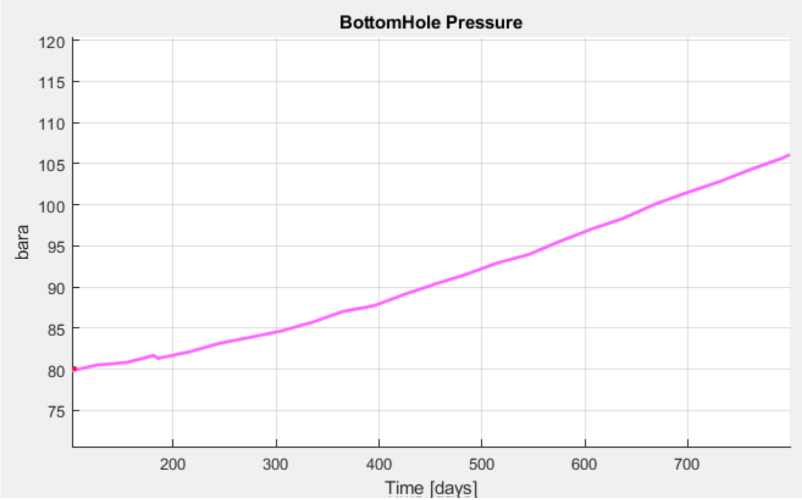
  - BHP evolution also shows small "oscillations" due to linear interpolation of thermodynamical properties
    → CALYSTO's approach is not fully accurate, but it is fast
    → Compromise between accuracy and computational efficiency
  - Remark: the effect disappears with reservoir heterogeneities or layering



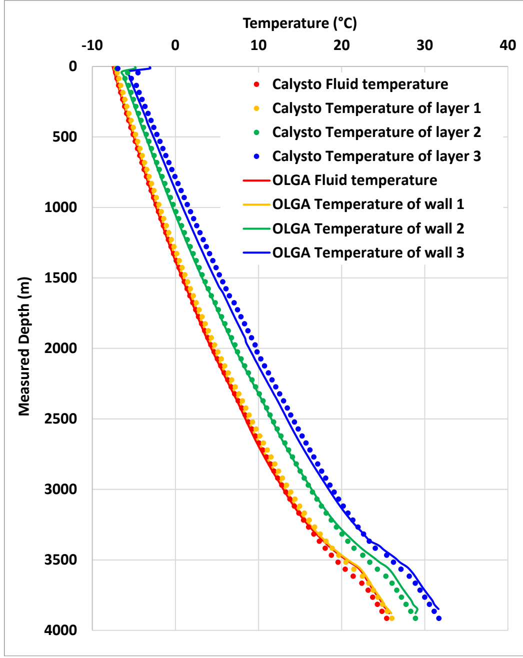


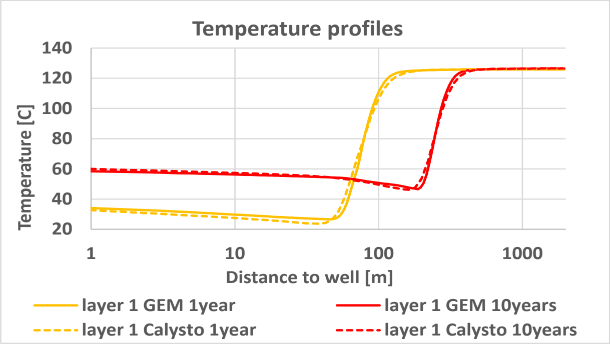
CALYSTO thermodynamical description

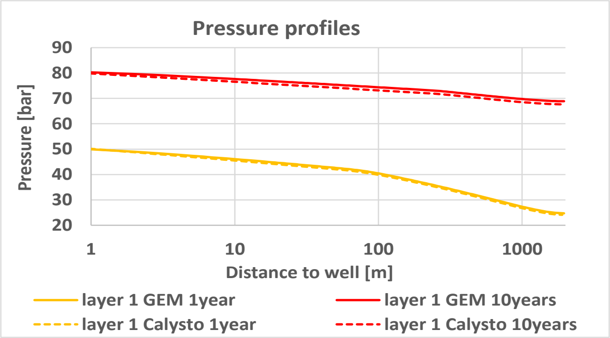
- CALYSTO benchmark against OLGA
  - Pure CO_2 (PVT according to Span and Wagner EOS), pseudo steady state conditions
  - No slippage between phases in the well

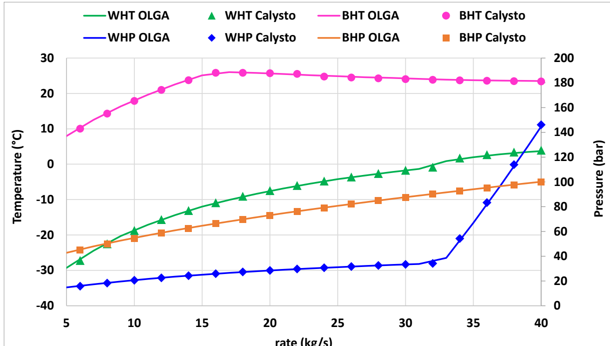
- CALYSTO benchmark against GEM
  - 4 layers reservoir NWB, Well bottom hole boundary conditions imposed: injection rate and injected fluid temperature, pure CO_2
  - Logarithmic mesh used in CALYSTO, constant cell size used in GEM: GEM model is finer far from the well, CALYSTO mesh is finer close to the well

