能源转型背景下的数值模拟技术

Energy Transition Enabled by CMG

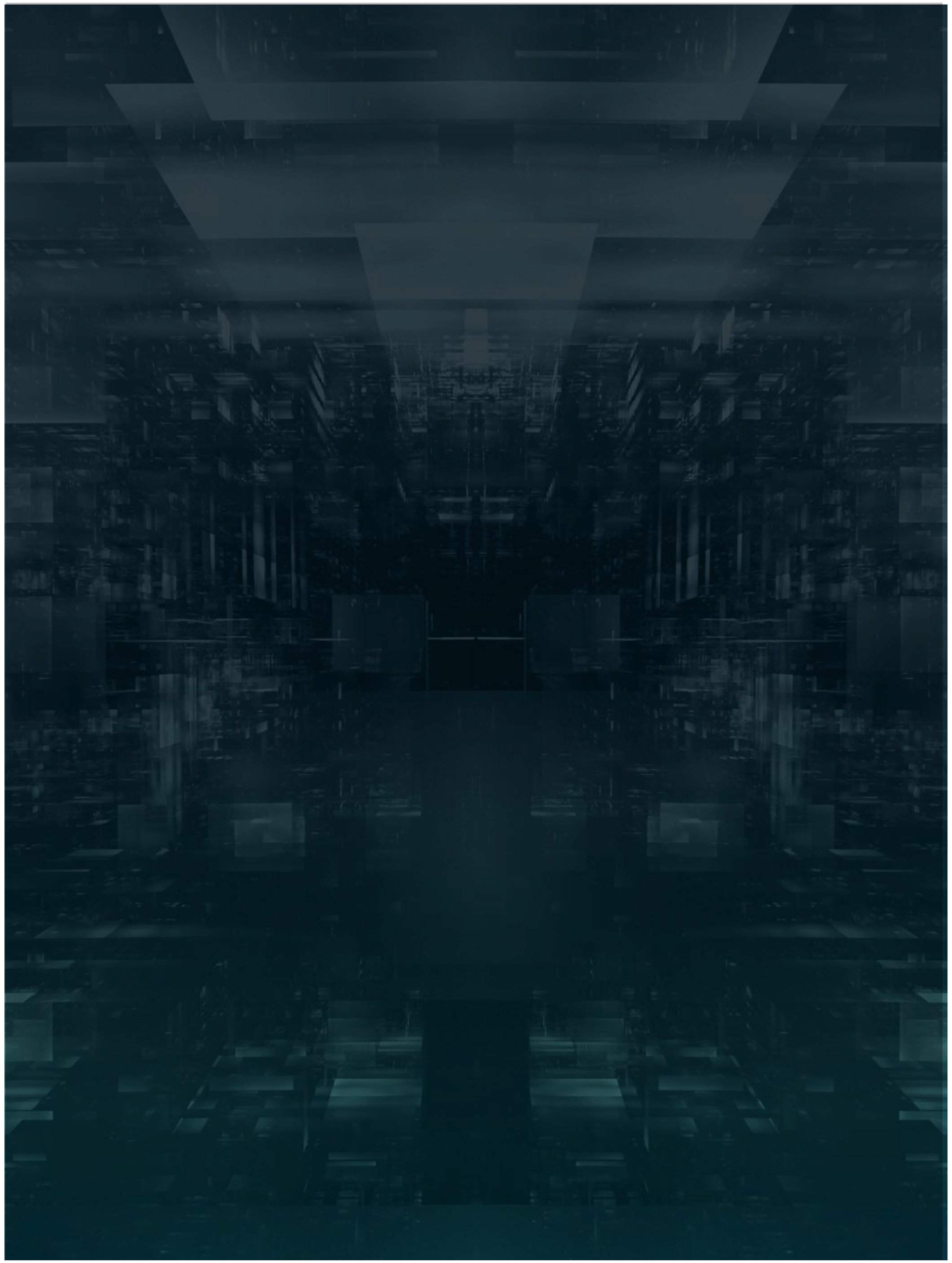
AGENDA

1 Introduction

2 Geothermal

3 CO_2 Storage

4 Lithium Extraction and H_2 Storage



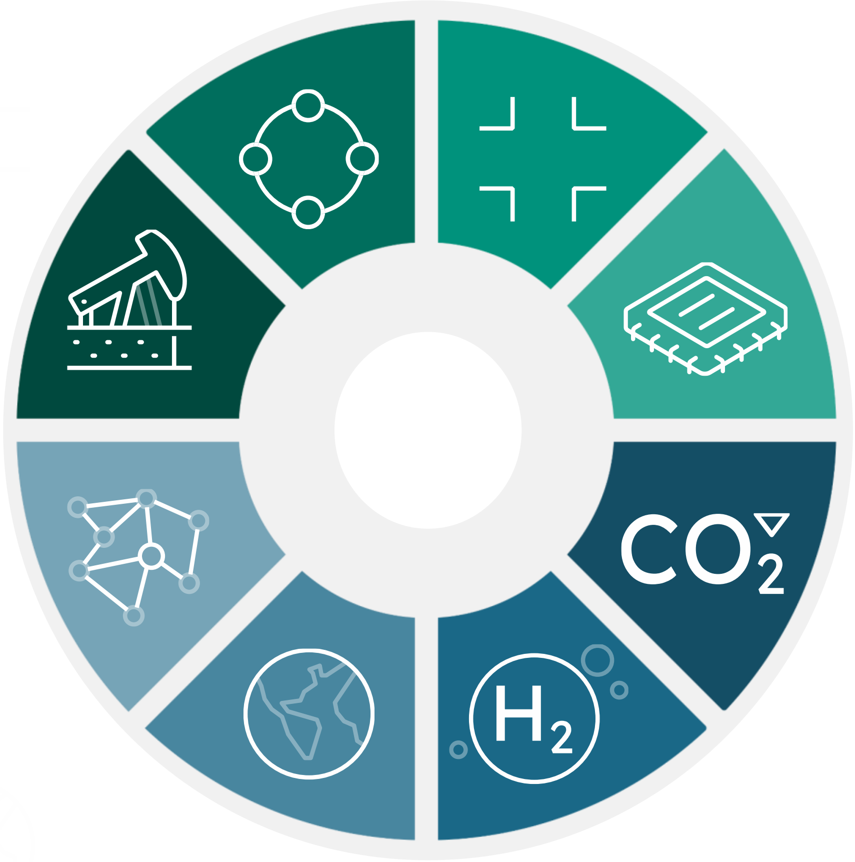
OUR EXPERTISE

CMG has a rich history of bringing industry-first solutions to the market

Our expertise spreads across a broad spectrum of energy workflows, and our technology can help energy companies navigate this complex landscape.

Traditional Oil and Gas

Conventional | Enhanced Oil Recovery | Unconventional | Heavy Oil



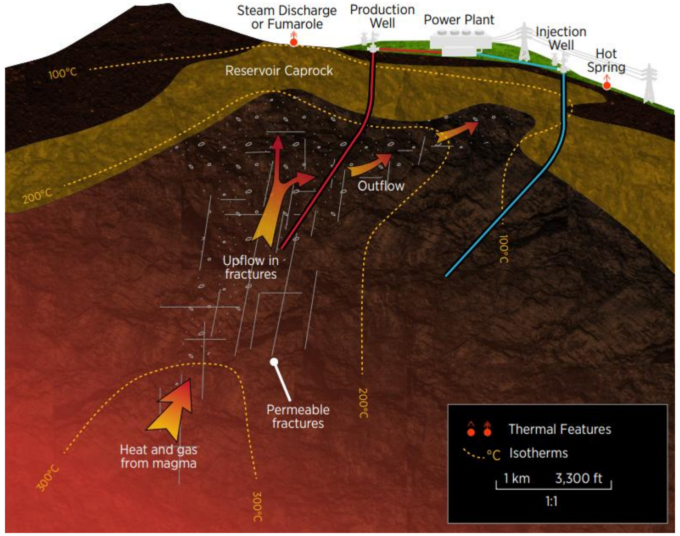
Energy Transition

Emerging Technologies | Geothermal | Hydrogen Storage & Production | Carbon Capture Storage (CCS)

Geothermal

Geothermal techniques modelled by CMG

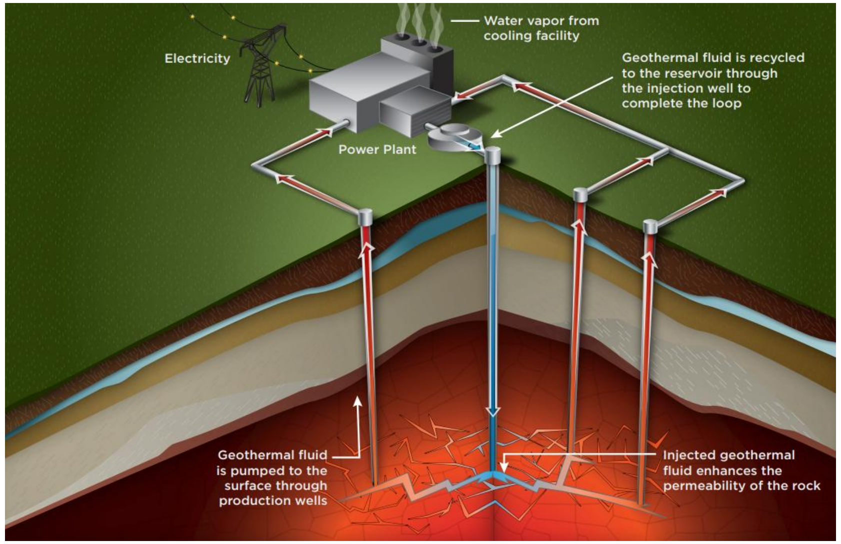
CONVENTIONAL (HYDROTHERMAL)



Source: GeoVision Analysis 2019, US DOE

- Heat, water, permeability present
- Hot water and steam production
- Water injection for pressure maintenance

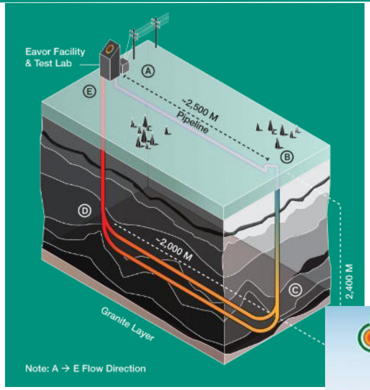
ENHANCED GEOTHERMAL SYSTEMS (EGS)



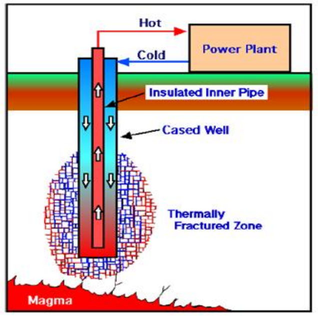
Source: US DOE, 2016

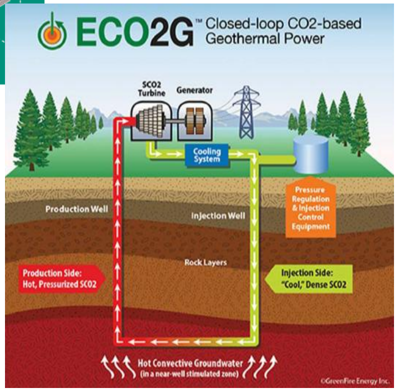
- Hot dry rock, no permeability
- Hydraulic fracture for permeability creation
- Hot water injection for circulation
- Hot water and steam production

CLOSED LOOP SYSTEMS



Source: Eavor.com



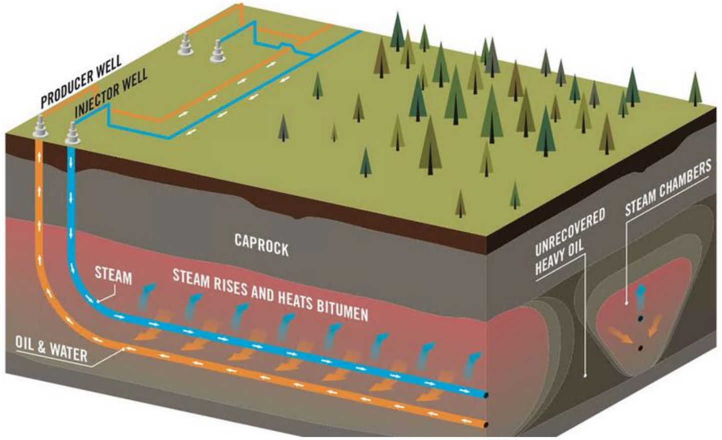


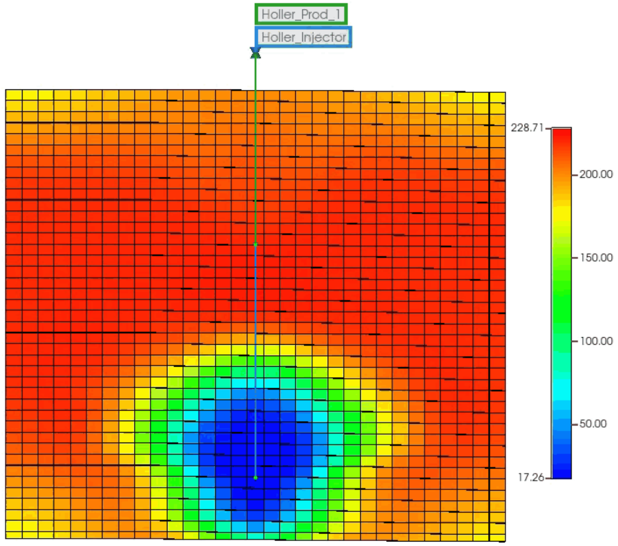
Source: GreenFire Energy

- No interaction of well & reservoir
- Only fluid recirculation, injected fluid heating via conduction

