集成井筒和油藏模型用于瞬态和稳态模拟
Integrated Wellbore and Reservoir modelling – Transient & Steady-state Approaches

18th June 2025

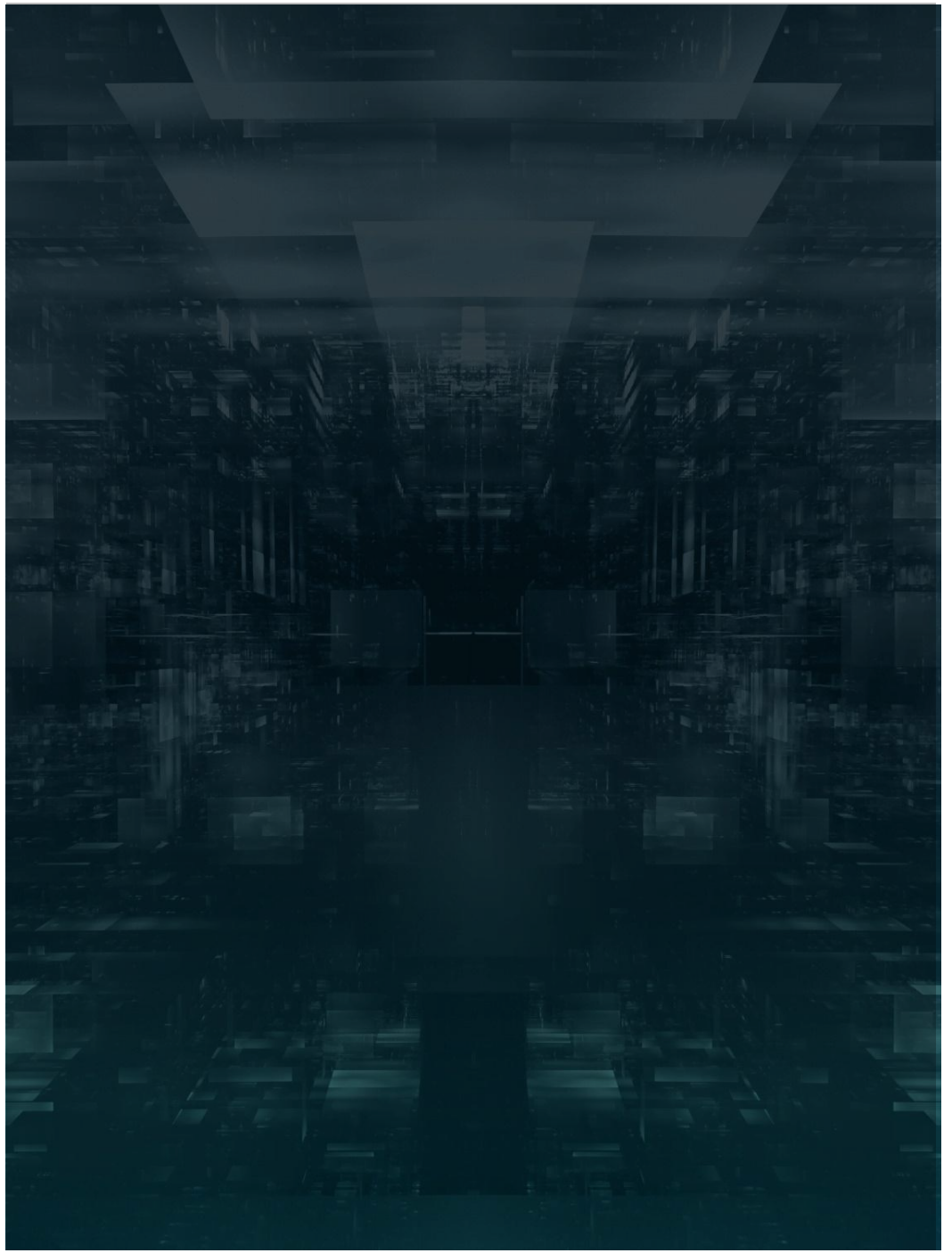
CMG

AGENDA

Transient vs. Steady-state Modelling

CO2LINK – Wellbore & Transients

CoFlow – Long-Term Planning & Steady State



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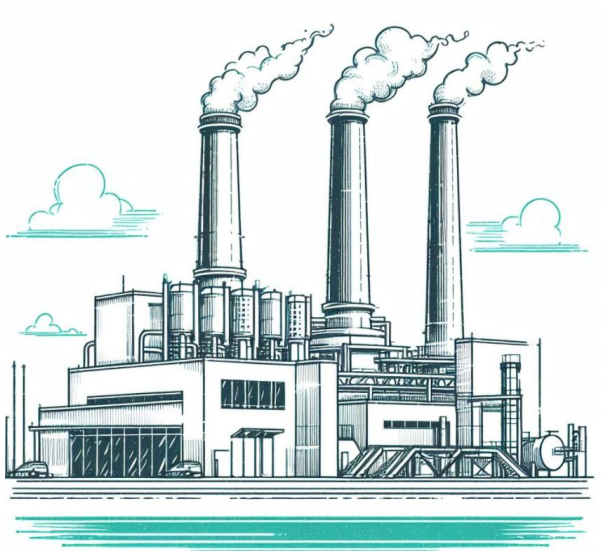
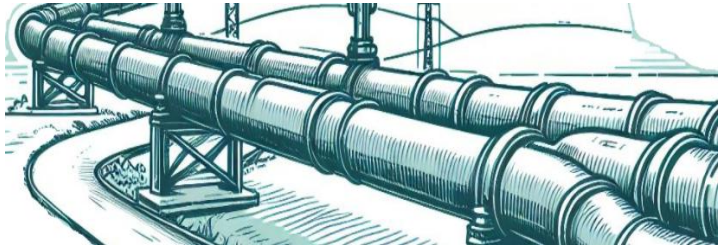
Introduction – CCS Lifecycle