➔ Excellent agreement: mismatch remains in the range ±1bar and ±1degC

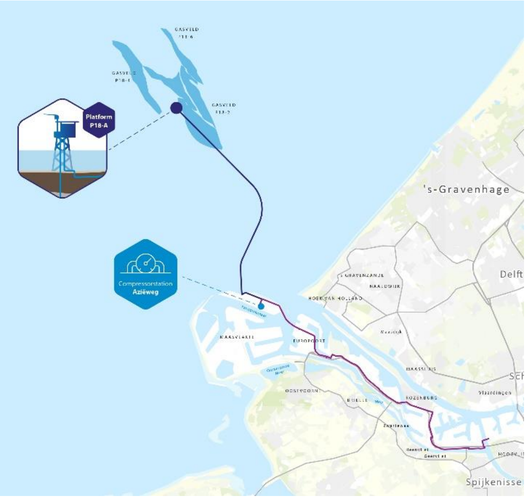








PORTHOS project



P18 platform

- ❑ Rate
  - Average: 2.5 MTPA (megatonne per annum)
  - Maximum rate = 100 kg/s (~ 3.2 MTPA)
- ❑ Reservoir
  - Capacity: 37 MT (megatonne) → ~15 years of injection
  - Pressure
    - At injection start-up ~20 bar
    - At end of injection ~3XX bar → pressure increase ~20 bar/year ~2 bar/month

Impact of CO_2 composition on PORTHOS project

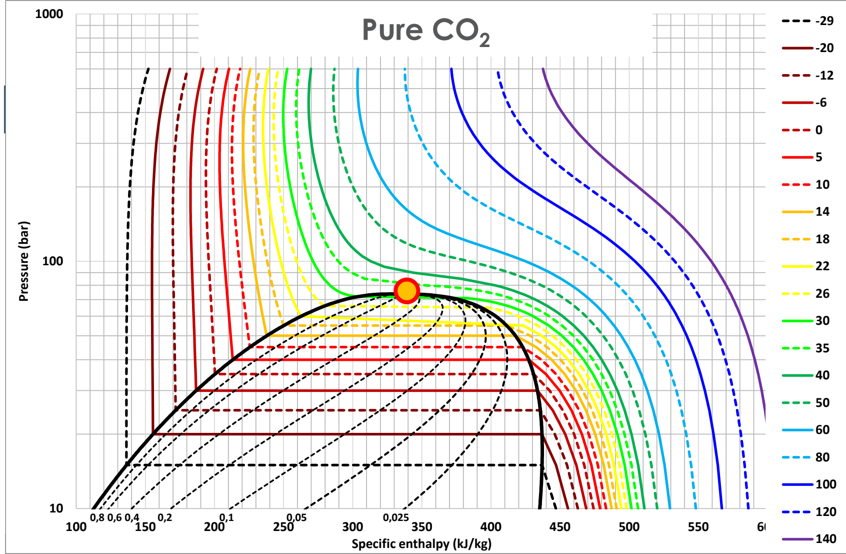
- Boundary conditions
  - Emitters CO_2 stream composition will vary in time
  - For PORTHOS project, expected maximum impurity content ~ 5%, most likely impurity content ~1%
  - Main components being Ar, N_2, CO, CH_4… and a complex mixture of many other impurities at ppm level (H_2S, SO_x, NO_x, H_2O…)

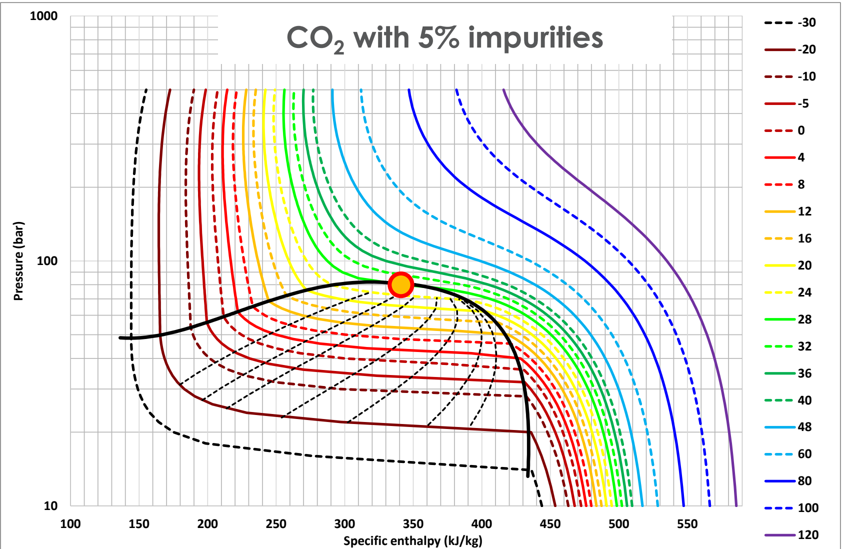
→ Purpose here is not to tackle impurity partitioning, liquid drop-out, acid corrosion…, but to evaluate the impact of CO_2 stream composition on the operating conditions of a CCS project.