Geothermal techniques modelled by CMG

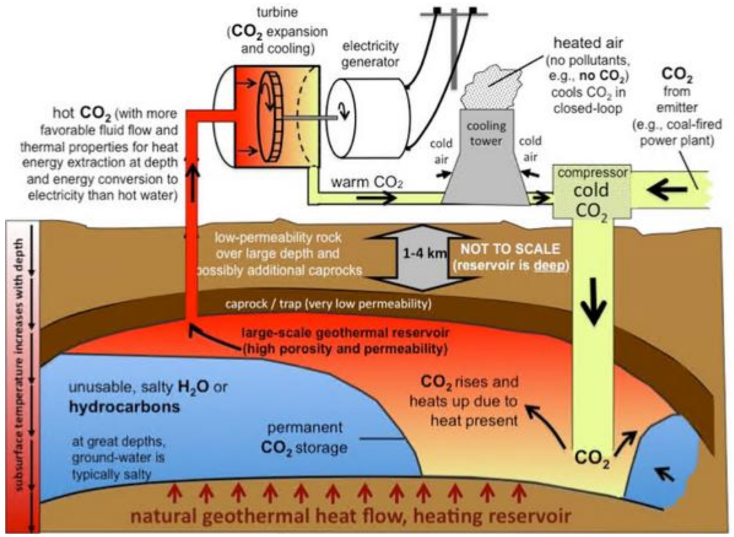
Heavy Oil Late Life Energy Recovery (HOLLER)





- SAGD wells near end of life
- Mature reservoirs at high temperatures (~300 F) used as a heat recovery medium
- Hot water and steam production

CO2 Geothermal



source: geg.ethz.ch

- Heated CO2 in a closed loop used to heat air to generate electricity
- Part of CO2 will be stored permanently in an aquifer underground

Physics in Geothermal Reservoirs

Fluid Flow in porous media

- Generally, naturally fractured reservoirs
- Hydraulic Fractures Modelling (Enhanced Geothermal Systems)

Heat Transfer

- Conduction/ Convection /Dispersion

Wellbore Heat Loss and Pressure Drop

- Wellbore conduction and convection for temperature drop
- Wellbore hydraulics calculations for pressure drop

Geomechanics

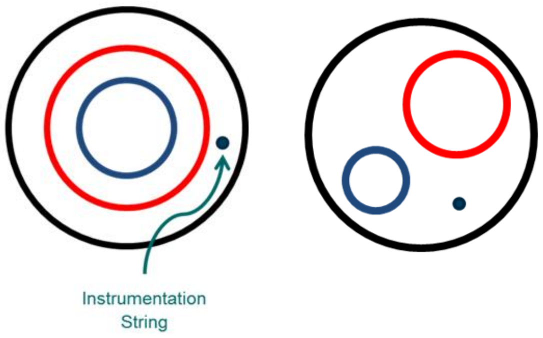
- Cap rock integrity / Thermal fracturing / Subsidence

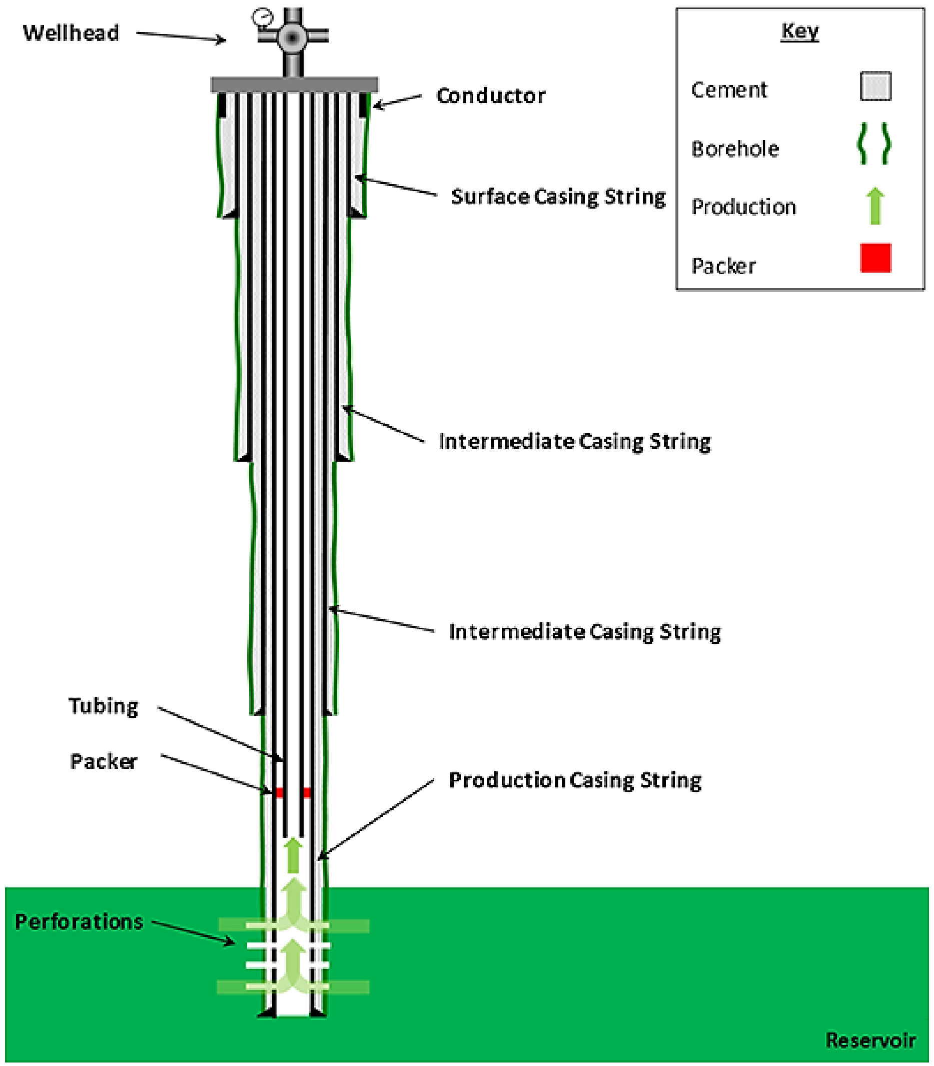
Geochemistry and Reactions

Geothermal Simulation: Wellbore Modelling

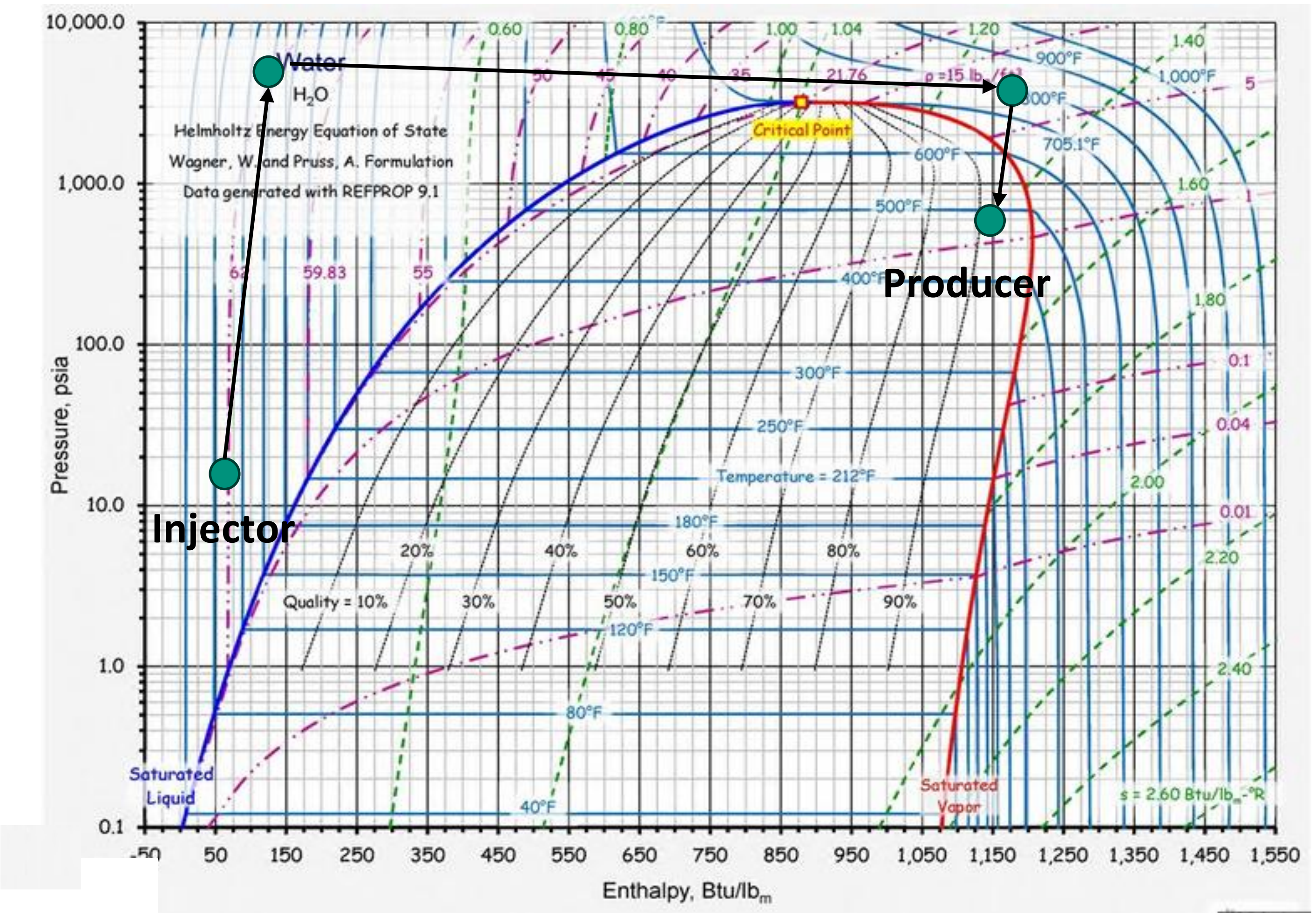
- Well calculations from first perforation to well-head:
  - **Semi-Analytical Model (SAM)**
  - **Flexwell**

- Flexwell can accurately handle:
  - Multiple tubing streams
  - Cross flow
  - Phase segregation
  - Different flow regimes





Water Enthalpy Model

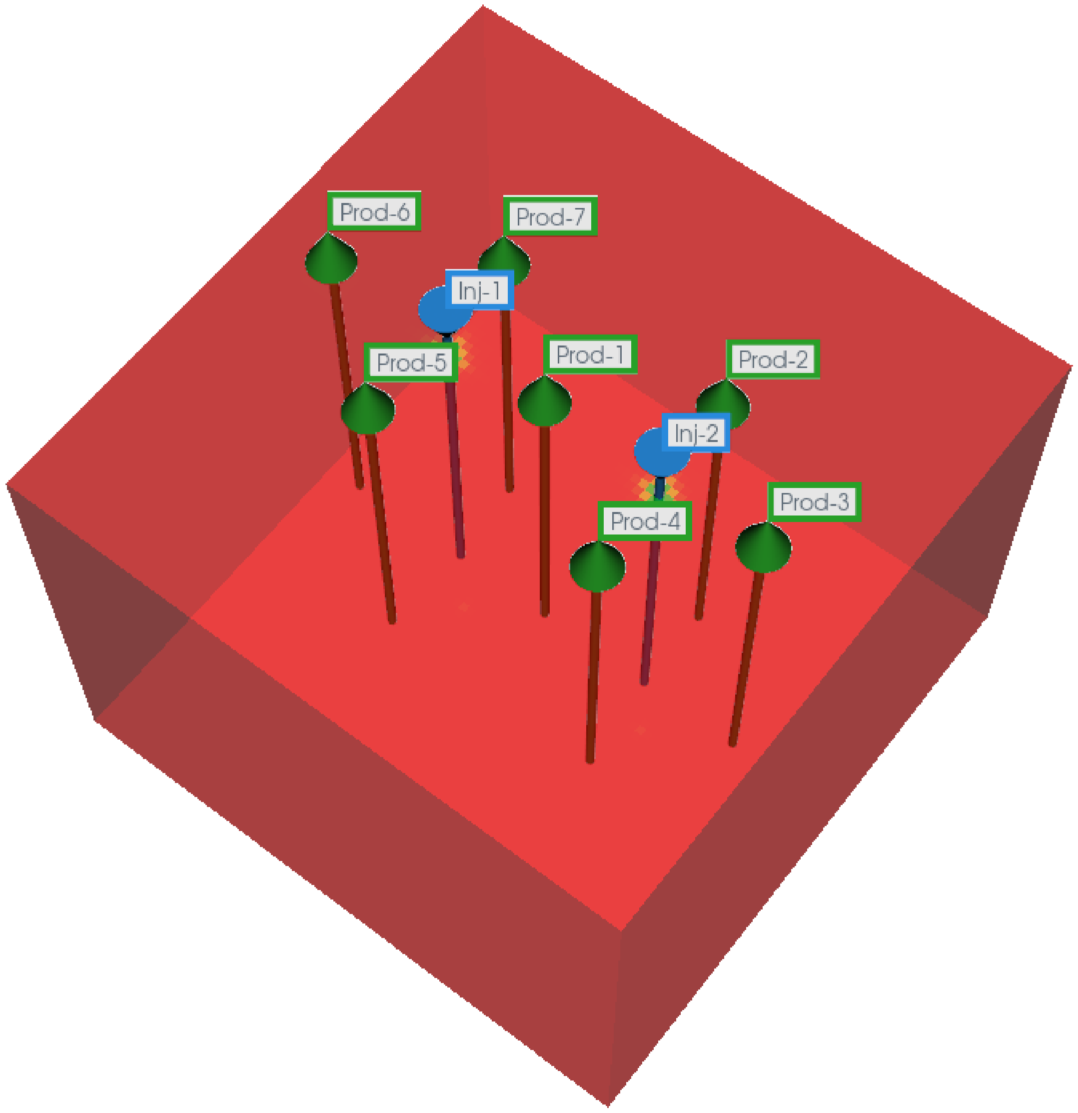


- **Steam Table for Water Enthalpy** Accurate table with higher resolution water enthalpy computation
- Modeling **Critical** and **Super-Critical** States of Water with **Flexible Wellbore**