CO_2 capture

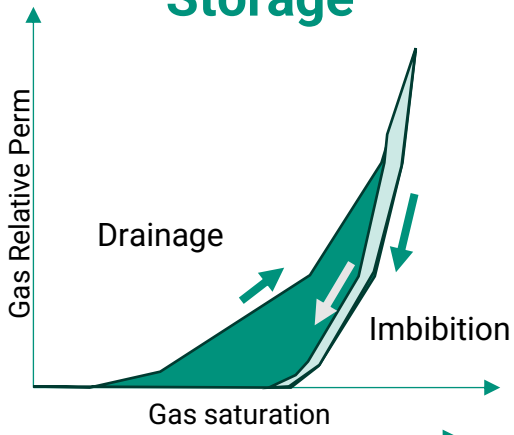


Transportation



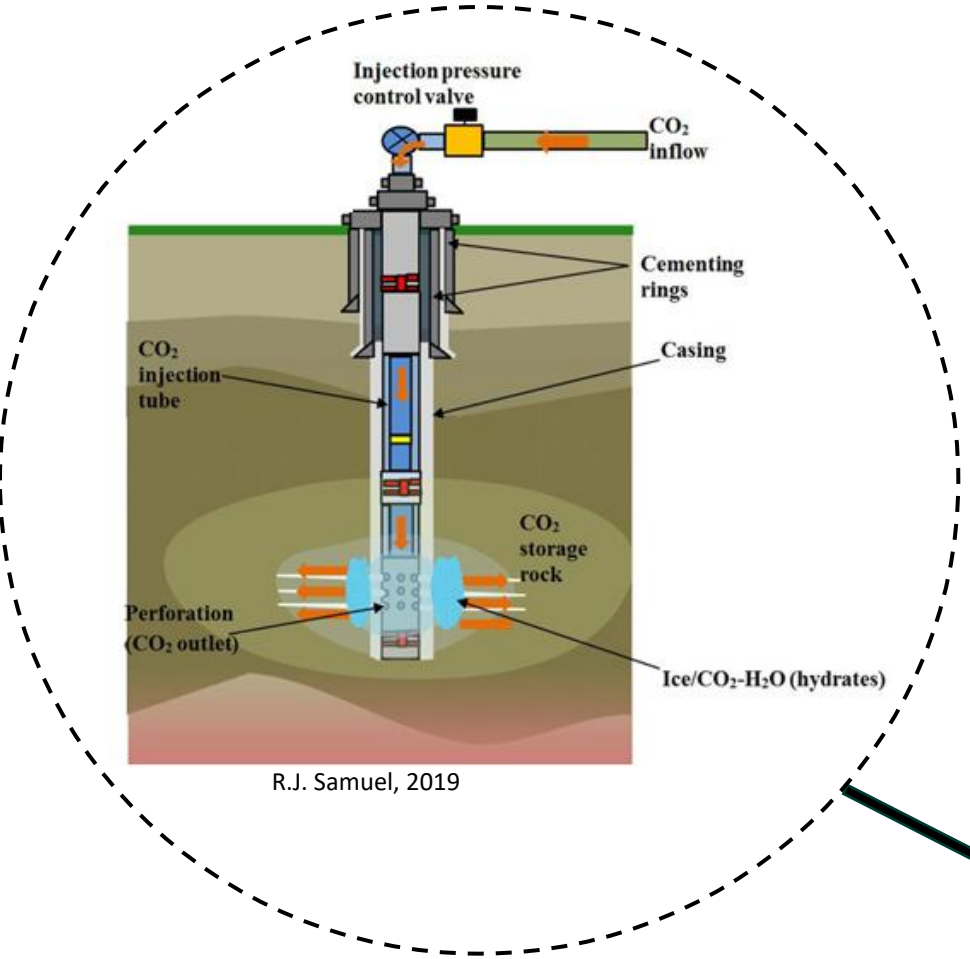
Injection

Storage

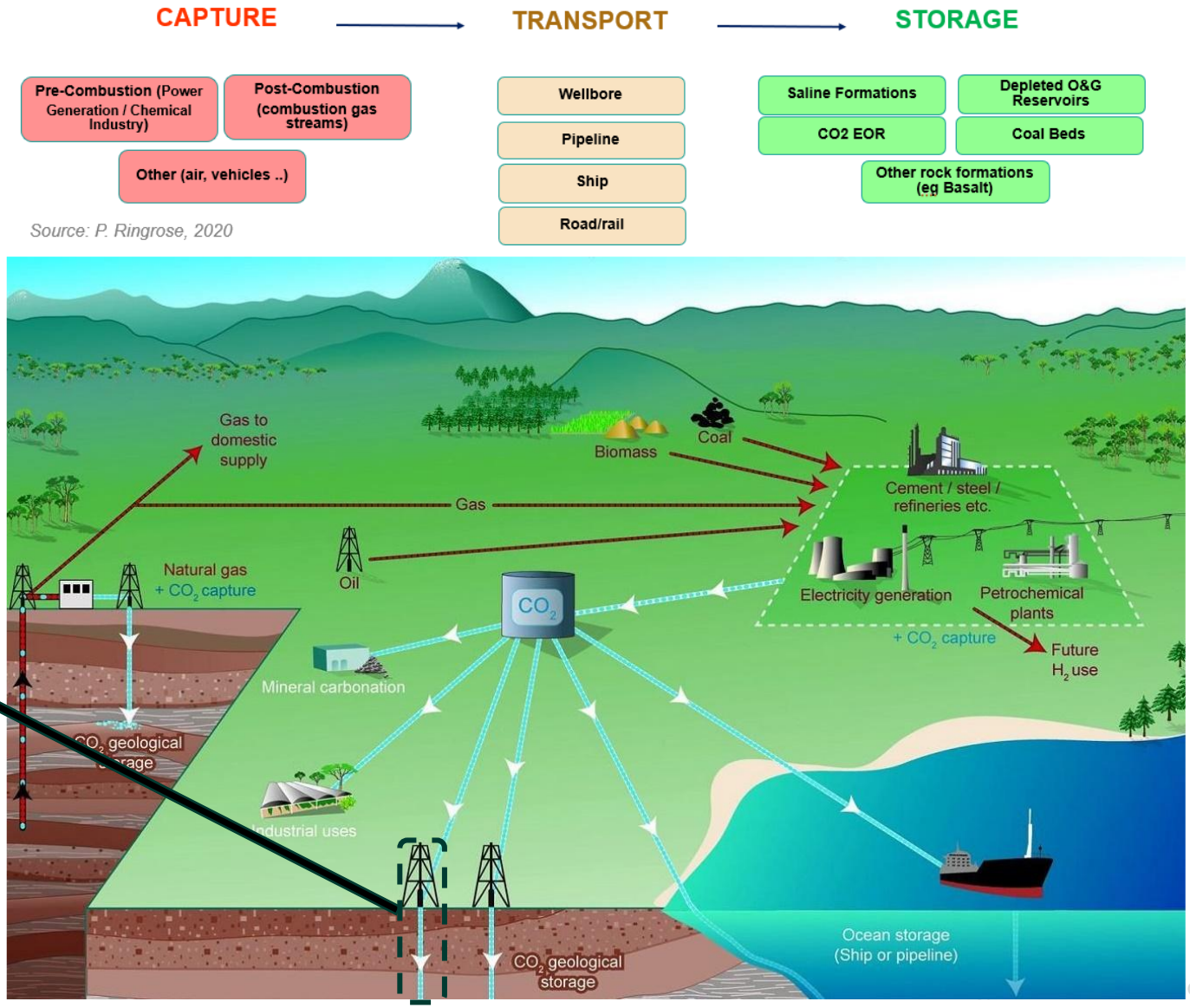


Minutes Hours Days Years Thousands of years

Integrated Subsurface Wellbore Facility System in CCS



R.J. Samuel, 2019



Source: IPCC Special Report on Carbon Dioxide Capture and Storage

Storage Project Challenges

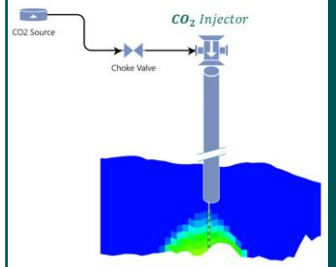
- All of these challenges may exist in a single asset
- One part of the system affects the other

ONE asset

ONE team

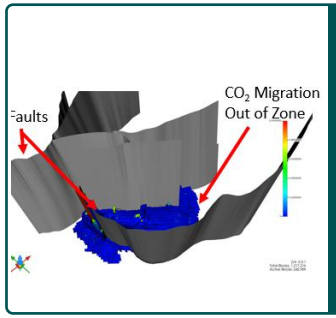
ONE SOLUTION

Extend Asset Life: Phased development, Evolve Injection Strategy

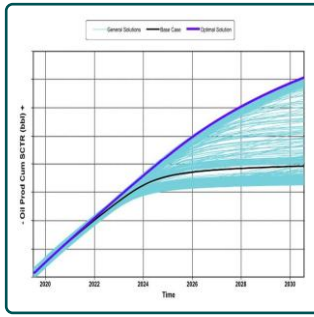


Well & Completion Design to Ensure Injectivity

Facility Sizing & Design, System debottlenecking



Reliable Storage: Geomechanics, Caprock integrity



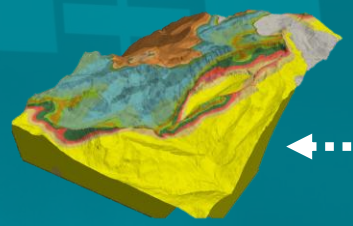
Plan for Operational & Process Issues – Optimize under uncertainty

Long-term Flow Assurance: Corrosion prediction, CO_2 phase behavior

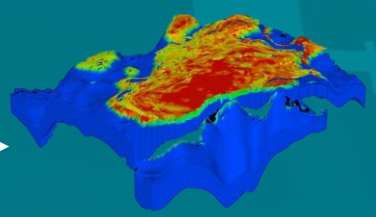
Connection with Surface and Well Models - CMG’s solutions

CMG's Platform for Full CCS System Modeling

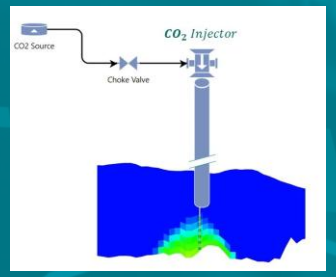
INSIGHTS



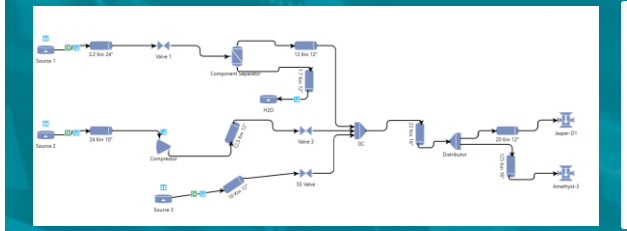
Geology & Earth Modelling



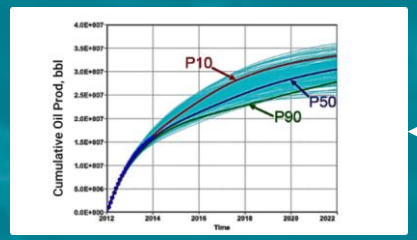
Reservoir Simulation



Well Engineering



Facilities Engineering



Integrated E2E Uncertainty & Optimization

Flow Assurance

DATA

CMG

CMG Solutions for the Lifecycle of a CCS project

Project Stages	Initial Feasibility	De-risking	Operations Monitoring
CMG Solution	**FOCUS CCS** • Geological Site Selection • Validate asset viability quickly • Access more storage capacity	**CMOST** / **GEM** • CO2 Trapping Mechanism • CO2 Plume monitor and surveillance • CO2 Injectivity Evaluation • CO2 Chemical interaction with reservoir fluids • Probabilistic Storage Capacity • Reservoir and Cap Rock Stress evaluation • Evaluation of interference with legacy wells • **Automated History Matching & Optimization**	**CoFlow (IPSM)** **CO2LINK + LedaFlow** • Sub-surface to Surface modelling • Well integrity assessment and Flow Assurance

Support, Training and Consulting Services during the lifecycle of your CCS projects

Integrated Coupling Solutions - Summary

Long-term Decisions

Coupling between transient reservoir and Steady-state wellbore/surface

GEM CoFlow

Short-term Decisions

Coupling between transient reservoir and transient wellbore/surface

GEM LedaFlow

CO2LINK LedaFlow®

Transient vs. Steady-state Simulation of Wellbore/Facility in CCS

Steady state models assume that all flow conditions and properties of the system are constant with respect to time.