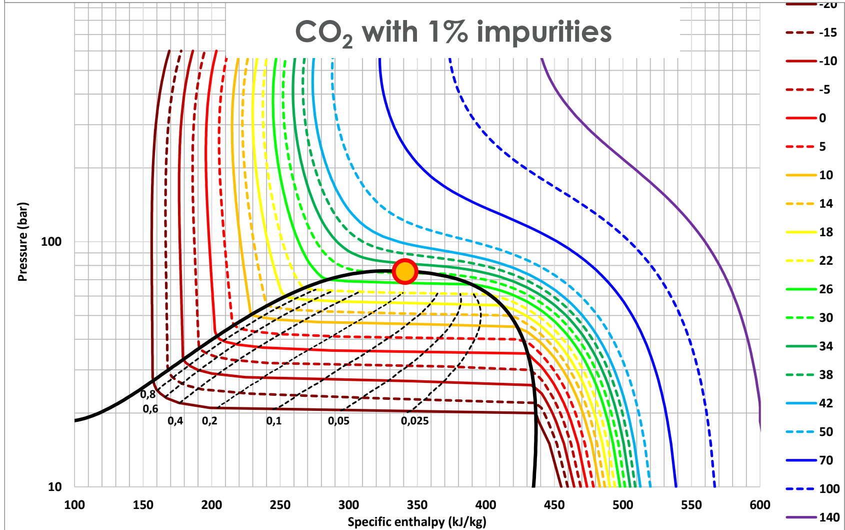
Impact of CO_2 composition on

- Phase envelope

	Pure CO_2	CO_2 + 1% impurities	CO_2 + 5% impurities
Tc (°C)	31.0	30.7	28.4
Pc (bar)	73.8	75.9	81.5
Critical density (kg/m³)	467.6	452.2	456.3

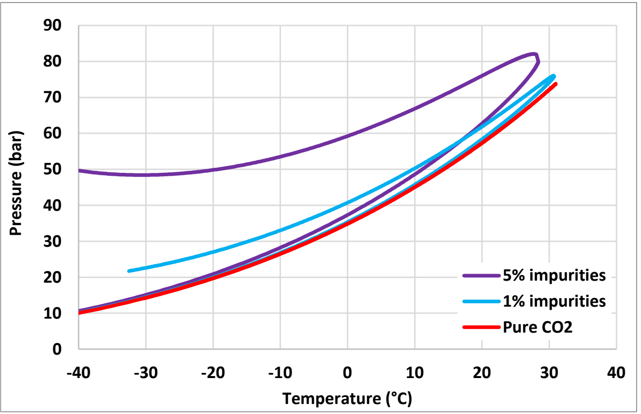


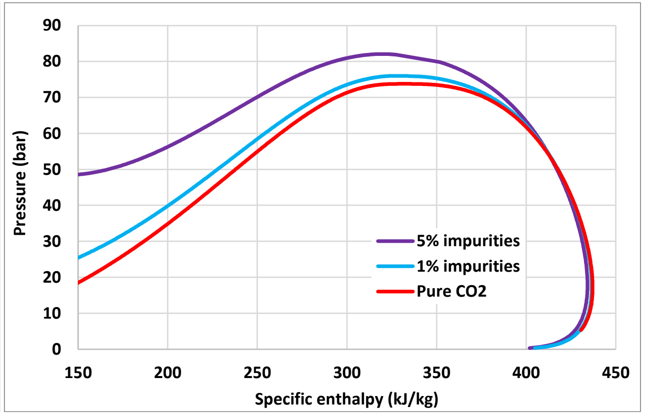


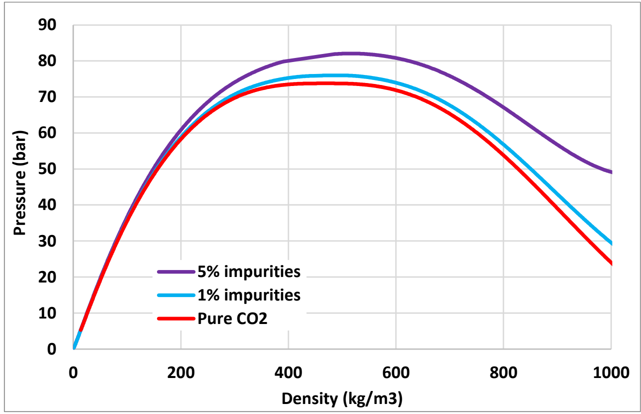


Impact of CO_2 composition on PORTHOS project

- Phase envelope
  - Dew curve of the phase line weakly affected by impurity content
  - Bubble curve more impacted by the impurity content → impact on operating conditions of any CCS project