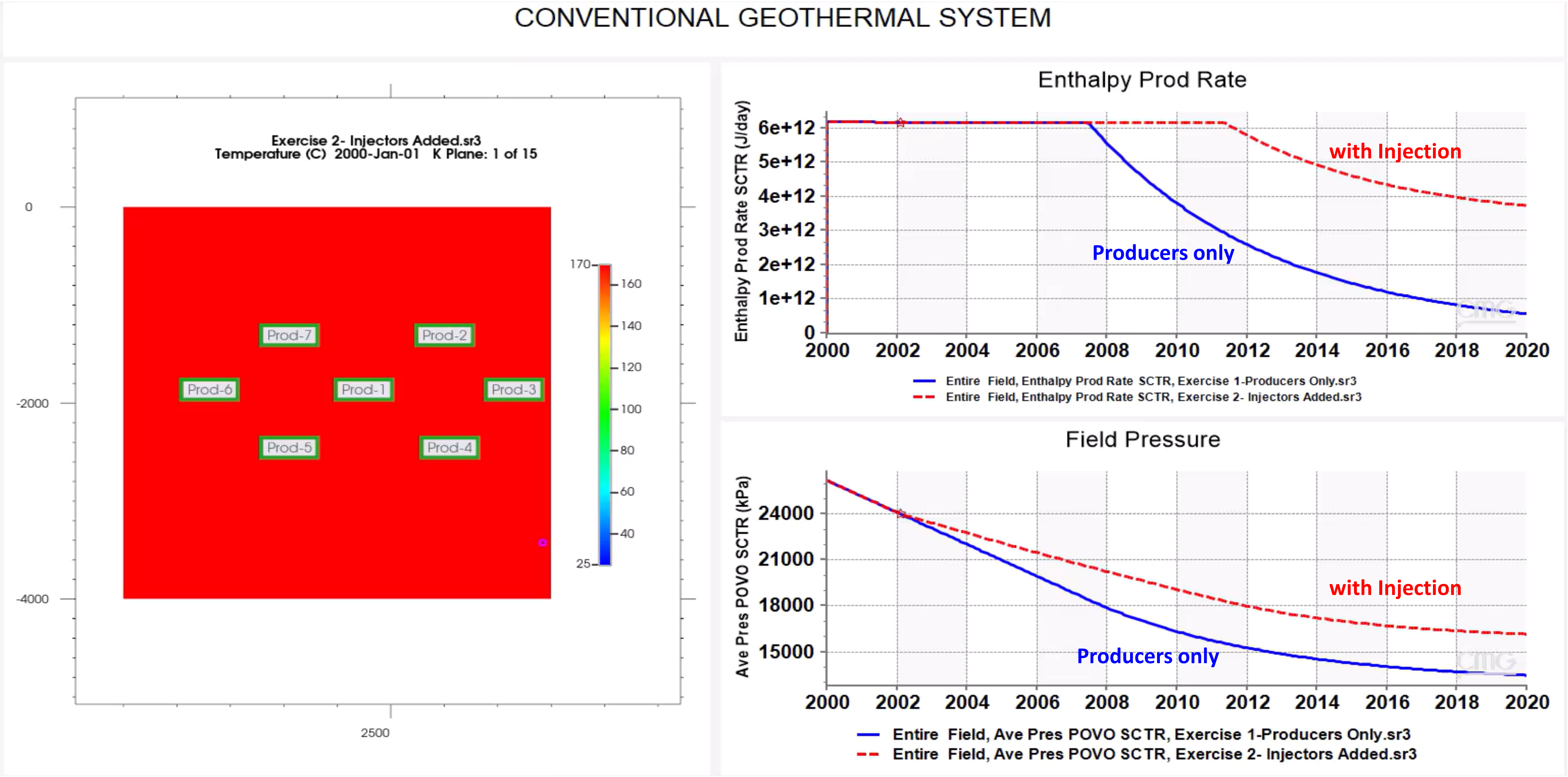
CMG

Conventional Hydrothermal – base model

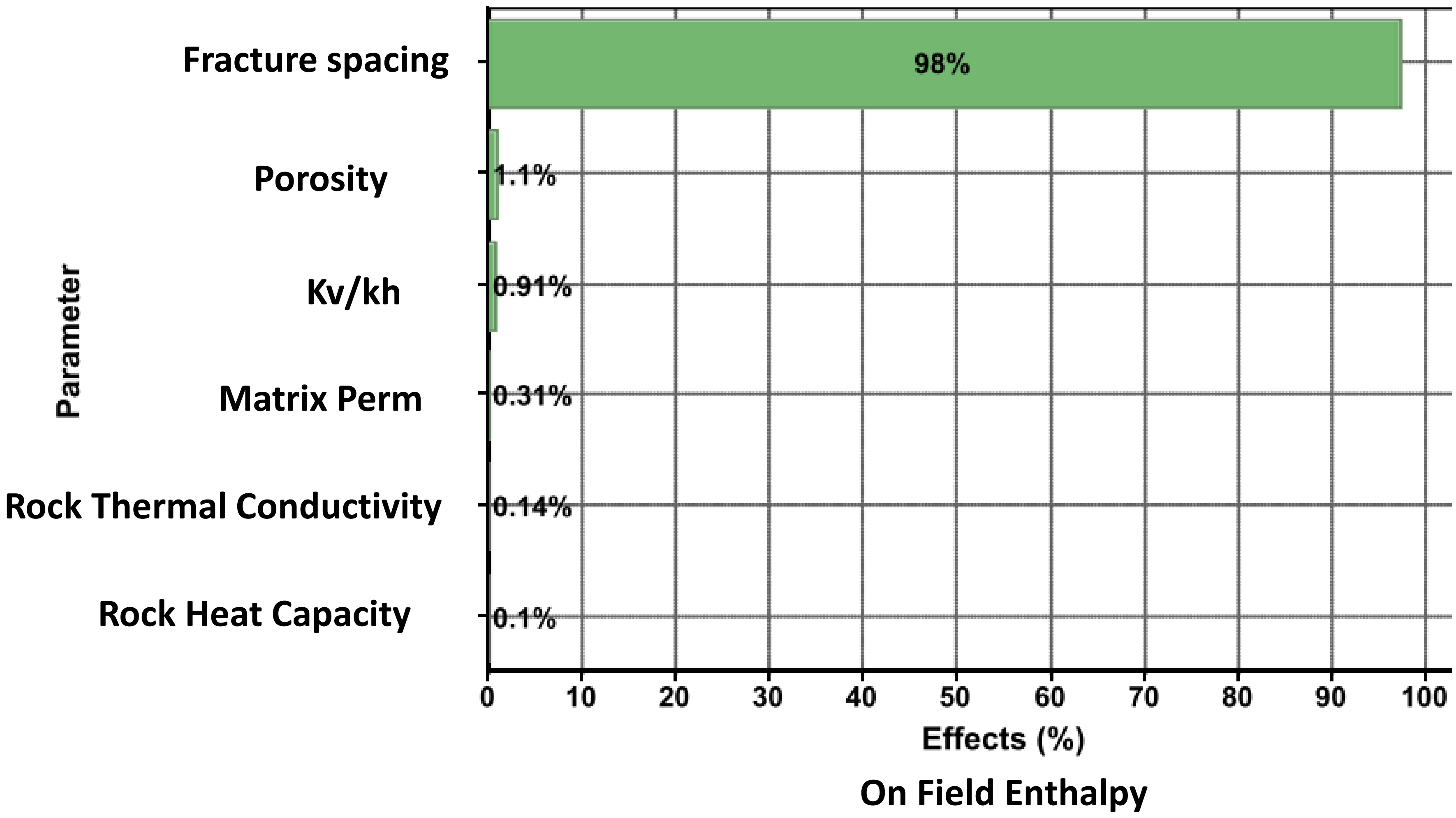
- Typical Geothermal resource, with a system of nat fractures
- T = 170 C, P = 26,000 kPa
- 7 Geothermal Wells
- Objective: Extension of Energy Production Plateau
- Injectors open based on pressure control



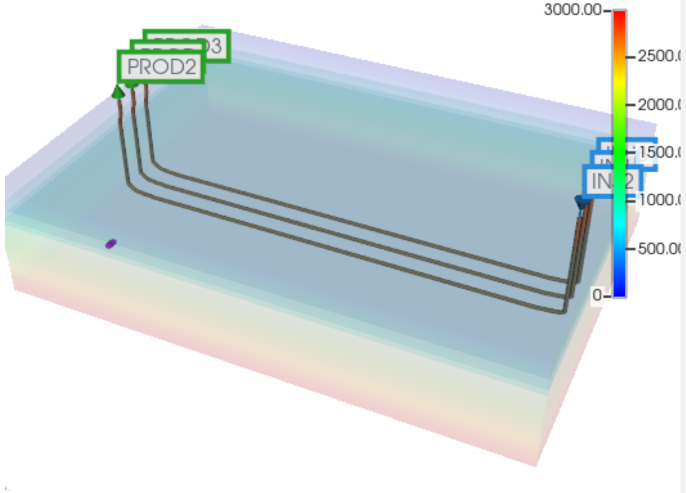
Conventional Hydrothermal – Results Analysis