Transient models can handle conditions that change with time and assess the time-dependent impact on thermal and flow predictions.

Long-term Decisions → Steady-state Modelling

- Draw an overall picture of the flow system
- Predicting operational constraints and limitations
- Injection rate capacity & wellbore performance
- Injection network design and optimisation
  - Fixed conditions at CO_2 supply
  - Constant valve opening
  - Constant compressor/pump condition

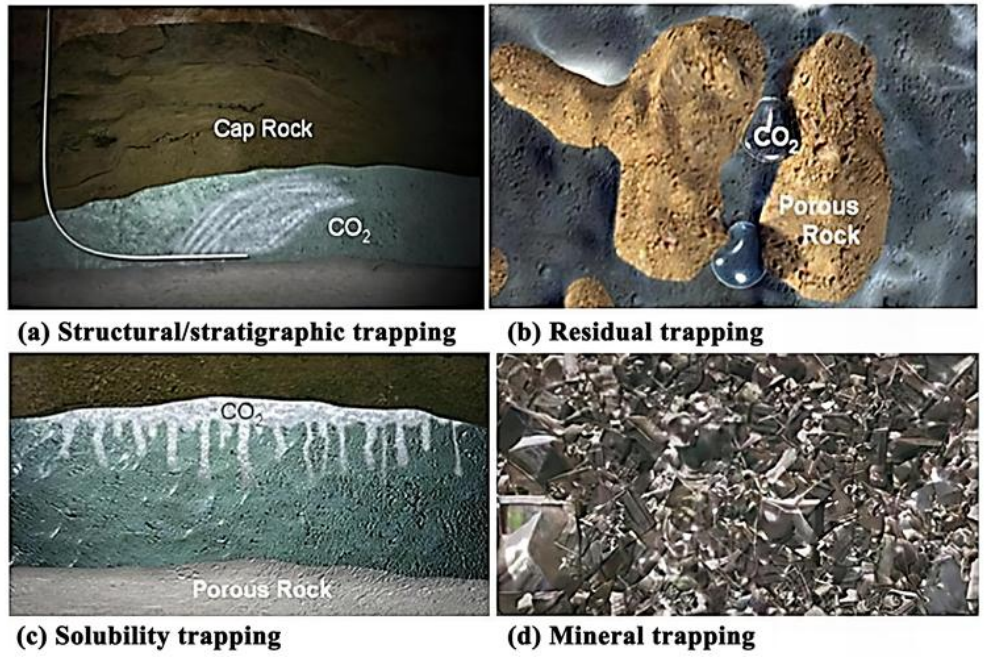
Short-term Decisions → Transient Modelling

- Rapid change in P & T (start-up, shut-in, restart, …)
  - Joule-Thompson cooling effect
  - CO_2 phase change
  - Changes in flow regimes
- Large T variation along wellbore
- CO_2 injectivity impairment
- Corrosion/Erosion

CMG GEM – Tool to Model CO_2 Geological Storage

Generalized Equation-of-State Modeling (GEM)

- Equation of State: Peng Robinson / Soave-Redlich-Kwong
- Convective and Dispersive flow
- Relative permeability hysteresis (Residual gas trapping)
- Gas Solubility in aqueous phase
- Predictions of brine density and viscosity based on Pressure, Temperature, Salinity
- H2O Vaporization (With additional effects of salt precipitation)
- Geochemistry
- Aqueous Equilibrium reactions
- Mineral dissolution and precipitation reactions (Kinetic or Equilibrium driven)
- Thermal module (including Joule-Thomson effects)
- Geomechanics (cap rock integrity / thermal fracturing / faults reactivation)



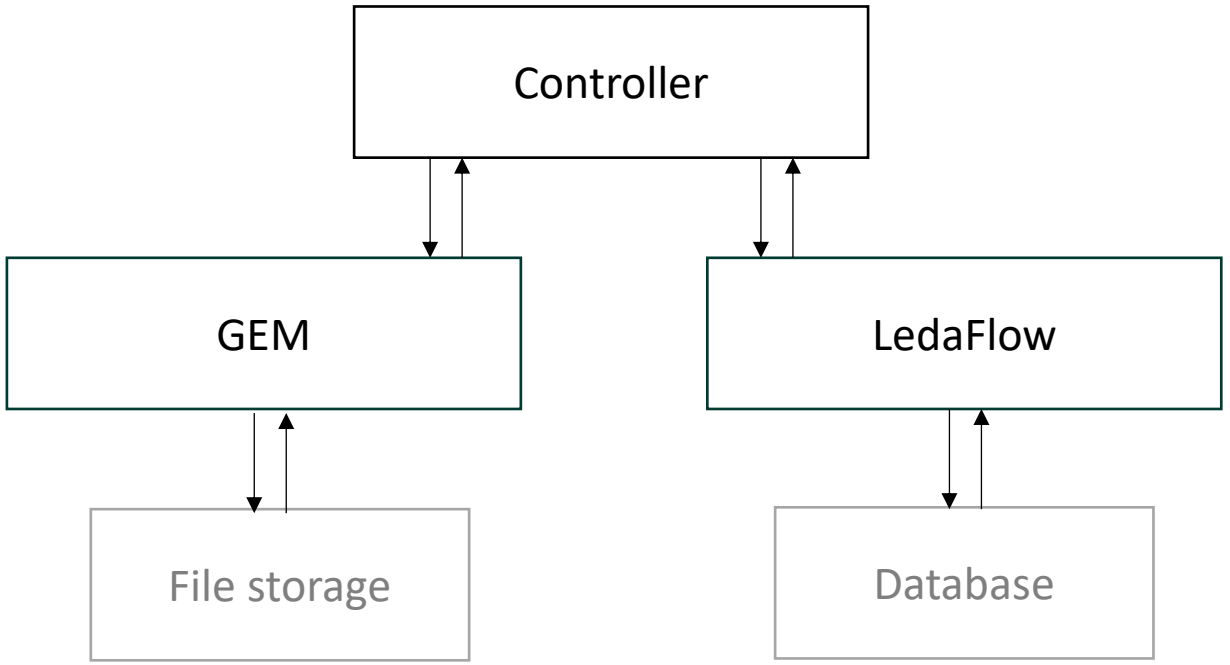
(a) Structural/stratigraphic trapping (b) Residual trapping

(c) Solubility trapping (d) Mineral trapping

CO2LINK – Wellbore & Transients

Coupling Concept: Software Architecture

1. A controller application has been developed as part of the GELECO2 JIP (12 industry partners)
   - Alternates running LedaFlow and GEM
2. Time-step for the information exchange between the simulators can be set by the user
   - GEM and LedaFlow each have their own numerical time-stepping (automatic)
3. Also supports fast-forwarding LedaFlow
   - No need to run LedaFlow all the time if there are no dynamics (i.e. steady-state injection)