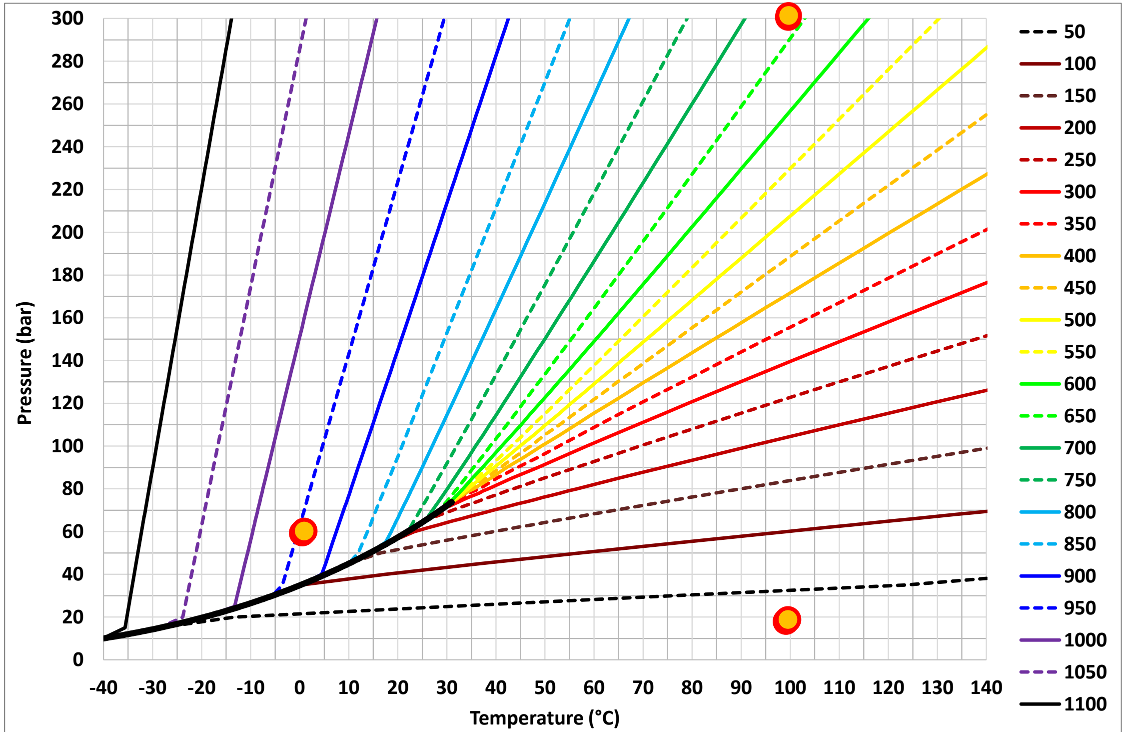


Impact of CO_2 composition on PORTHOS project

- Density
  - Pure CO_2 vs CO_2 + 5% impurities

	Pure CO_2	CO_2 + 5% impurities
0°C - 60 bar	948.2	
100°C - 300 bar	661.9	
100°C - 20 bar	29.8	

CO_2 density vs pressure and temperature



Impact of CO_2 composition on PORTHOS project

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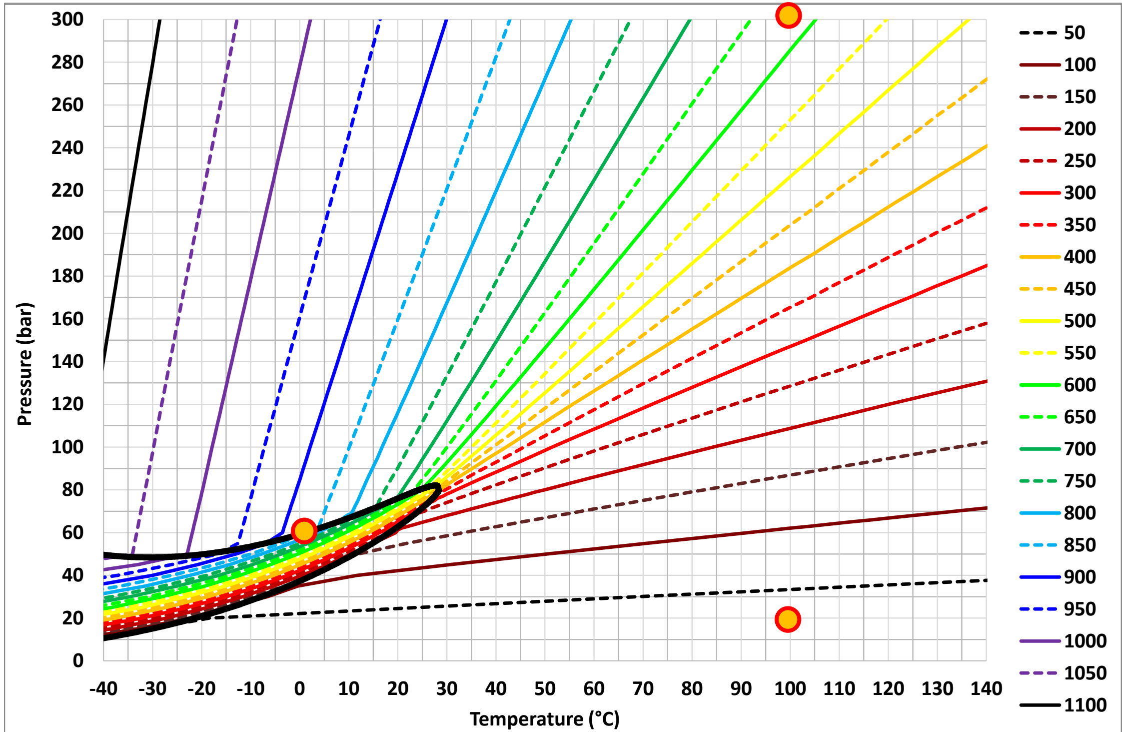
  - Pure CO_2 vs CO_2 + 5% impurities