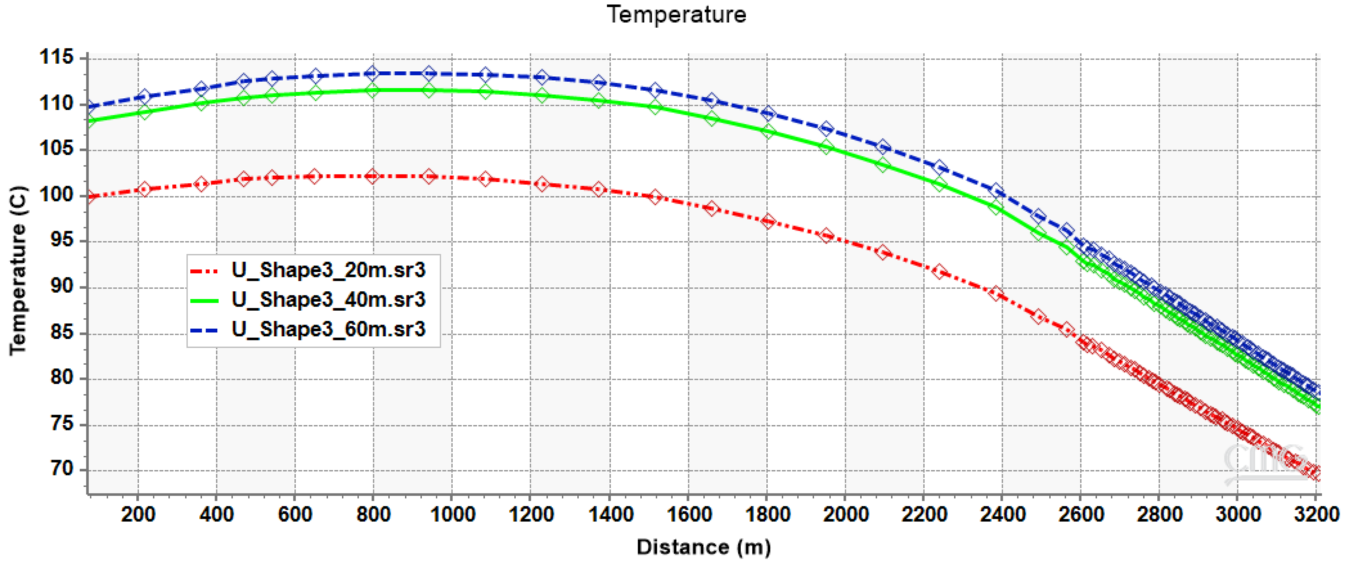


Conventional Hydrothermal – Uncertainty

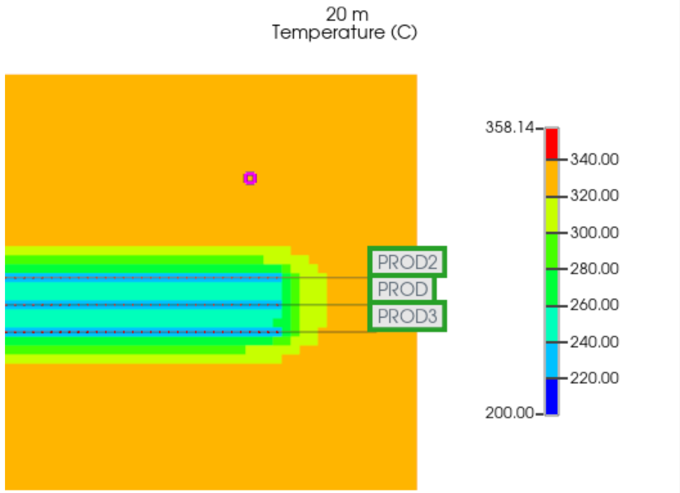


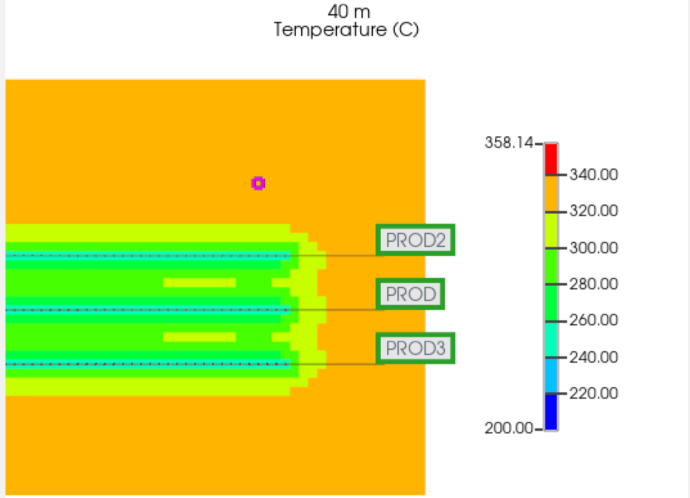
Closed Loop Geothermal- U-Shape Wells

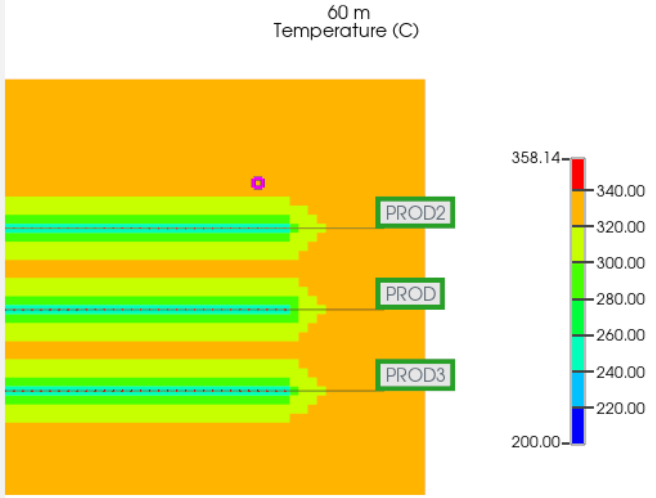




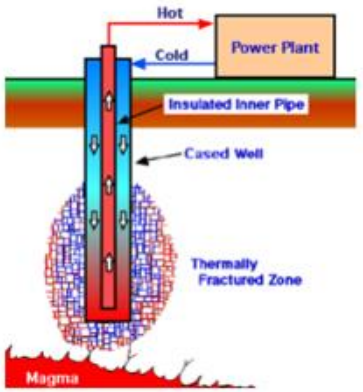
Increasing well spacing

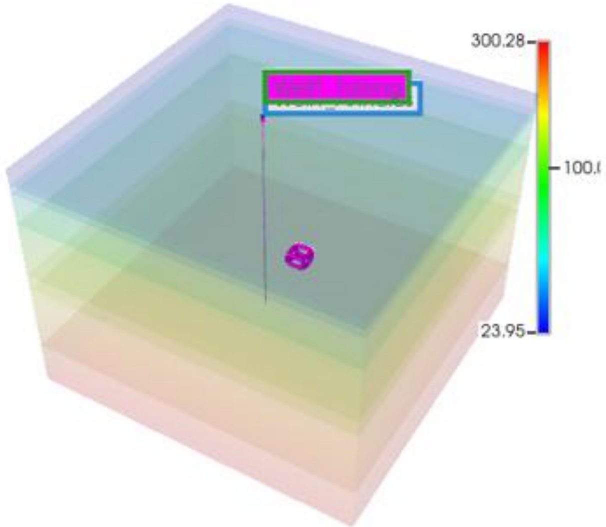


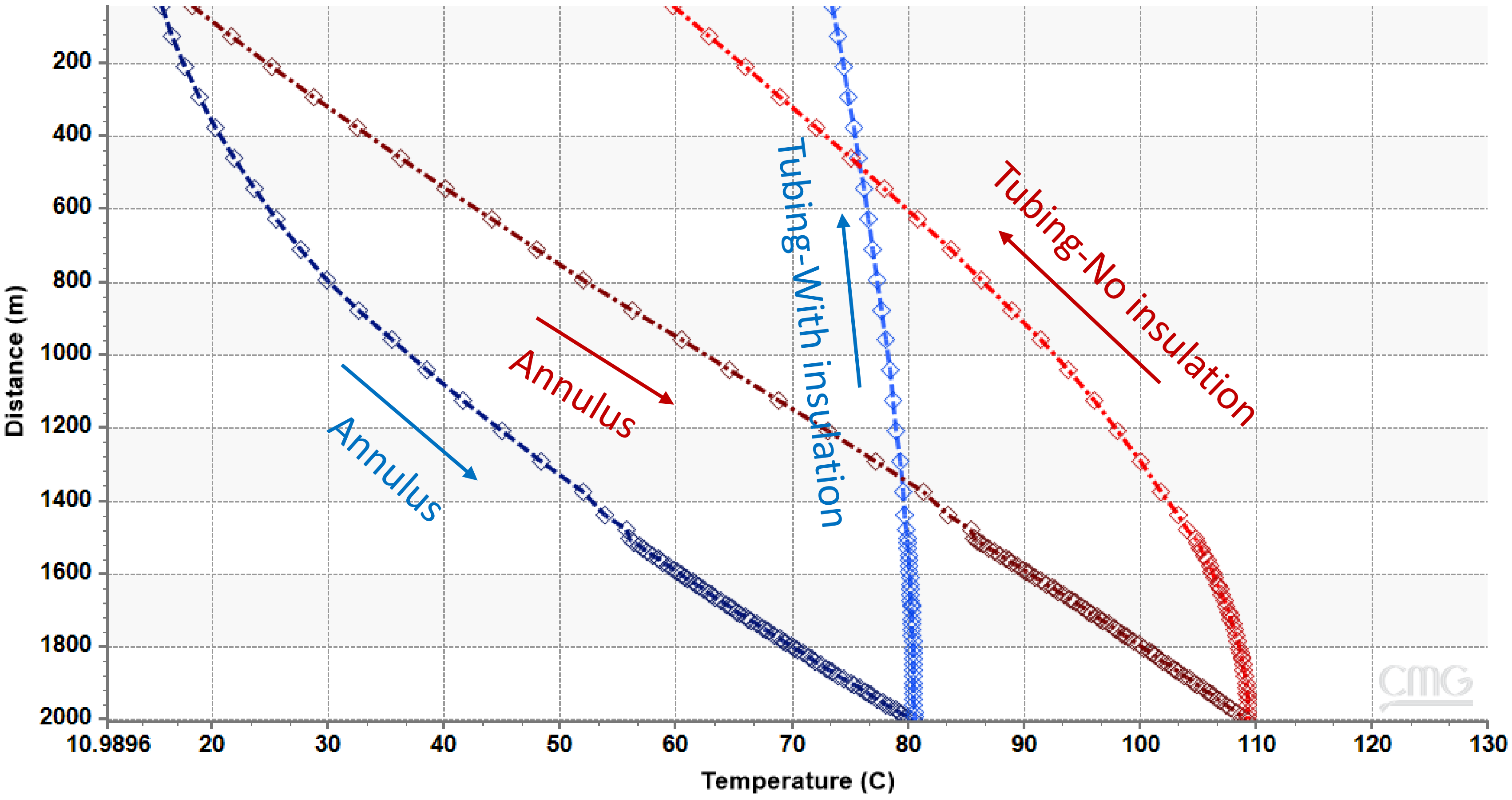




Closed Loop Geothermal – Single Vertical Well





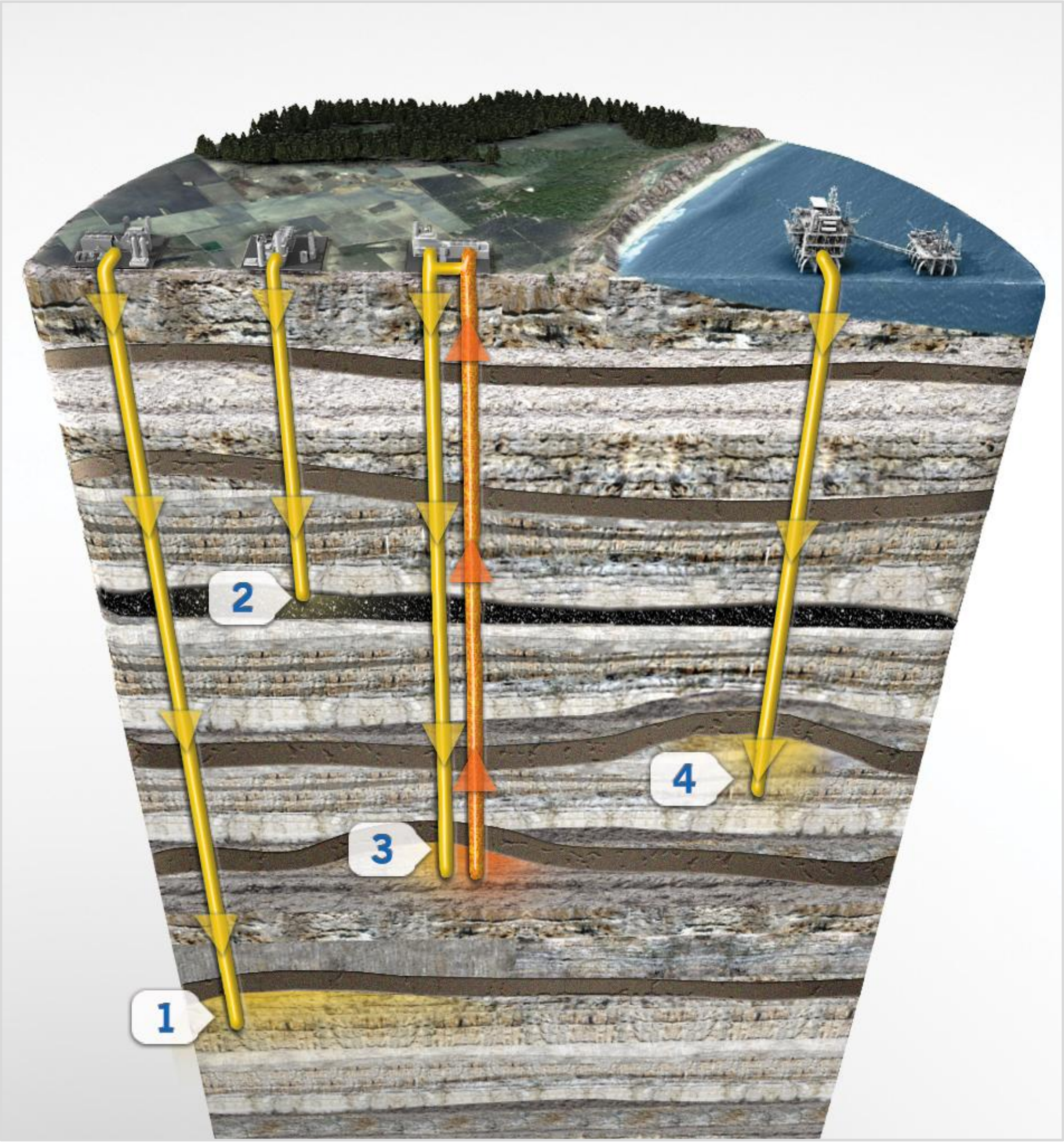


Flexwell Temperature Profile

CO_2 Storage

Geological storage options

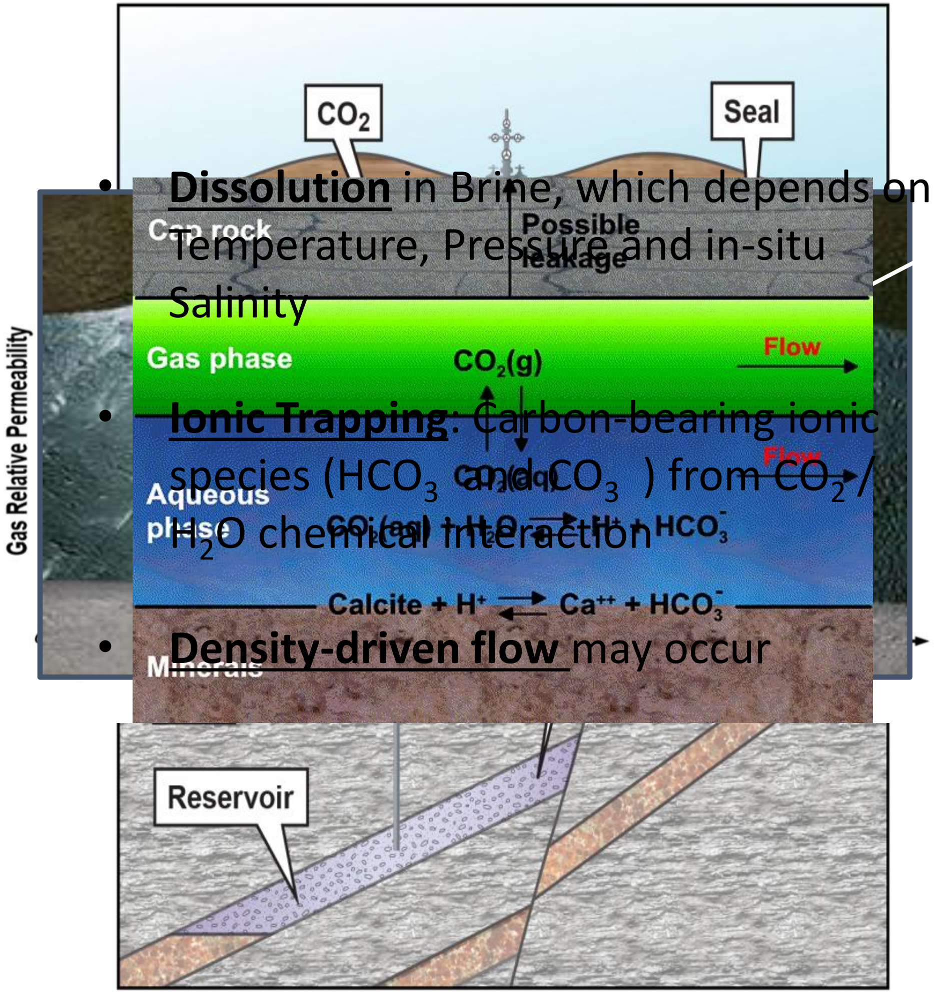
1. Saline Aquifers
2. Injection into deep coal seams and ECBM
3. Use of CO_2 in enhanced oil recovery (EOR) - CCUS
4. Depleted Oil and Gas reserves



Source: Global CCS Institute

Trapping Mechanisms

Trapping mechanism	Term
Structural Trapping	Short Term
Residual Gas Trapping	Short Term
Solubility Trapping	Medium-Long Term
Mineral Trapping	Long Term



- **Dissolution** in Brine, which depends on Temperature, Pressure and in-situ Salinity
- **Ionic Trapping**: Carbon-bearing ionic species (HCO_3^- and CO_3^{2-}) from CO_2/H_2O chemical interaction
- **Density-driven flow** may occur

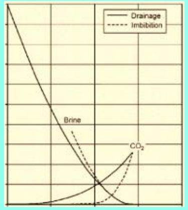
Negative buoyancy drives stored CO_2 away from top seal