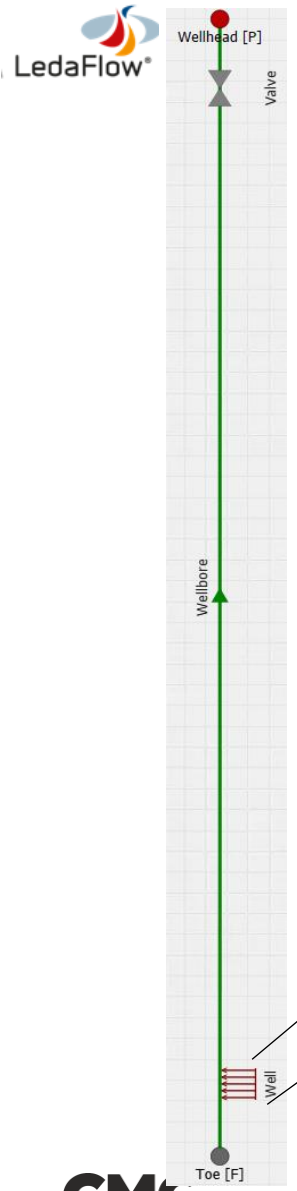


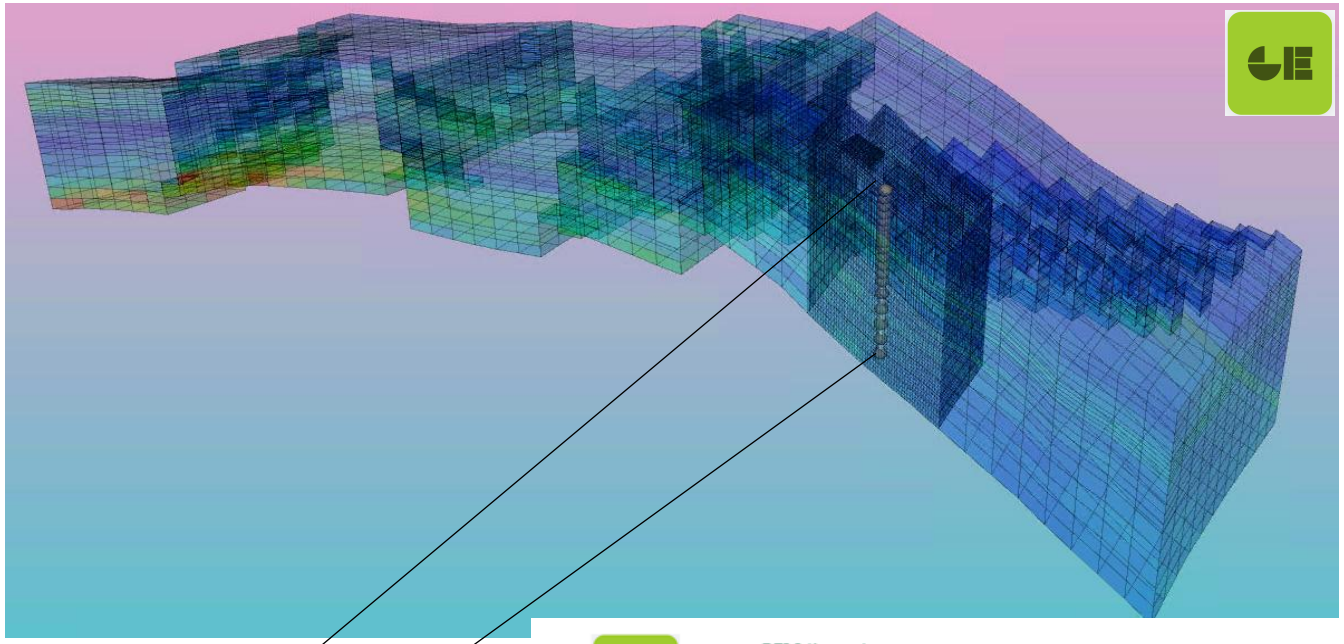
Ledaflow Application Areas

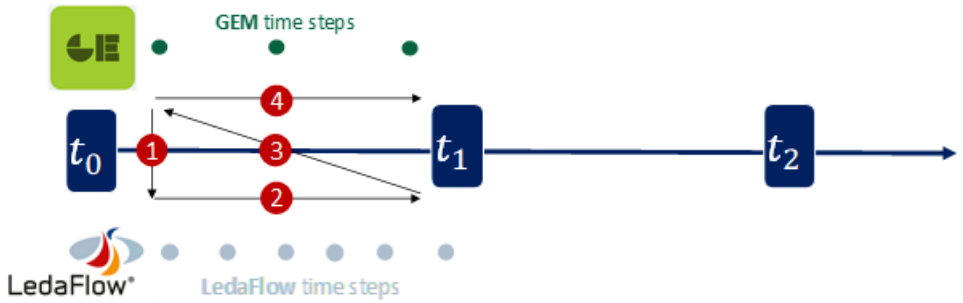
Oil & Gas production

CO2 transport and injection

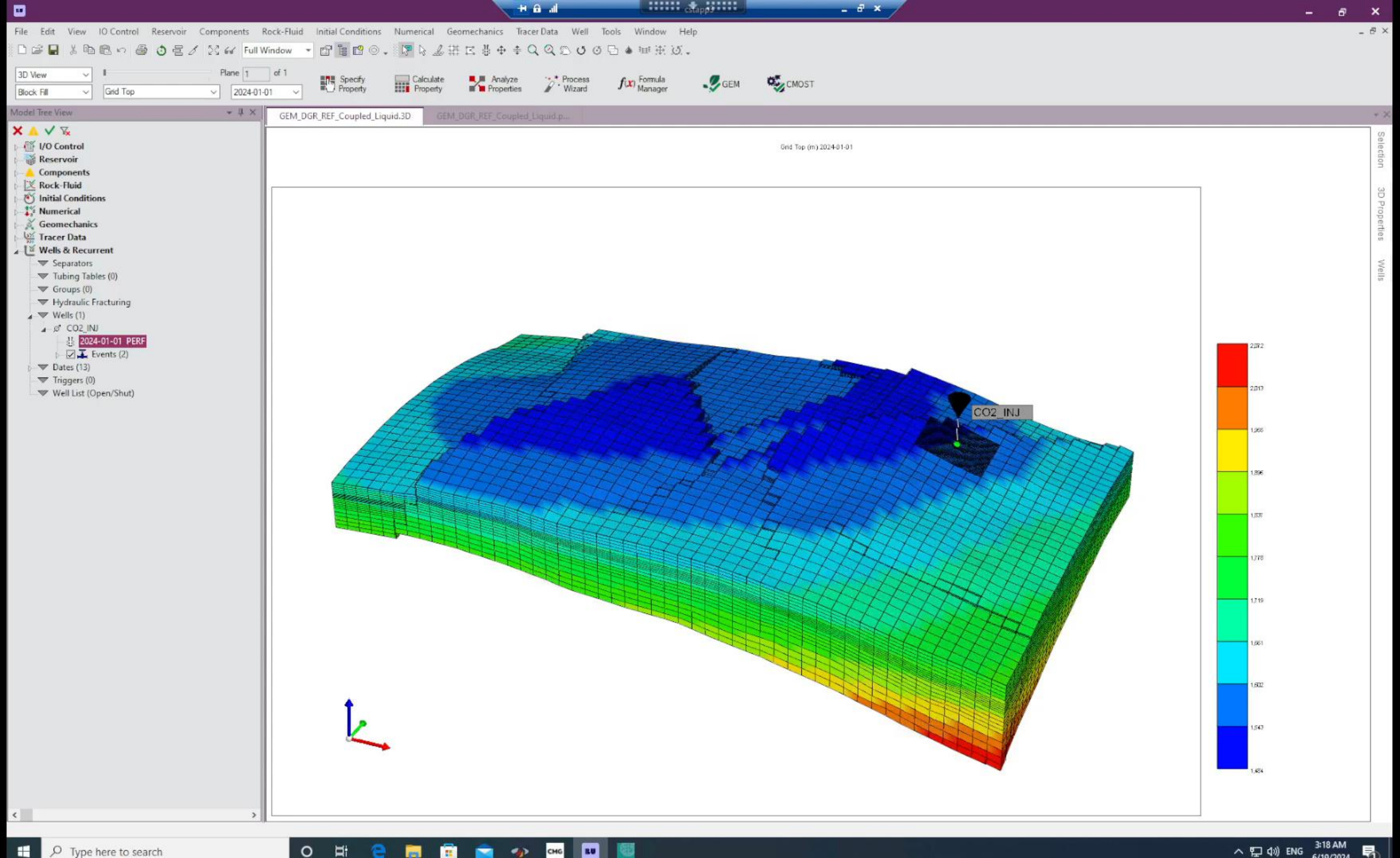
GEM LedaFlow Communication







1. **GEM** Generates IPR_0
2. **LedaFlow** takes $\mathbf{IPR}_0$ and marches to t_1.
3. **LedaFlow** generates q_1 and passes it **GEM**
4. **GEM** marches to t_1 and generates $\mathbf{IP}R_1$