	Pure CO_2	CO_2 + 5% impurities
0°C - 60 bar	948.2	876.4
100°C - 300 bar	661.9	618.9
100°C - 20 bar	29.8	29.0

CO_2 + 5% impurities density vs pressure and temperature

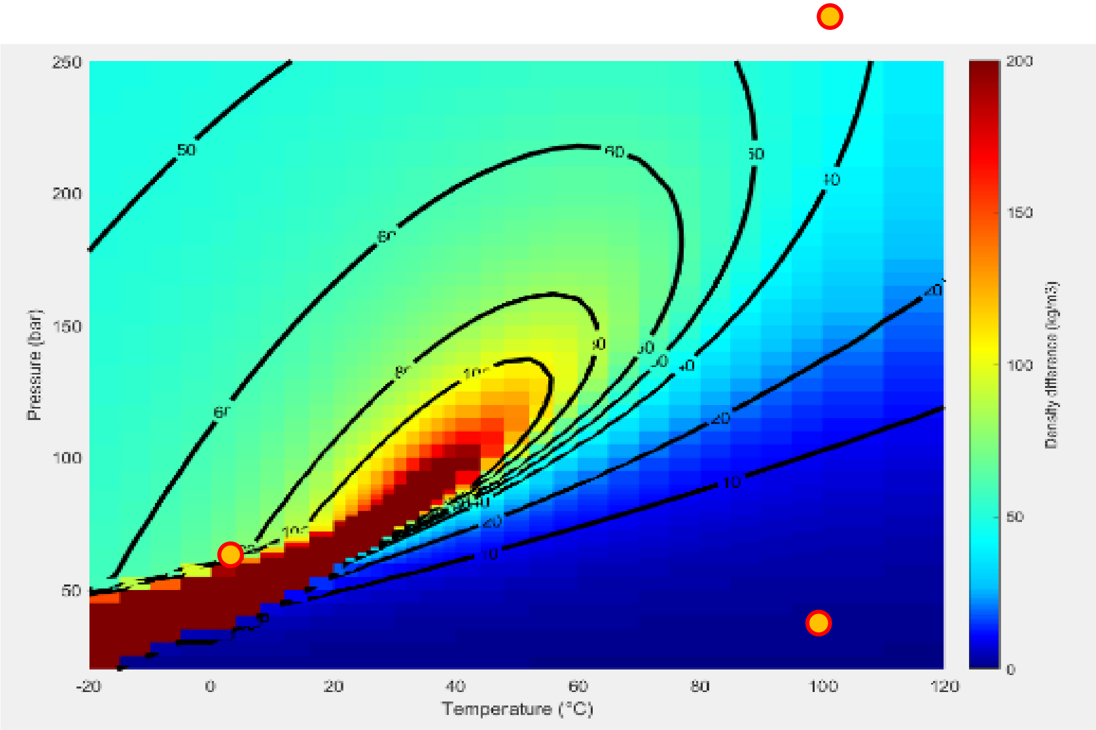


Impact of CO_2 composition on PORTHOS project

- Density
  - Pure CO_2 vs CO_2 + 5% impurities

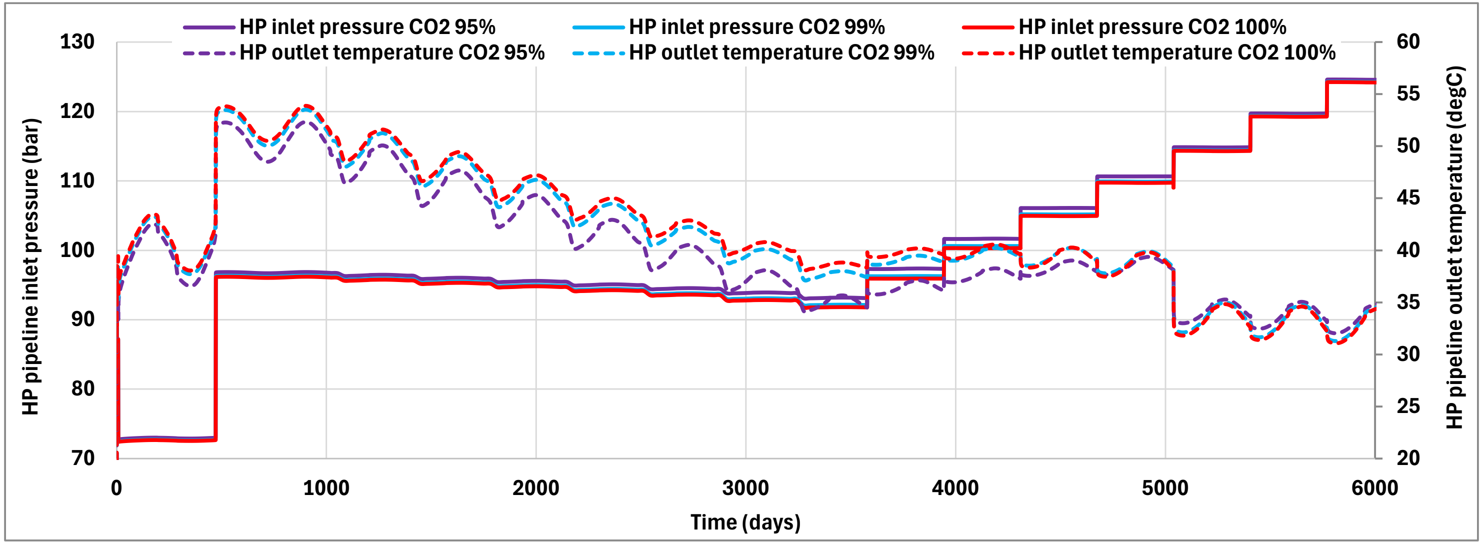
	Δ density
0°C - 60 bar	71.8
100°C - 300 bar	43.0
100°C - 20 bar	0.8