GEM – Tool to Model CO_2 Geological Storage

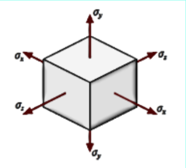
Generalized Equation-of-State Modeling (GEM)

➢ Thermal Multiphase Compositional Reservoir Simulator

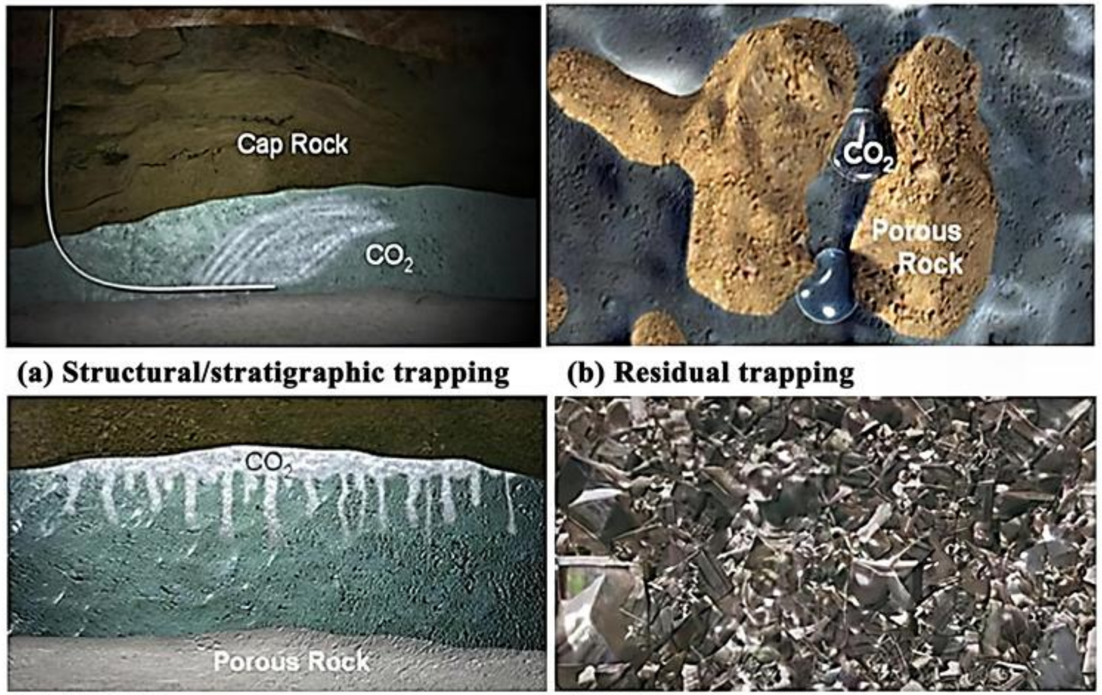
- Gas Solubility in aqueous phase
- H_2O Vaporization
- Geochemistry (Aqueous/Mineral Reaction)
- Joule-Thompson effect included



- Relative permeability hysteresis (Residual gas trapping)



- Geomechanics (cap rock integrity / thermal fracturing / faults reactivation)



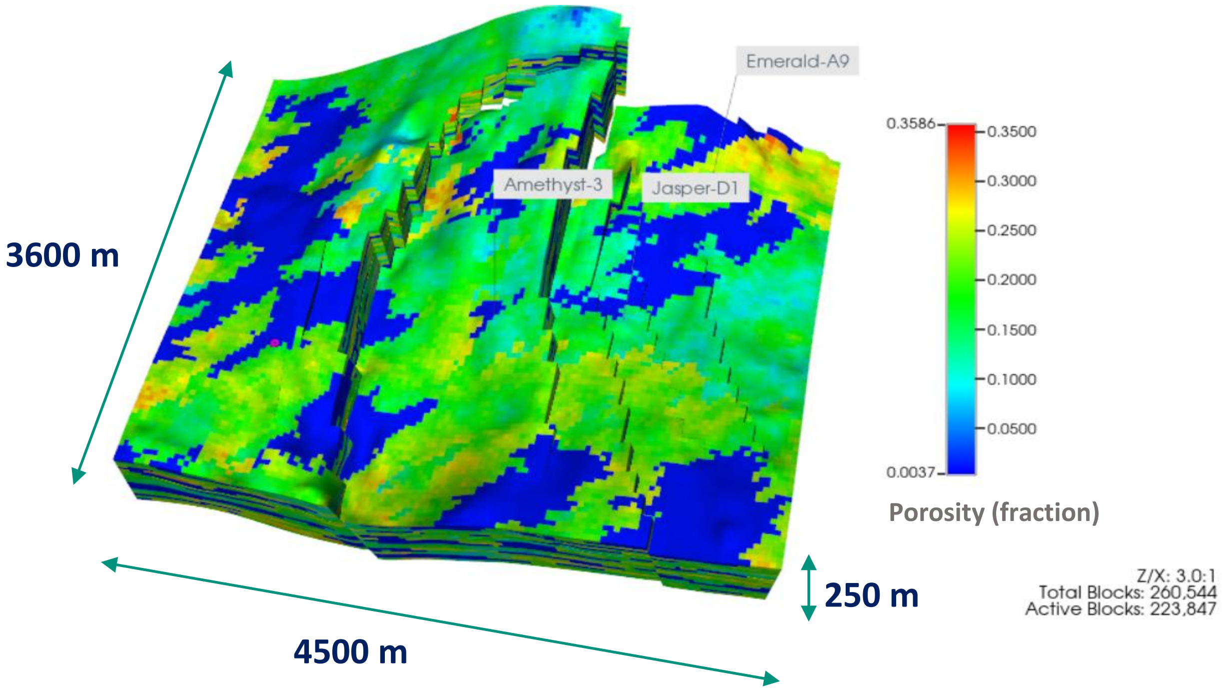
(a) Structural/stratigraphic trapping (b) Residual trapping

(c) Solubility trapping (d) Mineral trapping

CCS in Aquifer

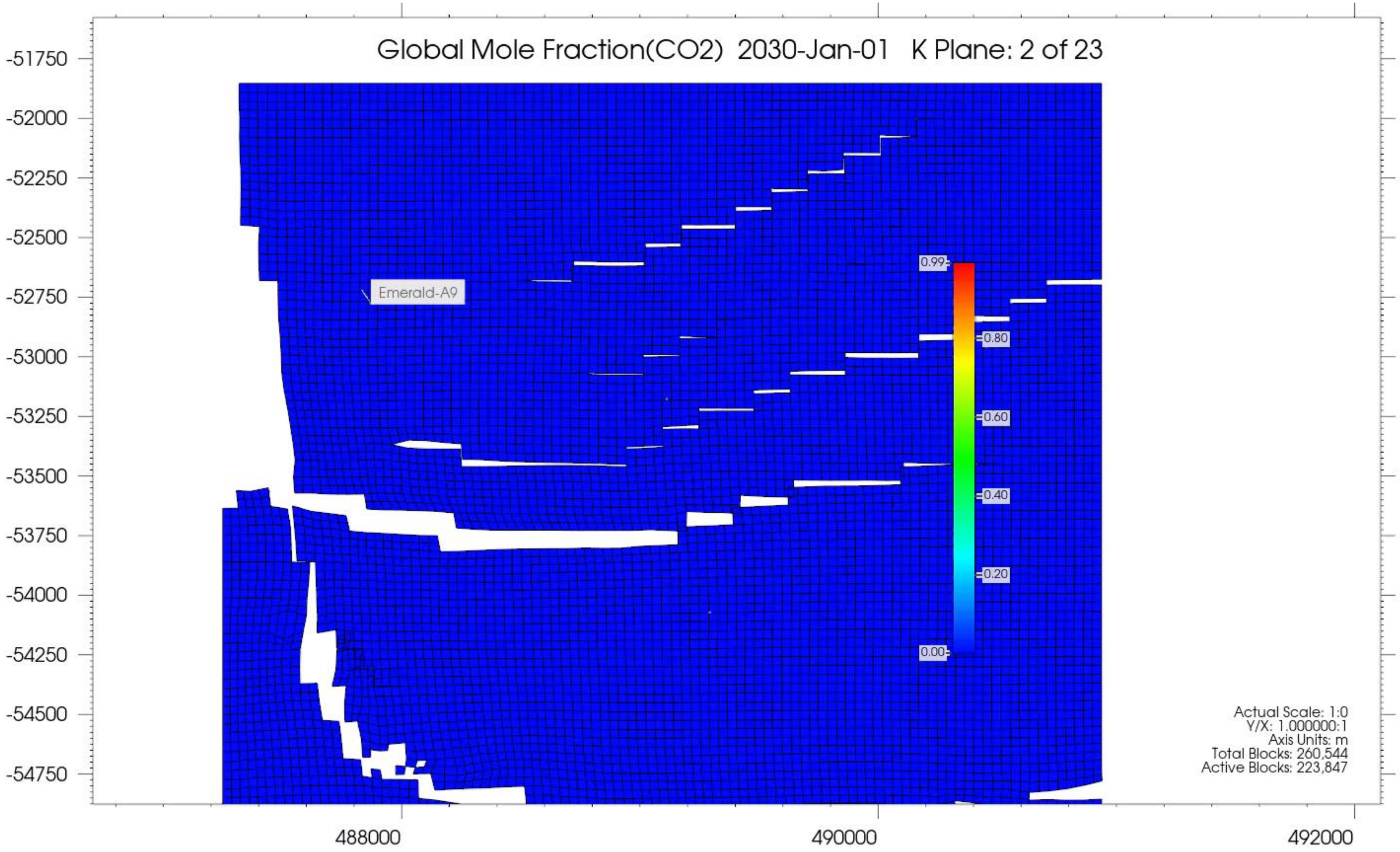
Aquifer Properties	
Permeability	70 mD
Porosity (fraction)	0.14
Depth	1900 m
Pressure	20,500 kPa
Temperature	50 C

3 CO_2 Injectors
Continuous injection of CO_2 for 10 Years
CO_2 Injection Rate, for each well: 1E5 Sm^3/day
Shut-in time: 190 Years