File Edit View IO Control Reservoir Components Rock-Fluid Initial Conditions Numerical Geomechanics Tracer Data Well Tools Window Help
Full Window
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Specify Property
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Wells (1)
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Triggers (0)
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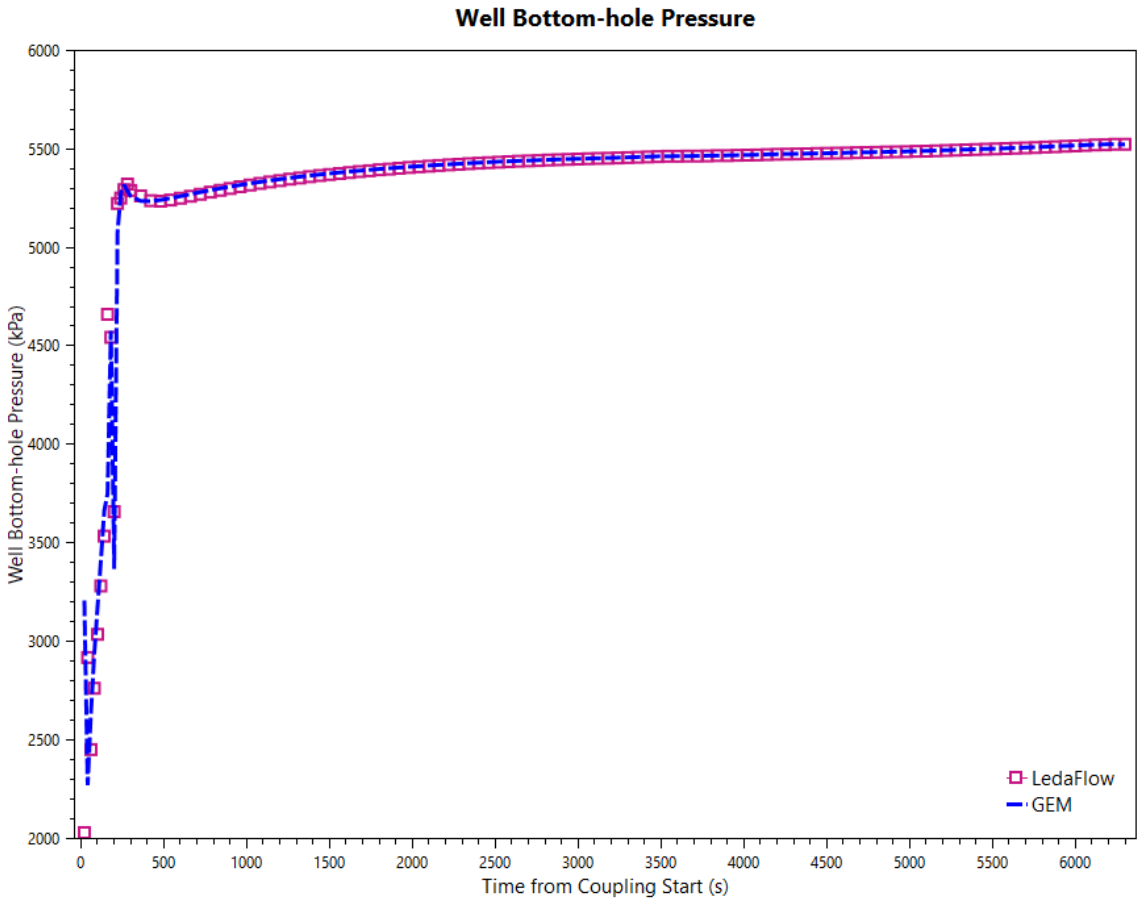
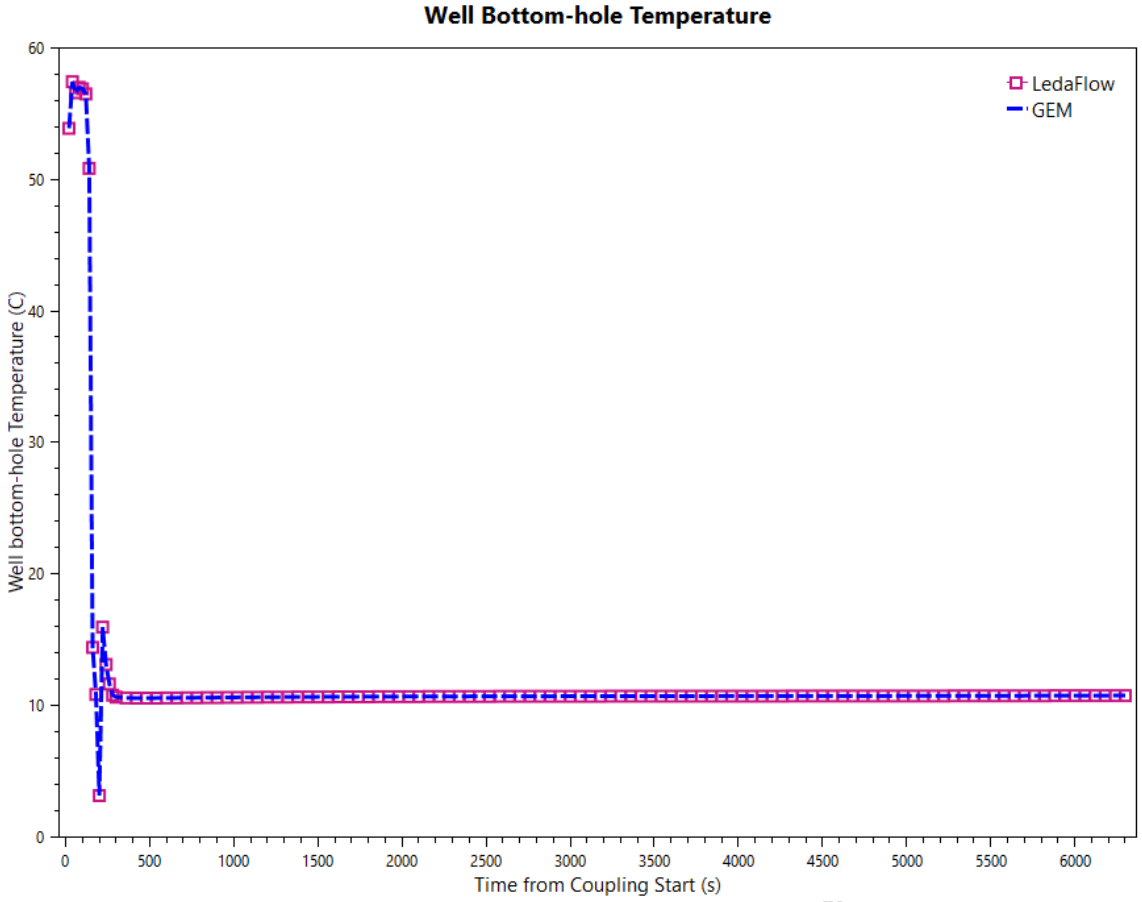
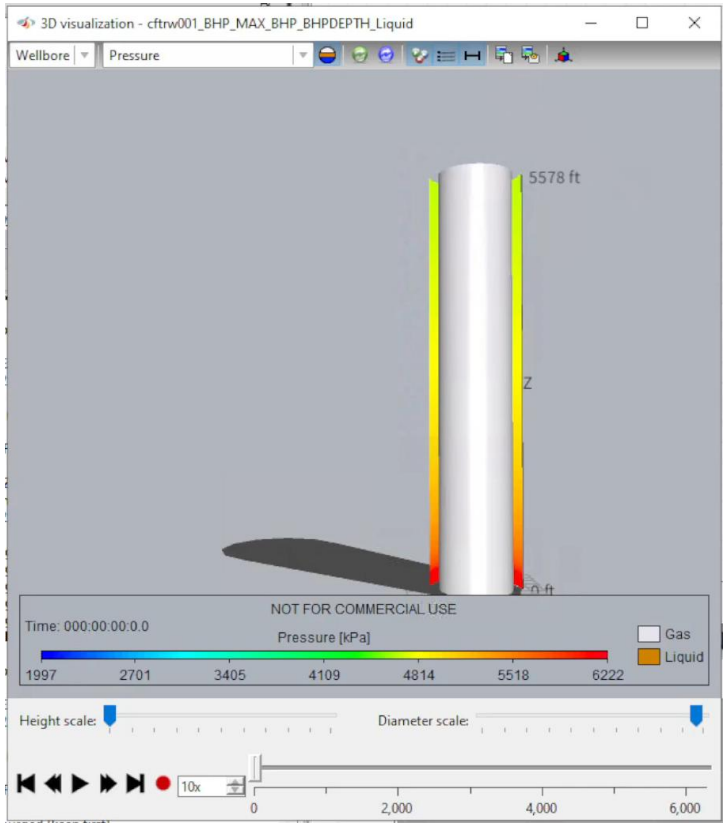
Simulation Example – CCS in Depleted Gas Reservoir

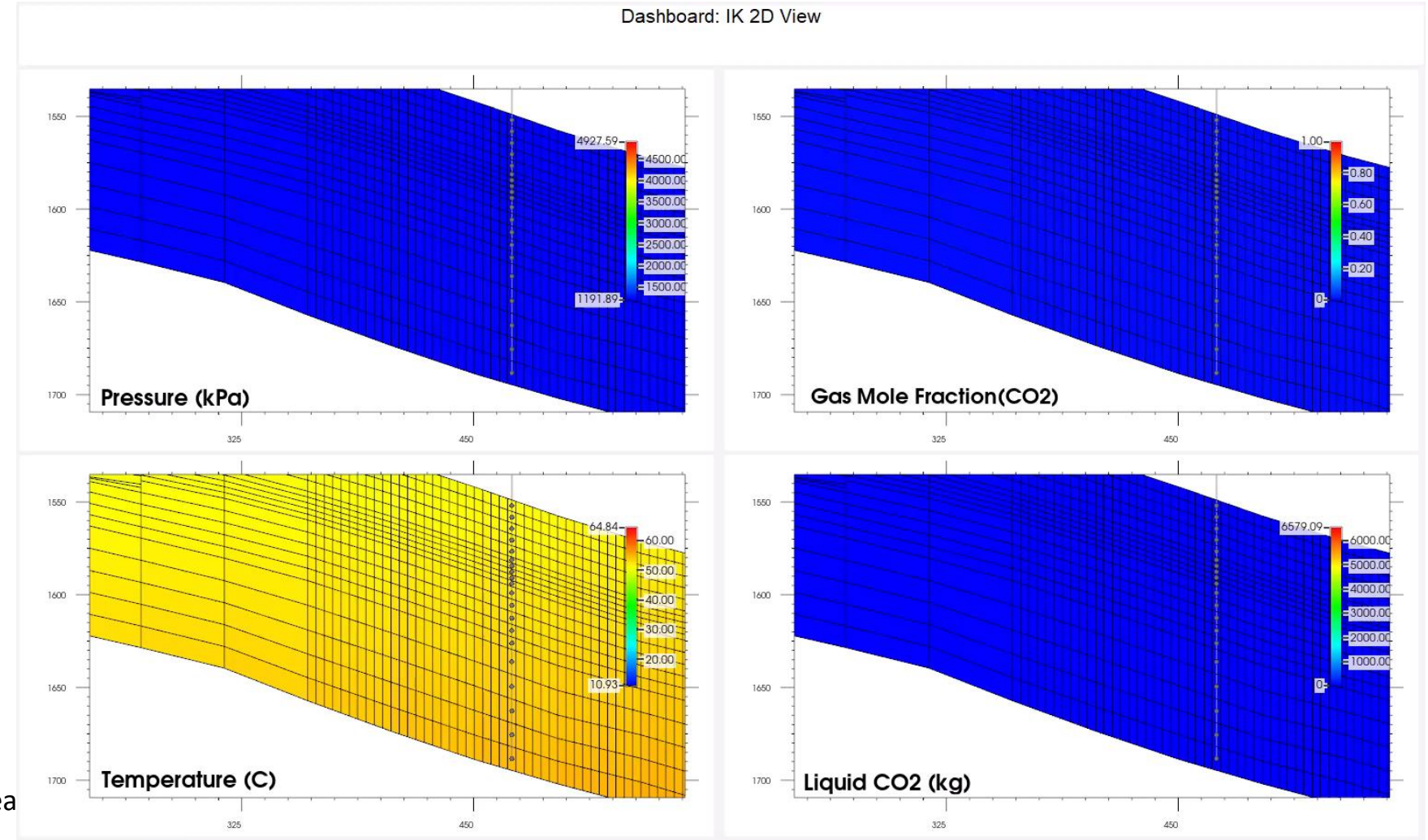
- CO2 injection at 4 C and 40 bar at wellhead.
- Injection rate maintained at 2e6 m^3/day.
- Depleted formation at 12 bar and 50 C.
- Saturated with water and 7-component gas composition