Δ density = Pure CO_2 density - CO_2 + 5% impurities density vs pressure and temperature



Impact of CO_2 composition on PORTHOS project

- Impact on the operating conditions
  - Minor impact on HP inlet pressure ~ 1 bar
  - Arrival temperature at platform manifold impacted by a few °C



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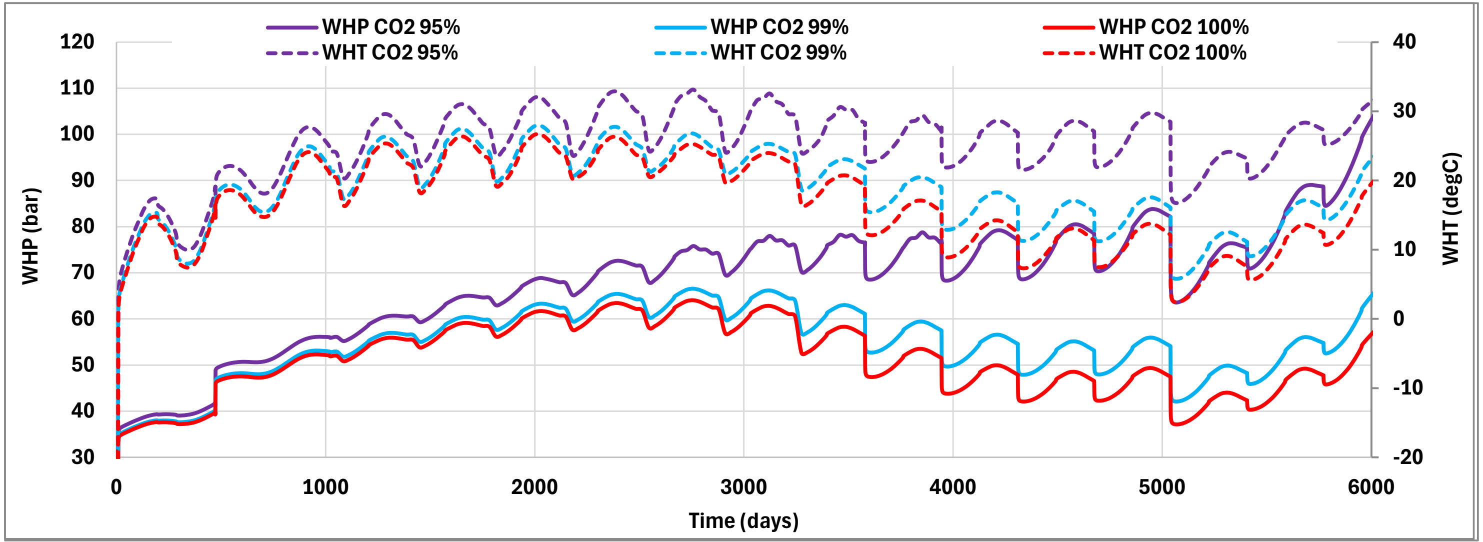
  - Impact is bigger at wellhead: up to 30 bar and 20°C