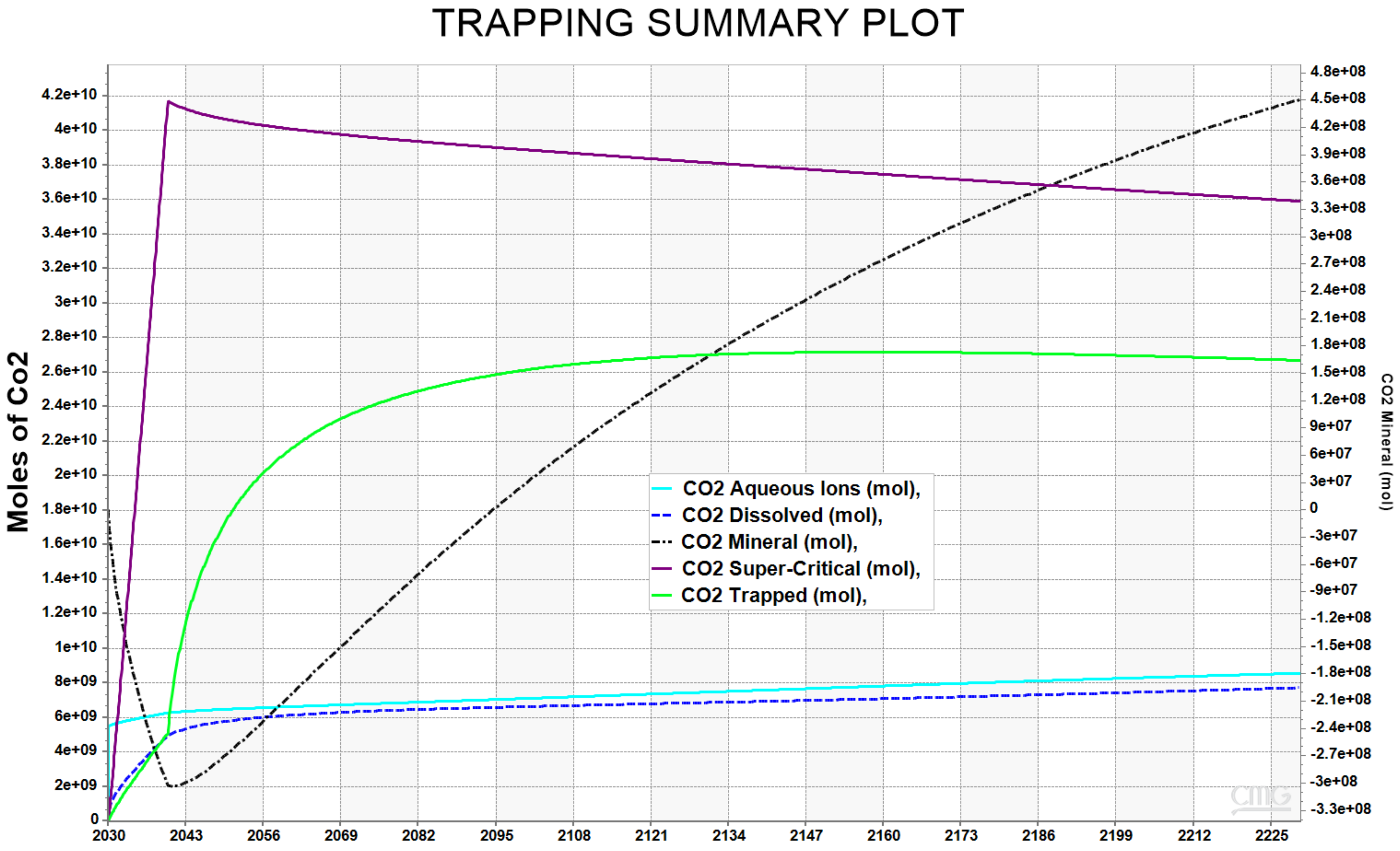


Total Pore Volume, res m^3 = 4.2E+08

CCS in Aquifer – Plume Growth

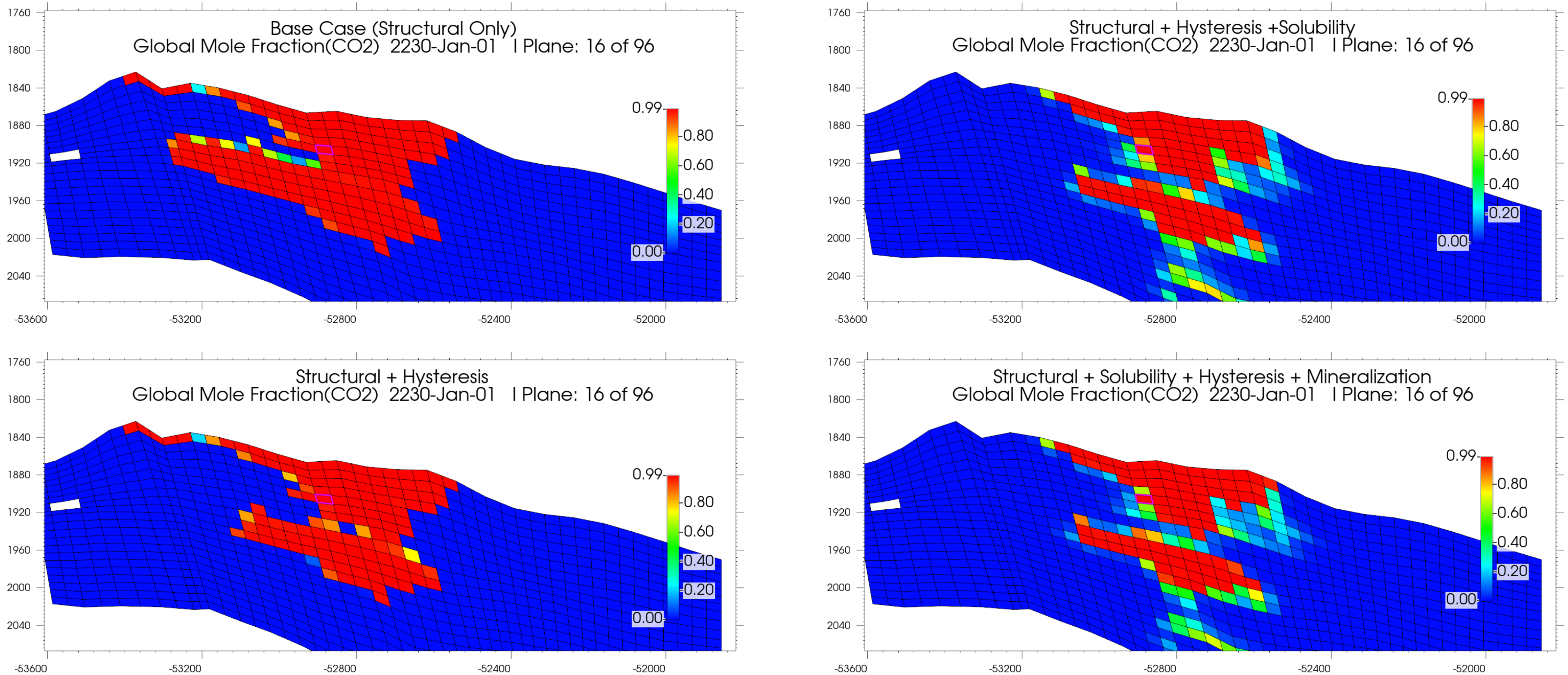


Trapping Mechanisms – including Mineralization

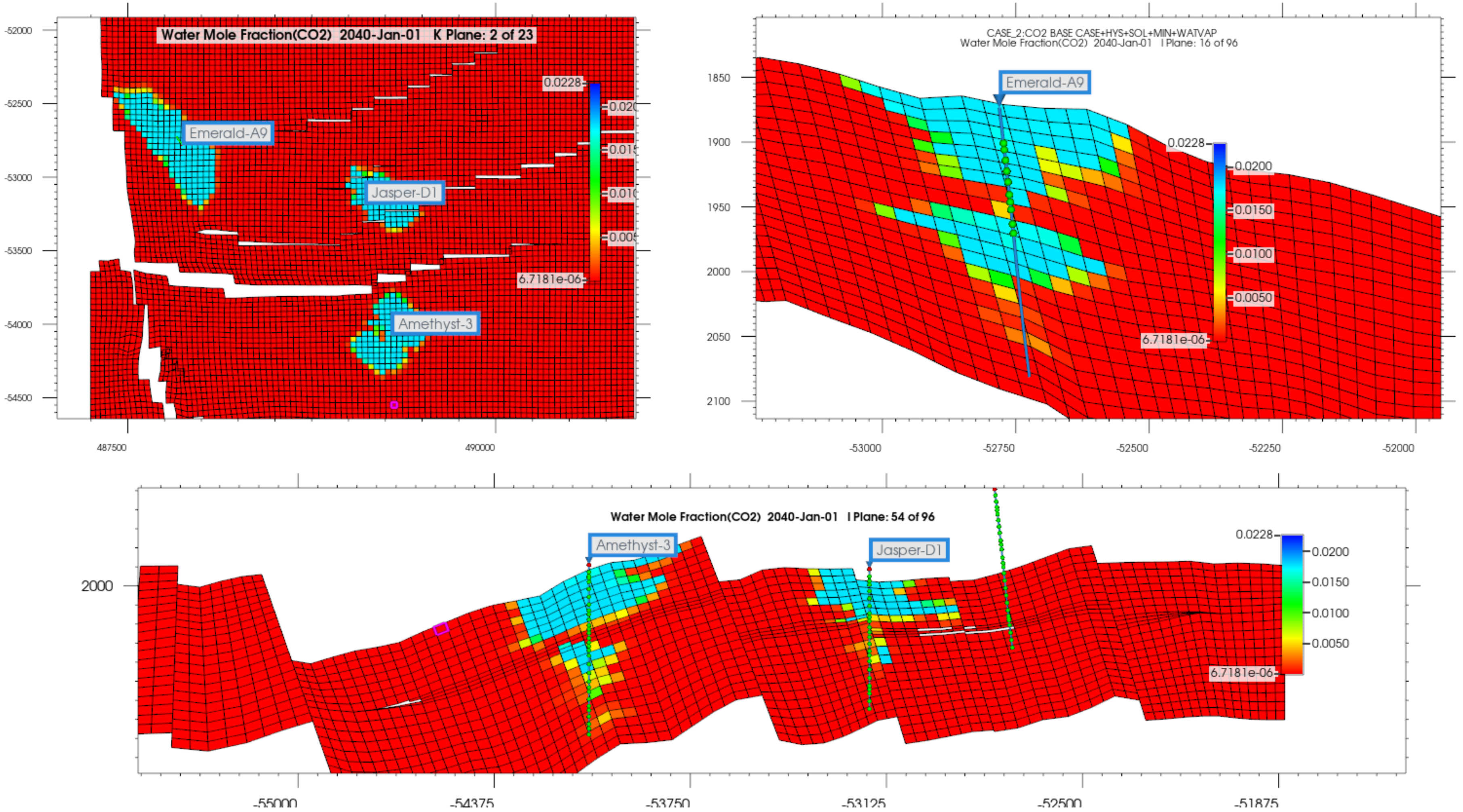


Trapping Mechanisms- Impact

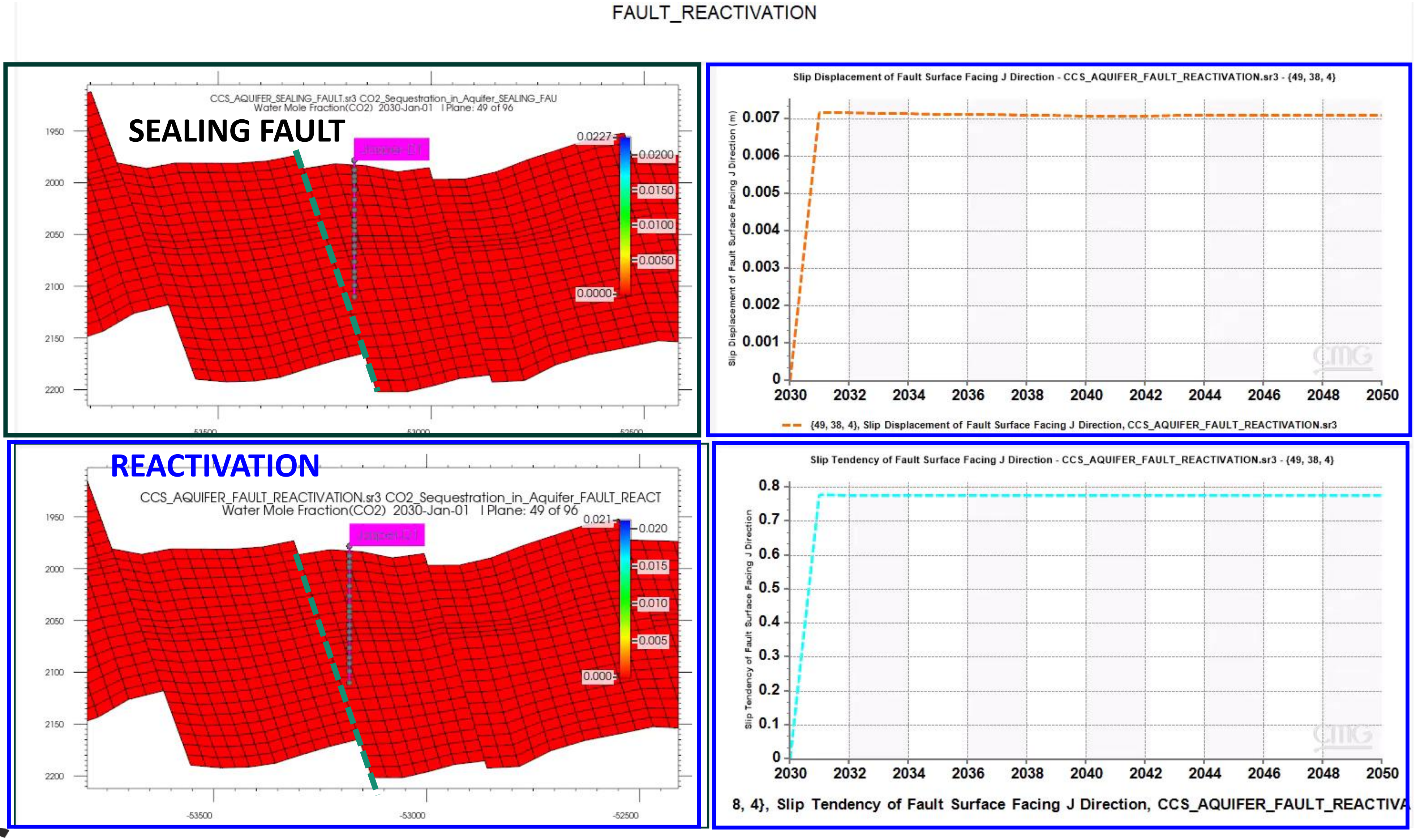
Impact of Trapping Mechanisms on Plume Growth