Simulation Example – CCS in Depleted Gas Reservoir



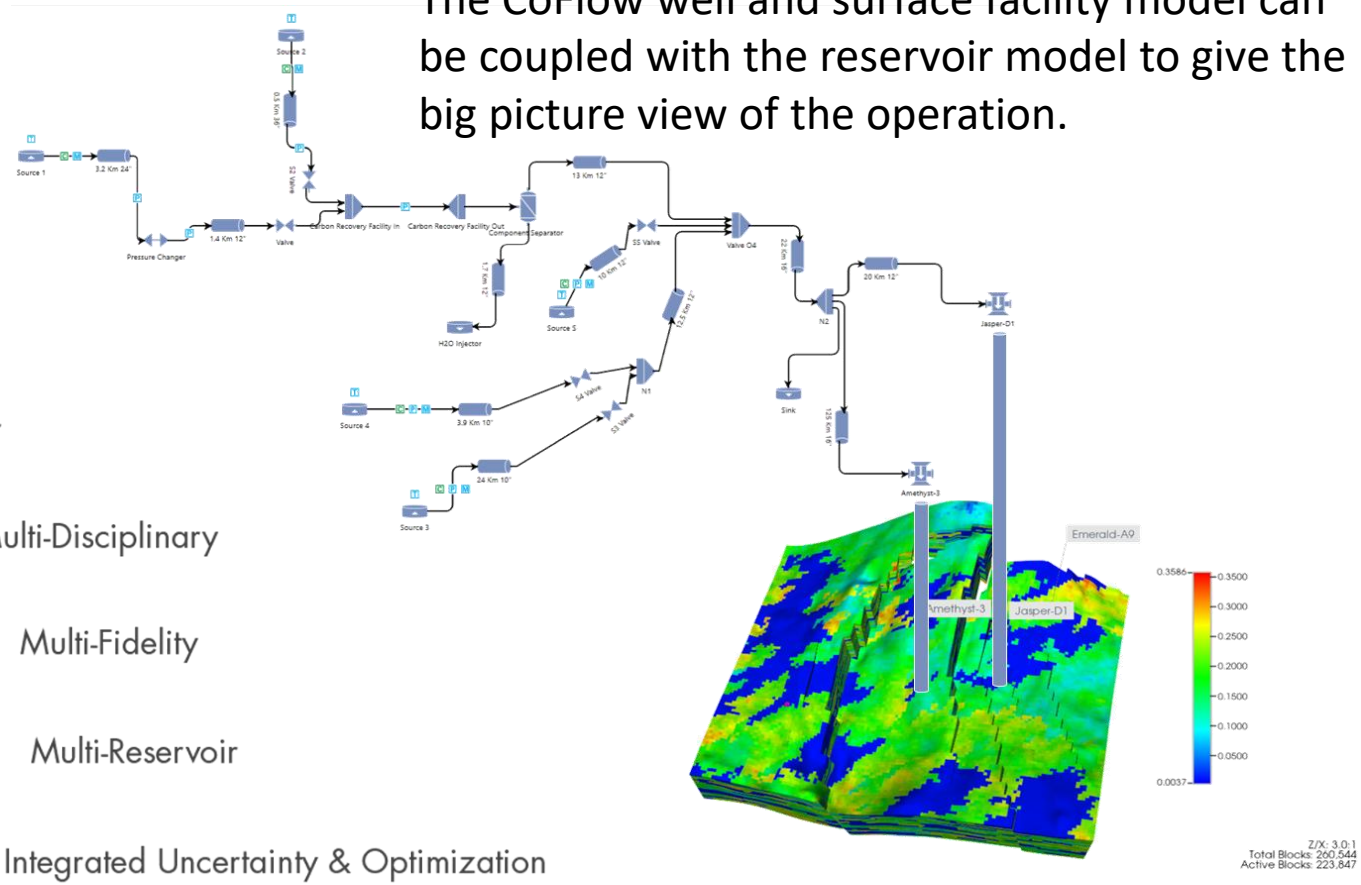


- CO_2 phase change across wellbore during start-up
- Dynamic P/T change inside the wellbore
- Pressurizing & cooling near the wellbore area
- CO_2 phase change near the wellbore

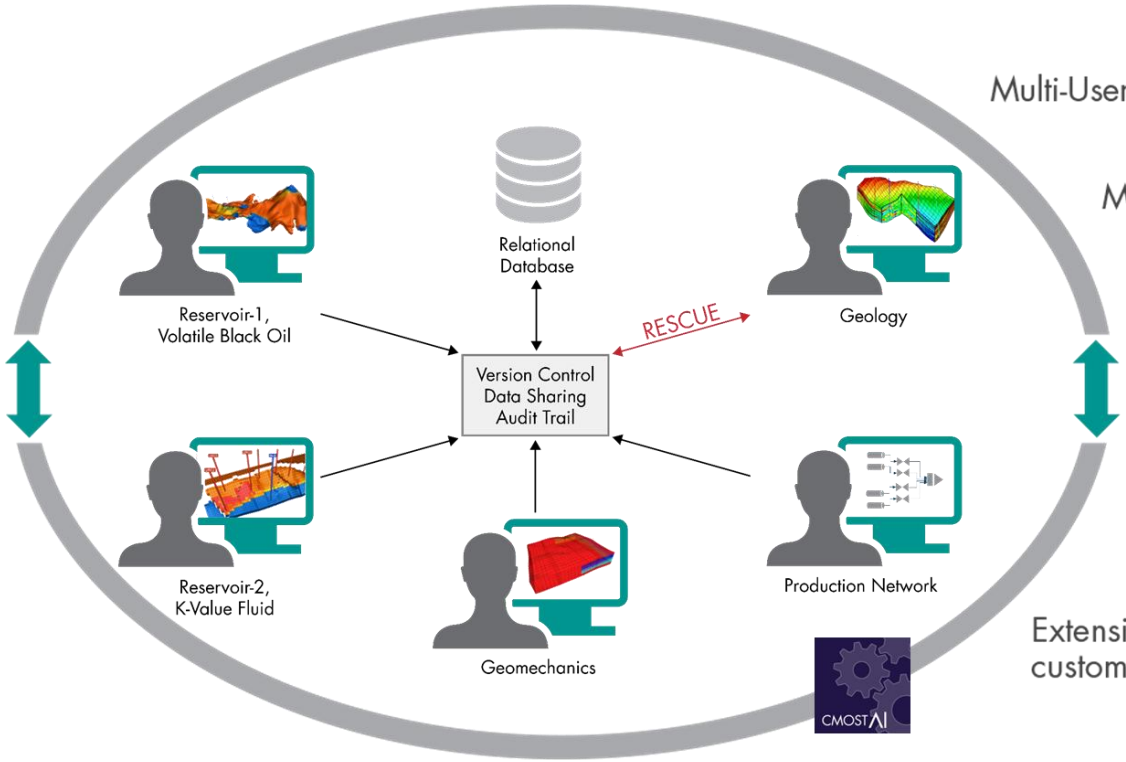
CoFlow – Long-Term Planning & Steady State

CoFlow – Steady-state Simulator

The CoFlow well and surface facility model can be coupled with the reservoir model to give the big picture view of the operation.