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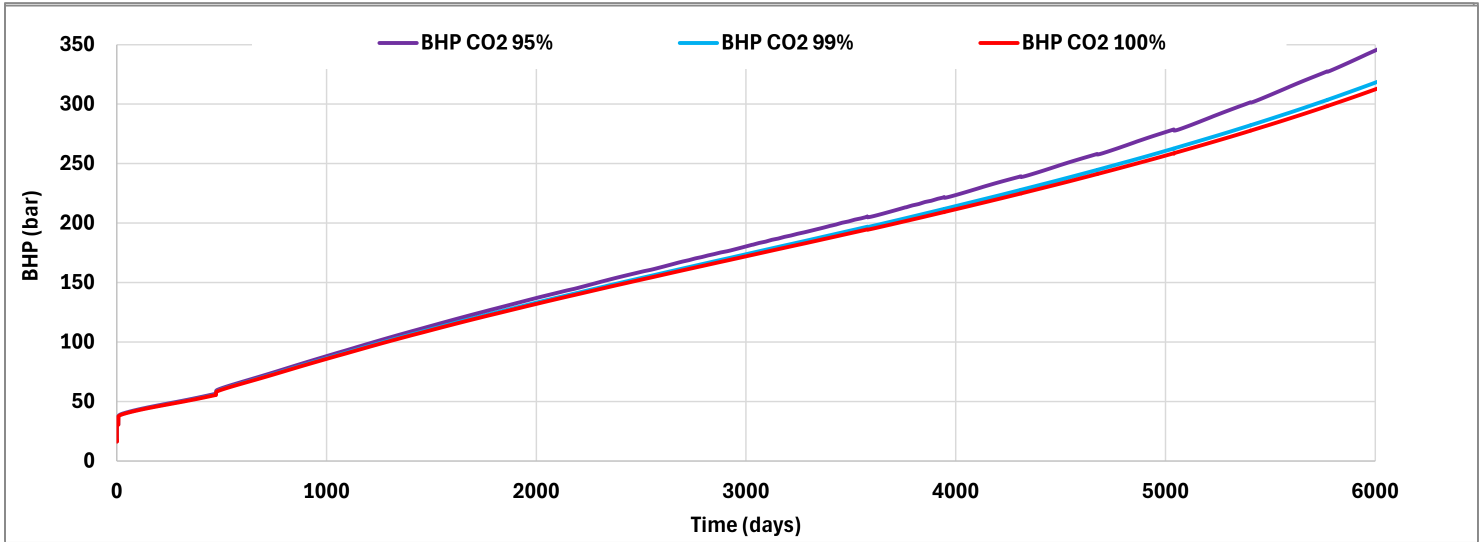
- Impact on the operating conditions
  - Minor impact on HP inlet pressure ~ 1 bar
  - Arrival temperature at platform manifold impacted by a few °C
  - Impact is bigger at wellhead: up to 30 bar and 20°C
  - Reason is partially in the pipes, but mainly in the reservoir which pressure increases more rapidly with higher impurity content (because of lower density)



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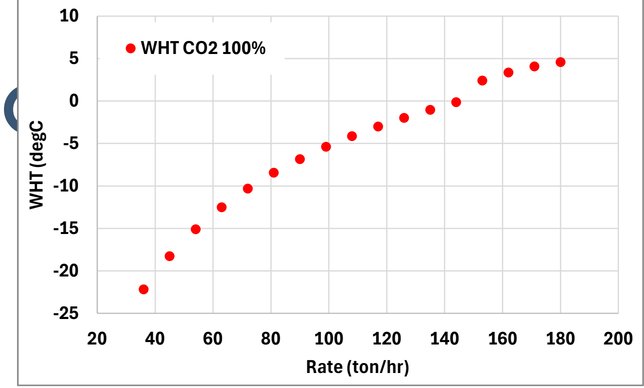
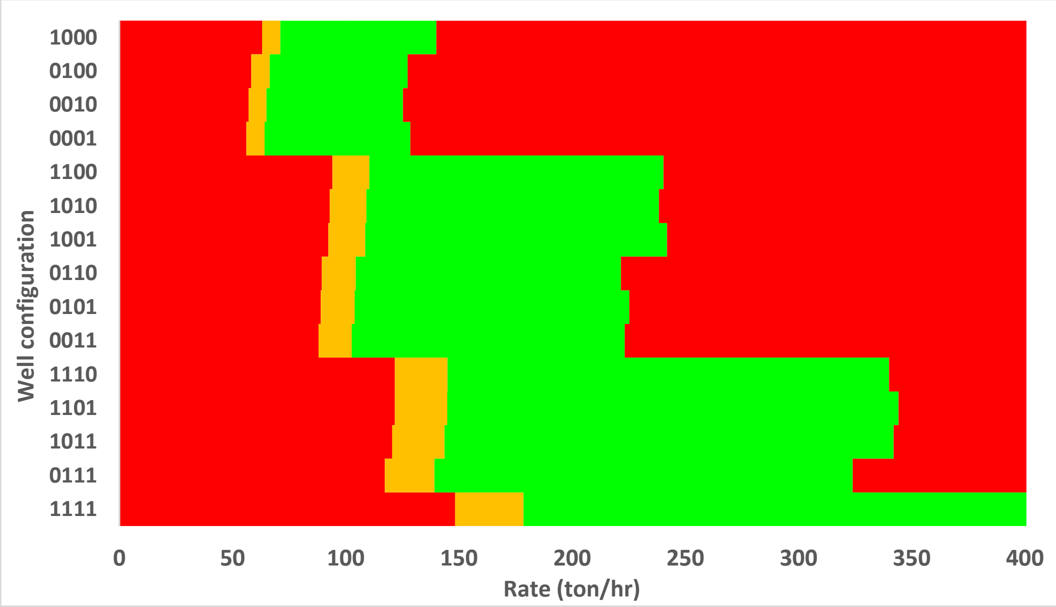