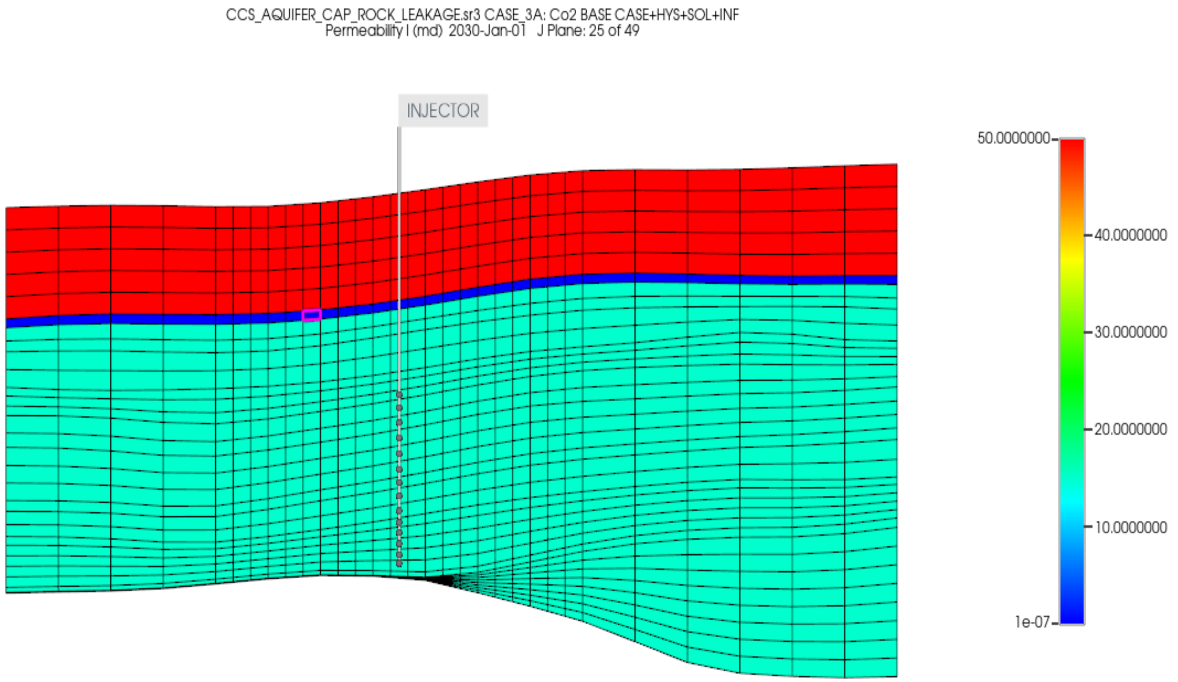
Well Placement & Plume Growth

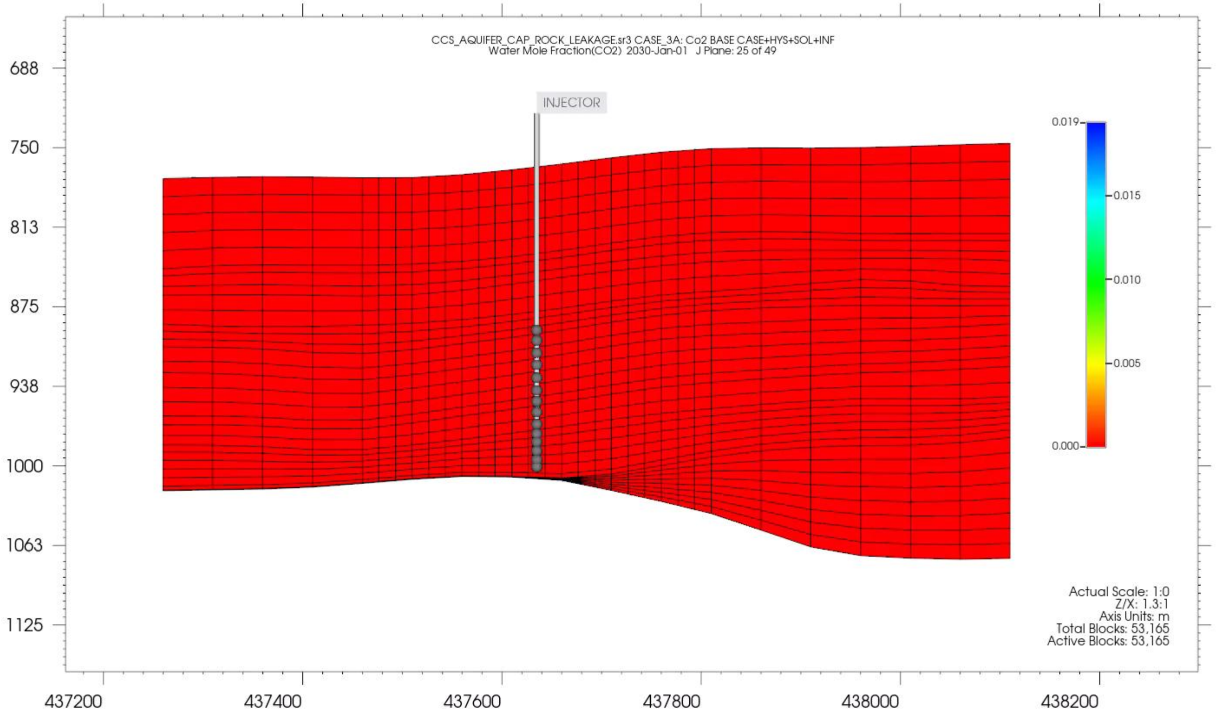


Geomechanical Effects : Fault Reactivation



Geomechanical Effects: Cap Rock Integrity





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Wellbore and Surface Facilities for CCS

Long-term Decisions

Coupling between transient reservoir and Steady-state wellbore/surface

GEM

CoFlow

Short-term Decisions

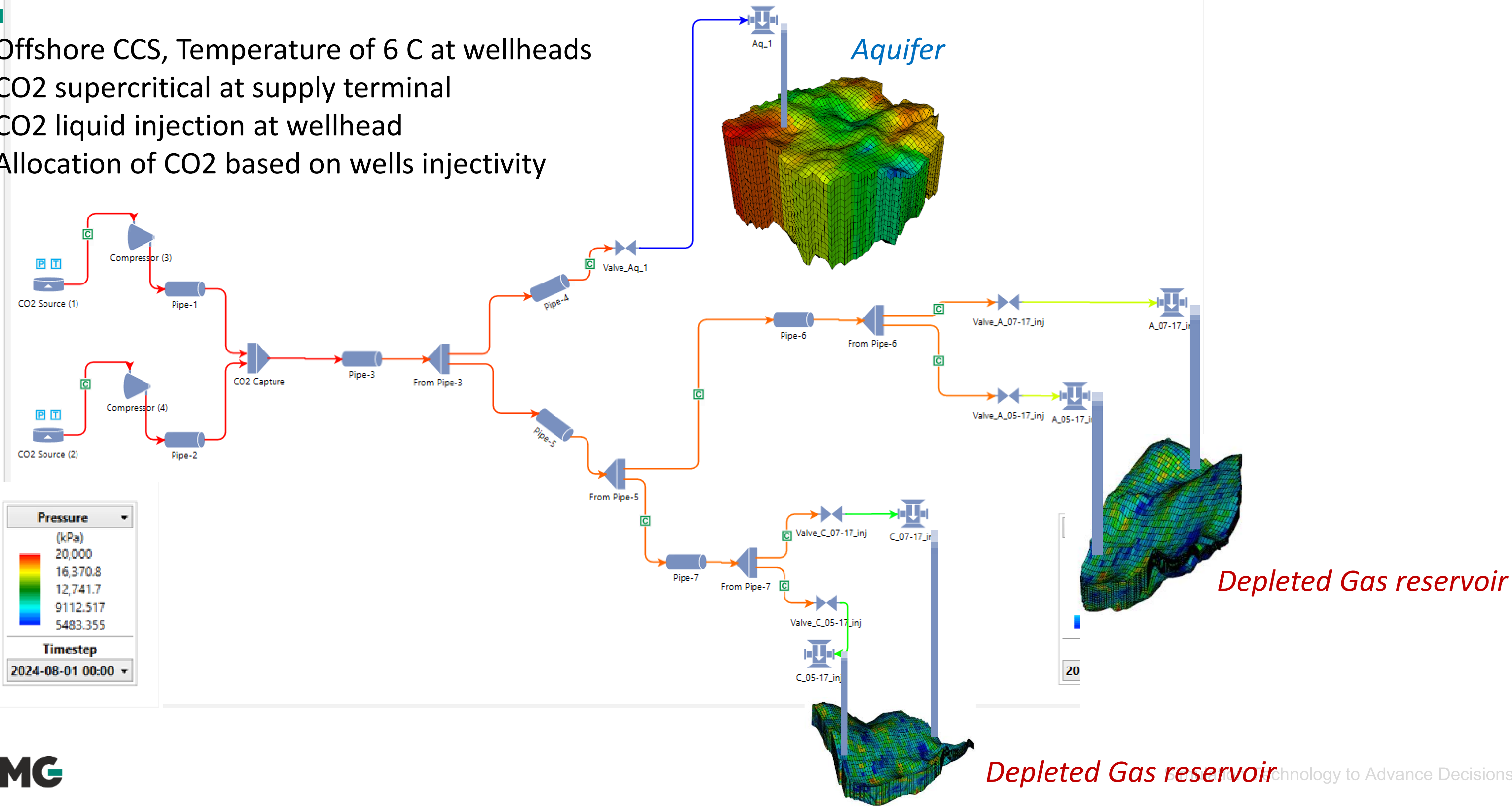
Coupling between transient reservoir and transient wellbore/surface

GEM

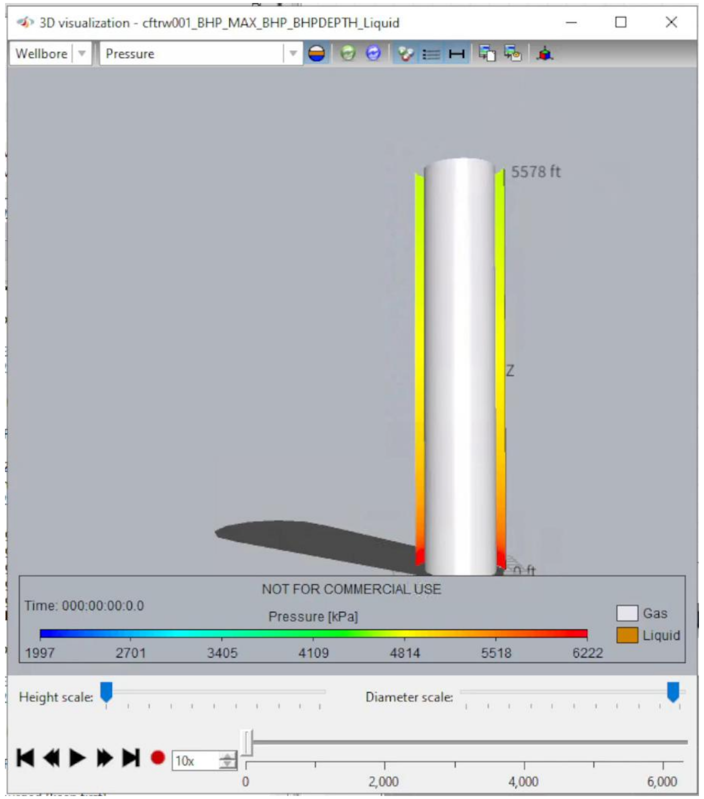
LedaFlow

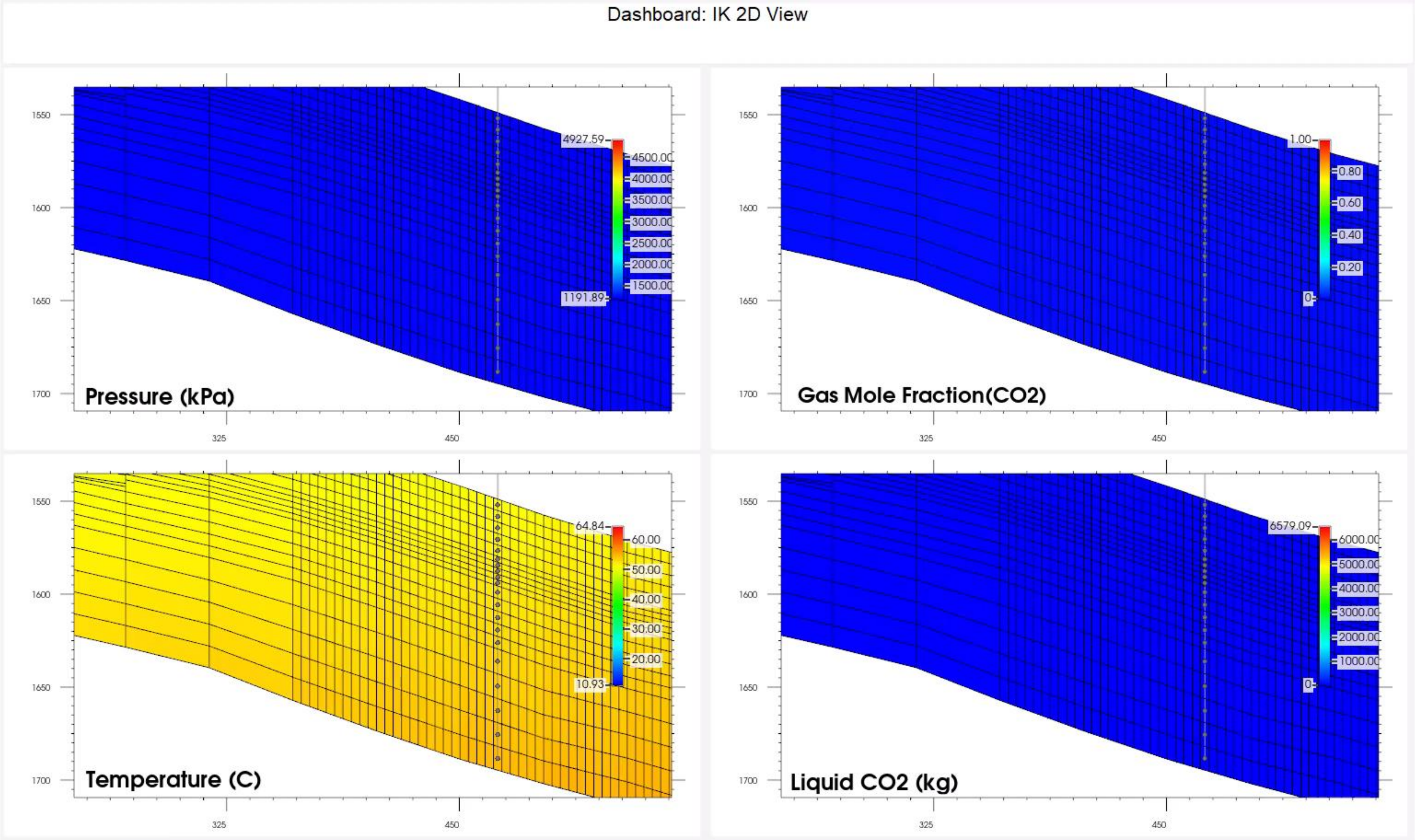
CoFlow + GEM – CCS in Aquifer & Depleted Reservoirs

- Offshore CCS, Temperature of 6 C at wellheads
- CO_2 supercritical at supply terminal
- CO_2 liquid injection at wellhead
- Allocation of CO_2 based on wells injectivity