CoFlow's Modern Approach to integrate subsurface and surface systems



Multi-User

Multi-Disciplinary

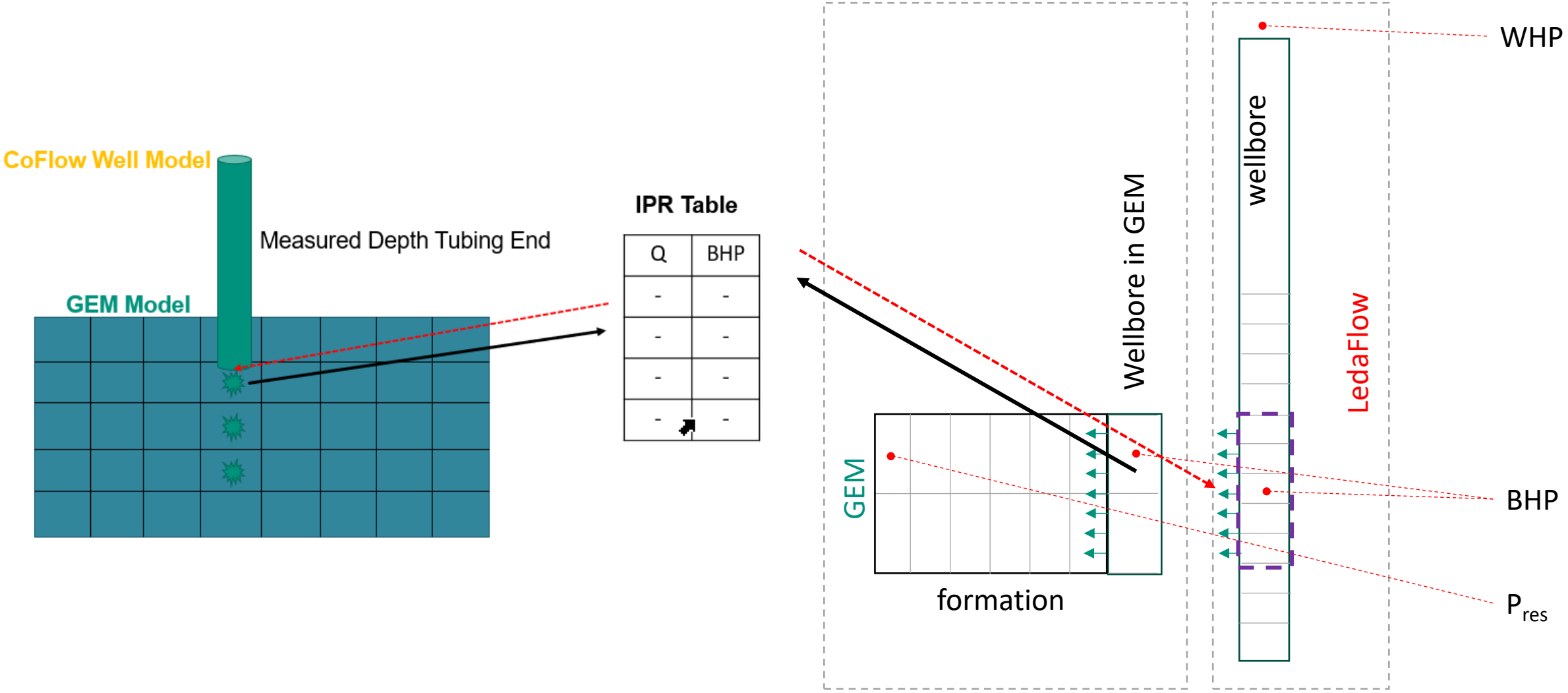
Multi-Fidelity

Multi-Reservoir

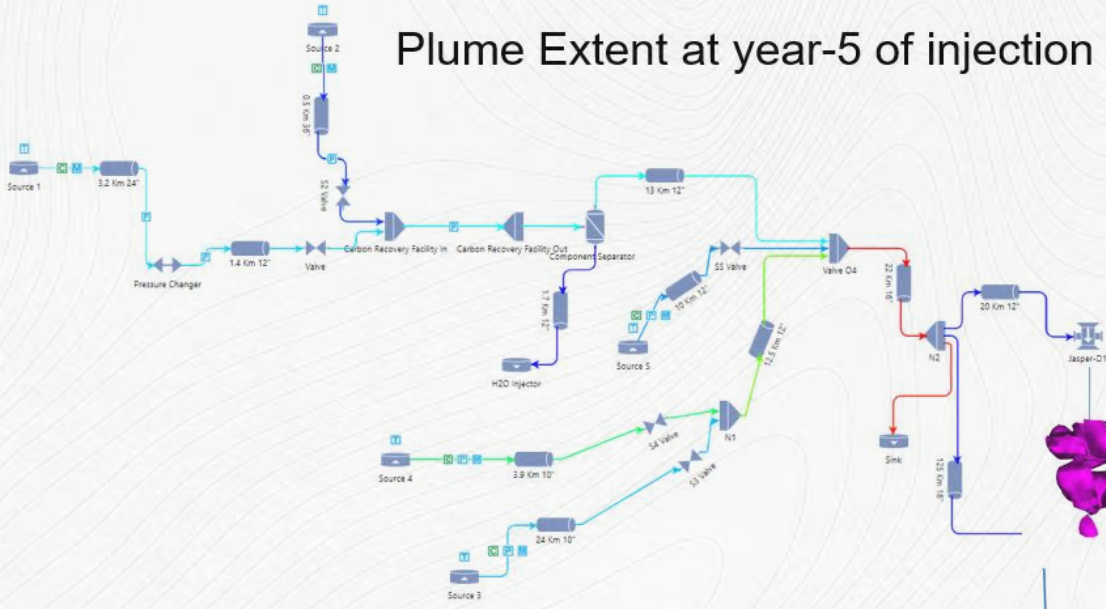
Integrated Uncertainty & Optimization

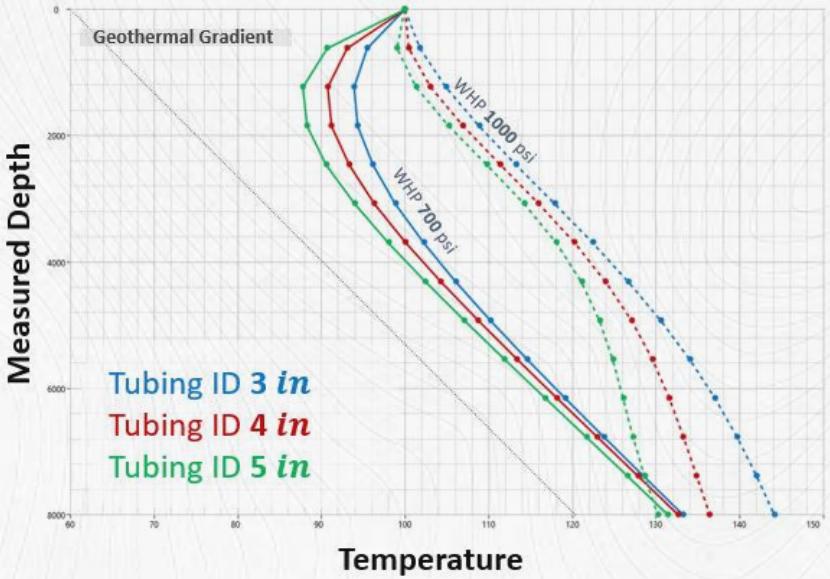
Extensible, allowing for full customization & plug-ins