- Well Operating envelopes
  - Well challenges (some of)
    - While injecting CO_2, wellhead conditions can go to very low temperatures
      → minimum injection rate is required to prevent from annulus freezing, thermal failure equipment…
    - Maximum injection rate dictated by network pressure constraint (or other constraint: erosion velocity…)

- PORTHOS Operating Envelopes (pure CO_2)

	Min rate	Max rate
1 well	~60 ton/hr	~140 ton/hr
2 wells	~90 ton/hr	~240 ton/hr
3 wells	~120 ton/hr	~340 ton/hr
4 wells	~150 ton/hr	~460 ton/hr



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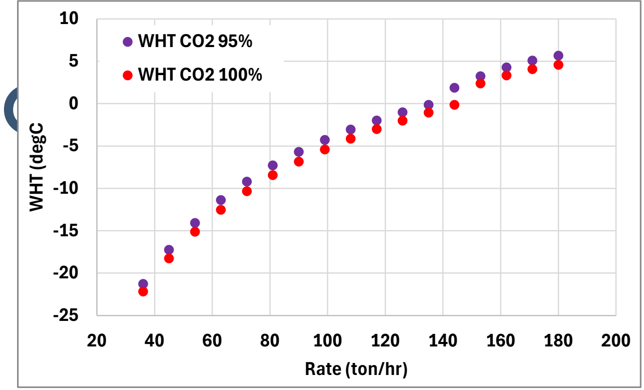

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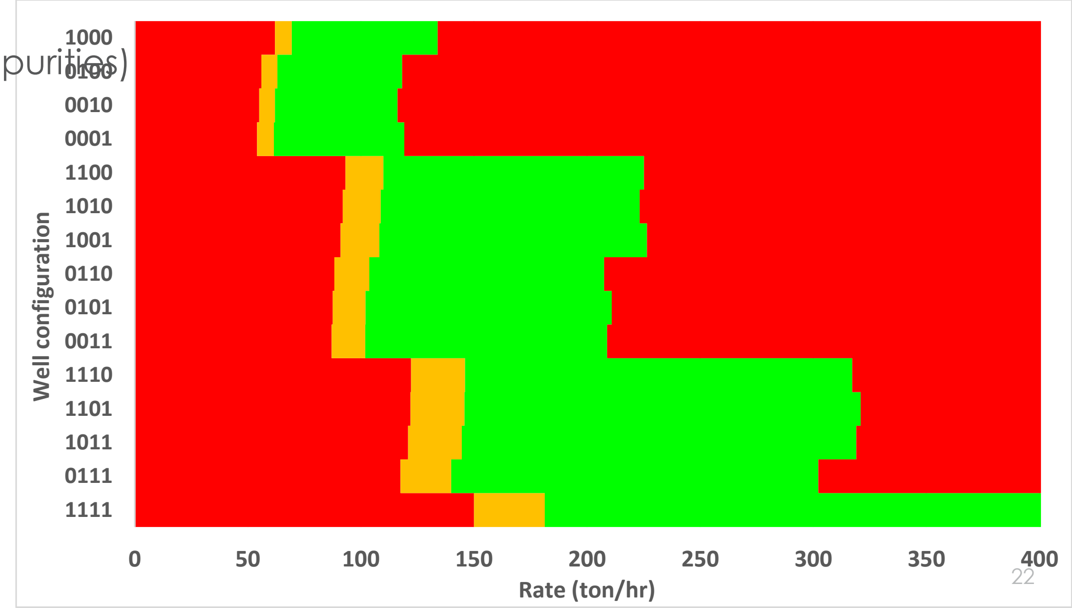
- PORTHOS Operating Envelopes (CO_2+5% impurities)

	Min rate	Max rate
1 well	~55 ton/hr	~130 ton/hr
2 wells	~85 ton/hr	~225 ton/hr
3 wells	~120 ton/hr	~320 ton/hr
4 wells	~150 ton/hr	~420 ton/hr



Conclusion

- CCS projects need *integrated simulation tools*

- CALYSTO is a fully coupled network, wells and reservoir(s) model

- One main simplification is related to thermodynamical description using PVT tables
  - Not fully accurate, but fast
    → Compromise between accuracy and computational efficiency
    → Run time is in minutes, not hours/days, because of simplifications/short-cuts
  - Drawbacks: many phenomena can't be tackled (species partitioning, mixing, liquid drop out, corrosion…)

- Is used for several CO_2 CCS projects ebn