CO2LINK : GEM LedaFlow Coupling

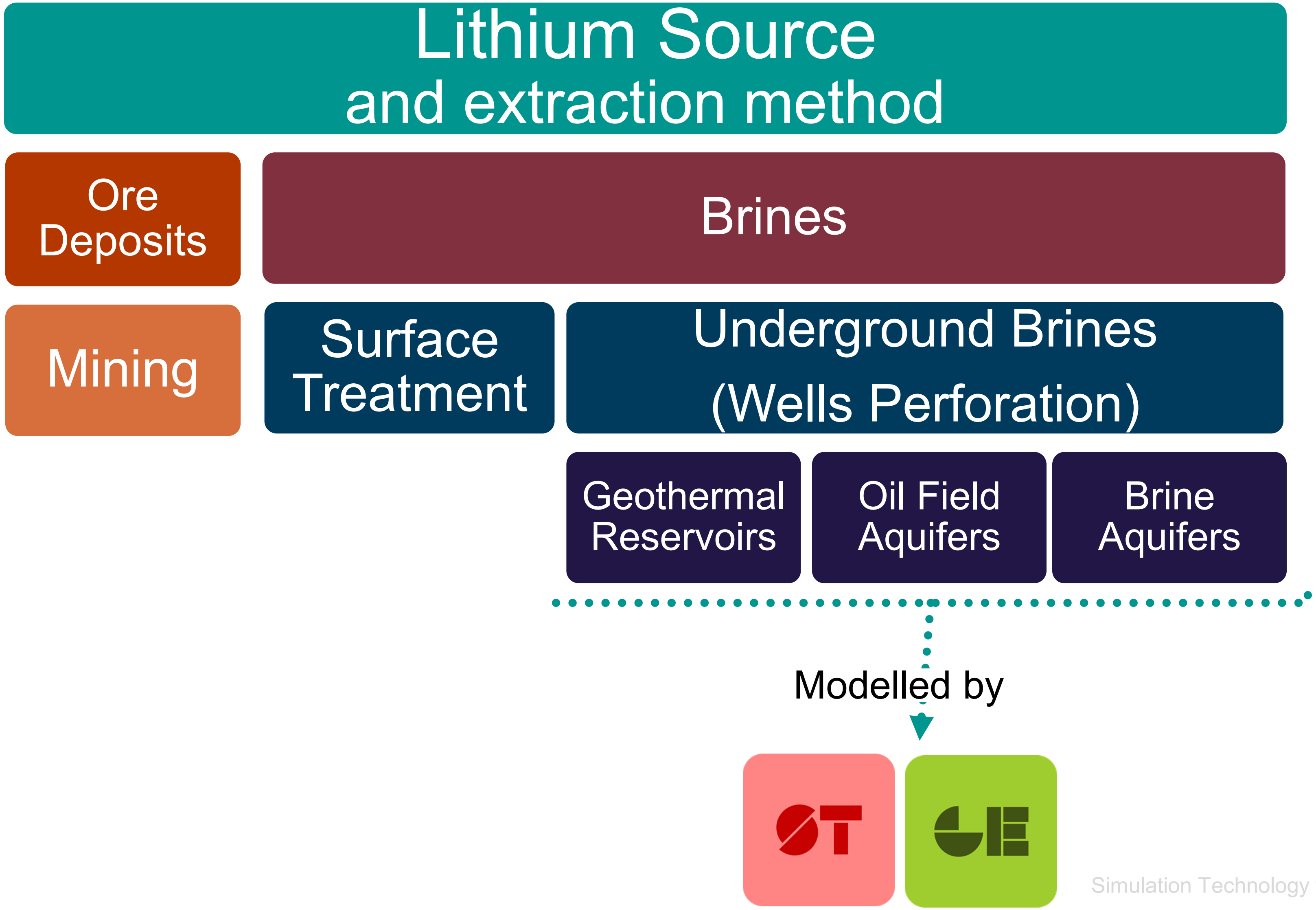




- CO_2 phase change across wellbore during start-up
- Dynamic P/T change inside the wellbore
- Pressurizing & cooling near the wellbore area
- CO_2 phase change near the wellbore

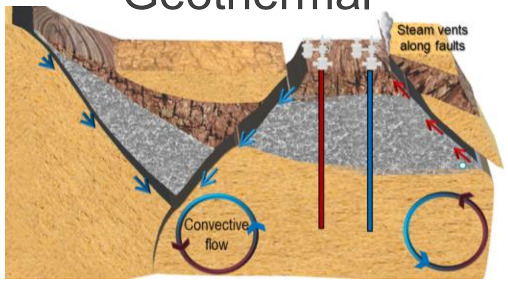
Lithium Extraction and H_2 storage

Lithium Extraction

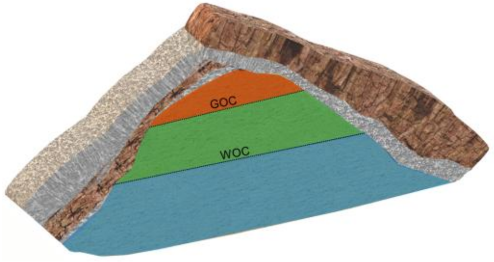


Lithium Extraction: Physics

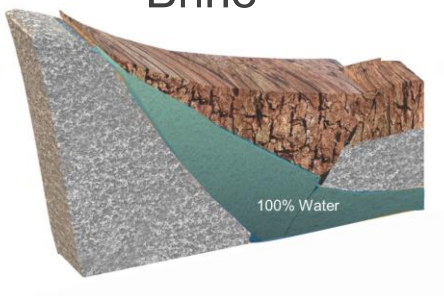
Geothermal



Oil Field



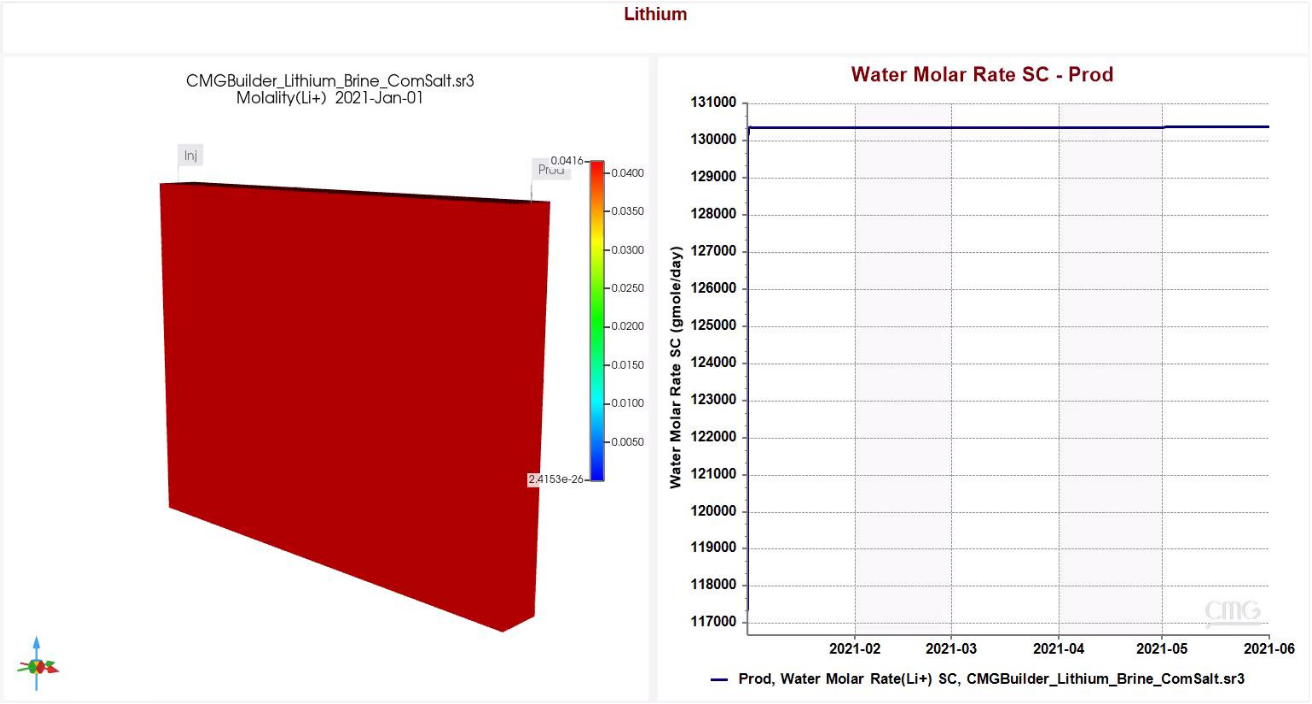
Brine



- Hydrothermal Alteration
- Thermal Support
- Reservoir Heterogeneities
- Mineral Deposition
- Porosity Reduction
- Fluid Alteration Due To Reaction With The Rock
- Complex Geology / Active Faults
- Subsidence

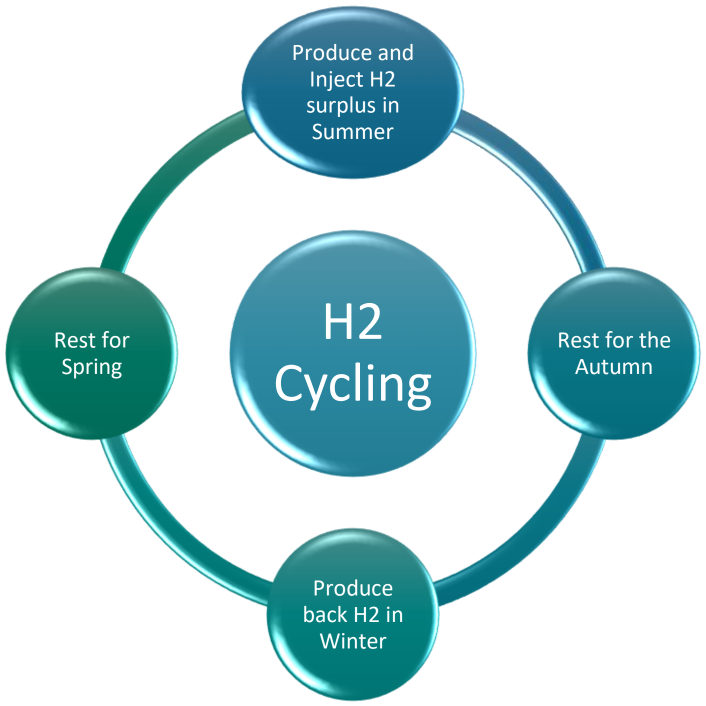
Lithium Extraction from Brine

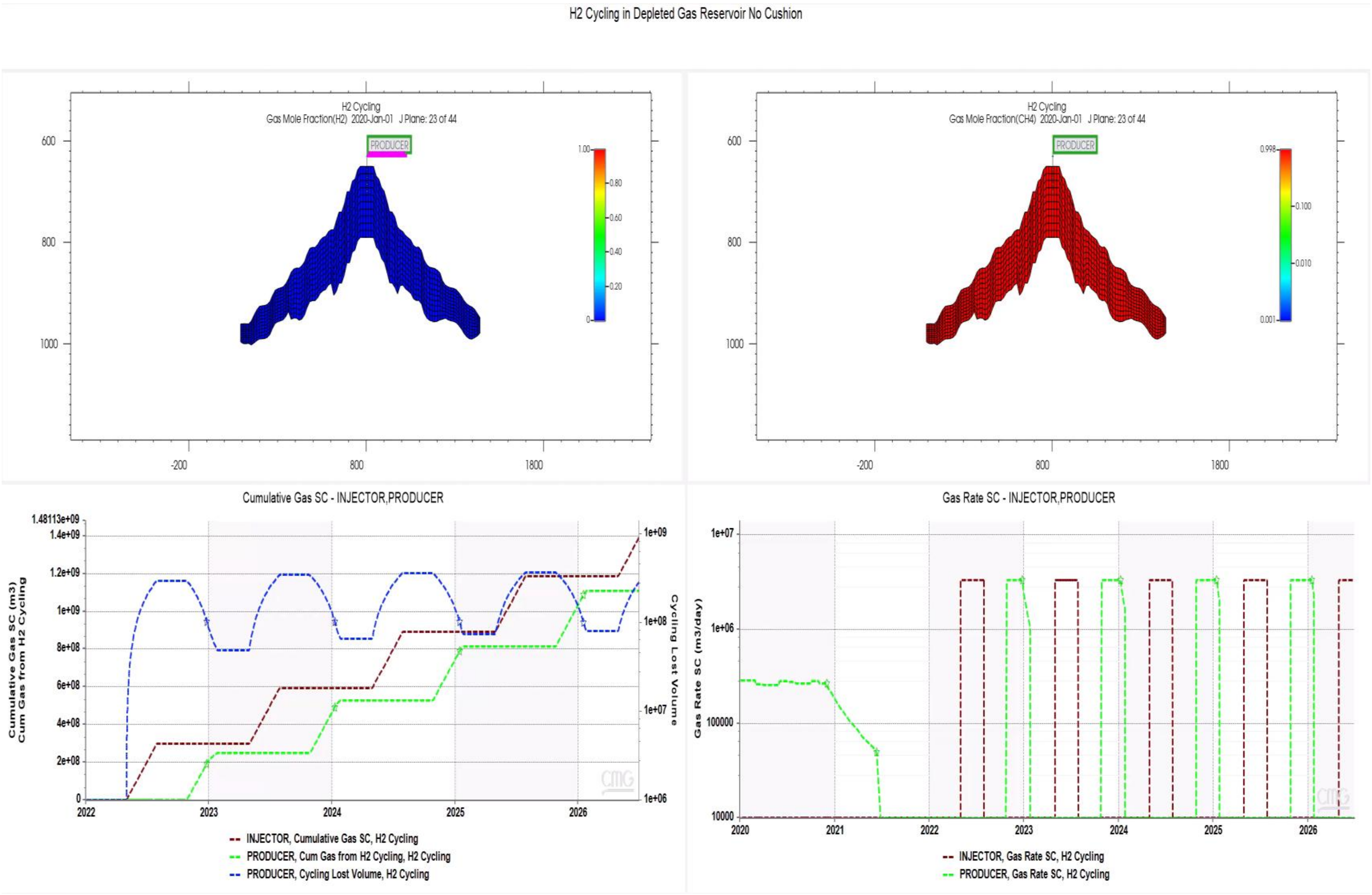
- Extract lithium brine through injecting fresh water
- Maximize lithium production while maintaining reservoir pressure by sensitivity on:
    - ***Well configurations & spacing***
    - ***Injection/production rates***
    - ***Reservoir heterogeneity***



- **Output:**
    - Injection/production rate
    - Well bottom hole pressure
    - Water recovery factor
    - Lithium production rate
    - Mass rate (*kg Li+/day*)
    - Volumetric rate (*m3 Li+/day*)
    - Lithium molarity (*Mol Li+/m3 H2O*)

Hydrogen Storage: Example





Hydrogen Storage: Geochemical Reactions

Chemical equilibrium

$$H_2O \;=\; H^+ \;+\; OH^-$$

$$HCO_3^- \;=\; H^+ \;+\; CO_3^{--}$$

$$CO_2(aq) \;+\; H_2O \;=\; H^+ \;+\; HCO_3^-$$

Mineral dissolution and precipitation

$$Calcite \;+\; H^+ \;=\; Ca^{++} \;+\; HCO_3^-$$

$$Kaolinite \;+\; 6H^+ \;=\; 5H_2O \;+\; 2SiO_2(aq) \;+\; 2Al^{+++}$$

$$Anorthite \;+\; 8H^+ \;=\; Ca^{++} \;+\; 2Al^{+++} \;+\; 2\,SiO_2(aq) \;+\; 4\,H_2O$$

Methanation

$$CO_2(aq) \;+\; 4H_2(aq) \;\rightarrow\; CH_4(aq) + \;2H_2O$$

Thank You
…questions?