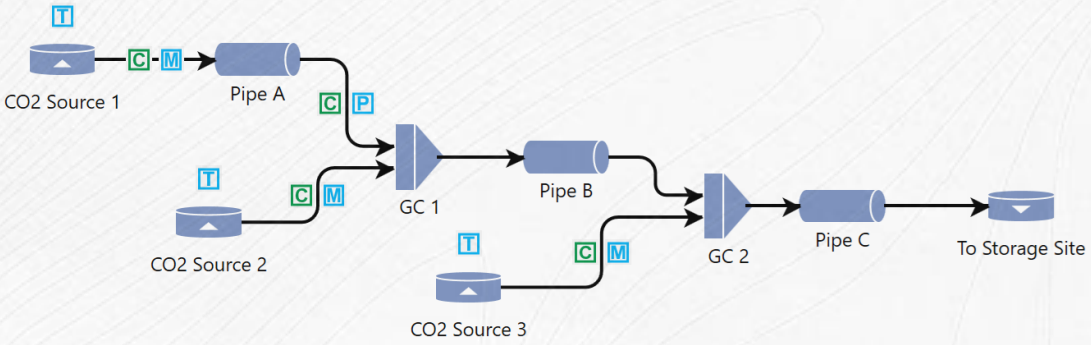
Coupling Concept

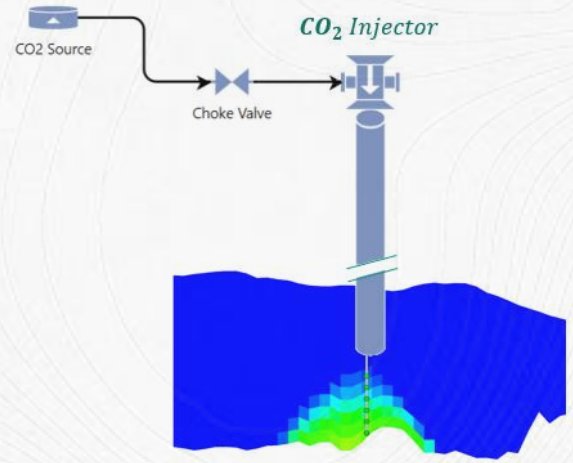


CoFlow : Connecting Subsurface to Wells & Facility





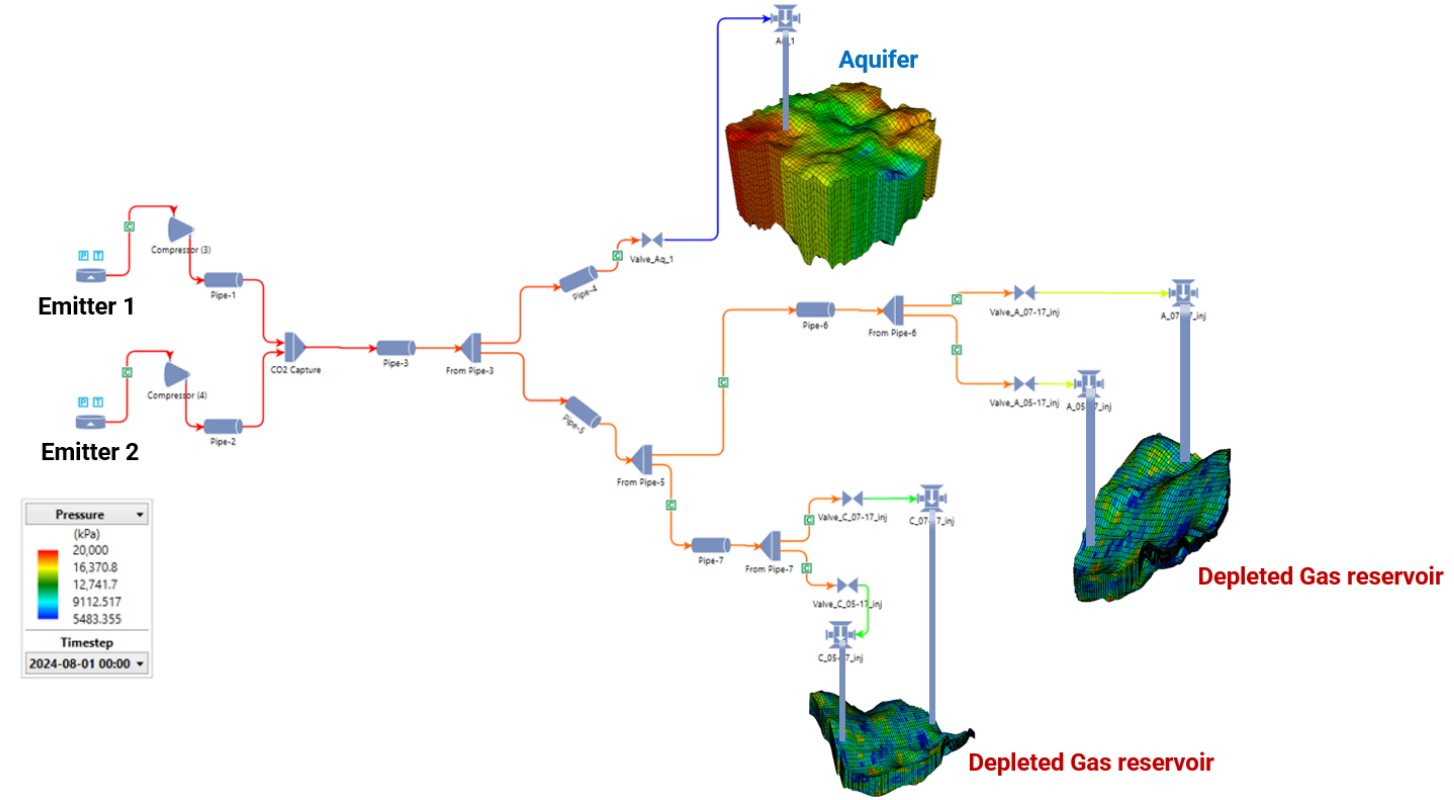


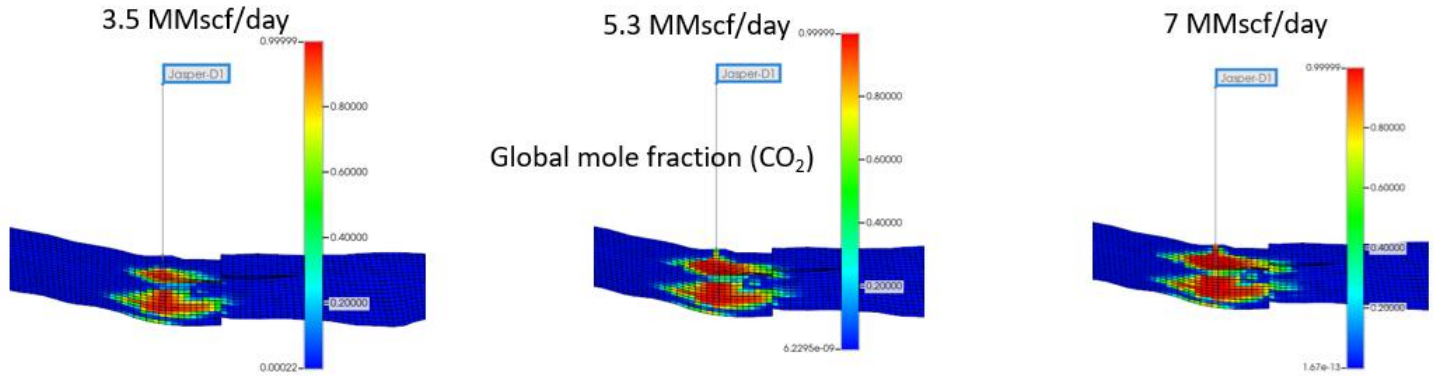


End-to-End Modelling for Hybrid Depleted Field + Aquifer CCS

Long term storage modelling to consider:

- Multi-fluid blending in facilities → Different emitters flowing into one injection system
- Distribution & optimization of CO2 injection between multiple storage sites
- CO2 phase behavior from capture to sandface – single phase or transitioning?
- CO2 injection conditions & properties at sandface
- Geomechanical impact in subsurface & long-term storage predictions
- What-if scenarios, optimization, …





Changing one characteristic will generally have an impact on all of the others.

HOW IS IT BEING USED?

Trudvang, Norway

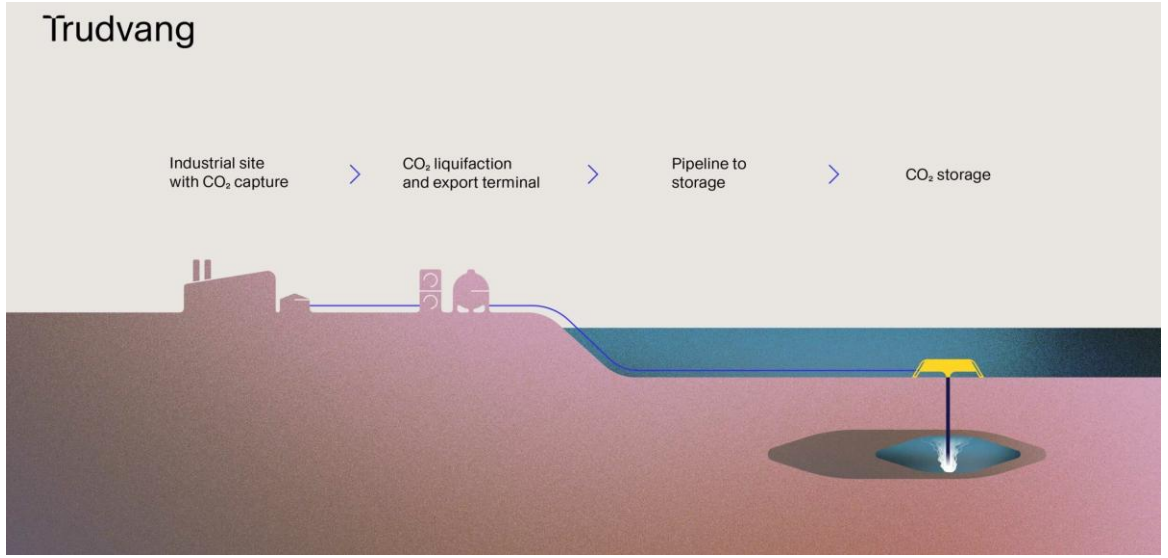
Massive injection project in Utsira formation – that has safely stored CO2 for +30 years!

The Project

At pre-FEED, reference case being identified

- +10 MMTPA
- +300 MMT capacity
- Phase-1 est. start date 2029

Source: Trudvang-ccs.com



Source: Trudvang-ccs.com

How is CoFlow helping?

1. **Get right inlet conditions for CO2 → Geomech. significance**
2. **Test facility scenarios – Assist in ref. case picking**
3. **Optimal design to ensure dense phase CO2 injection**
4. **Well scheduling plan to ensure capacity utlization**

Global CoFlow Customers & Assets

Questions & Discussion