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Design rules for high-efficiency geological storage of hydrogen in depleted gas fields

#FutureOfSimulation

DEVEX 2022

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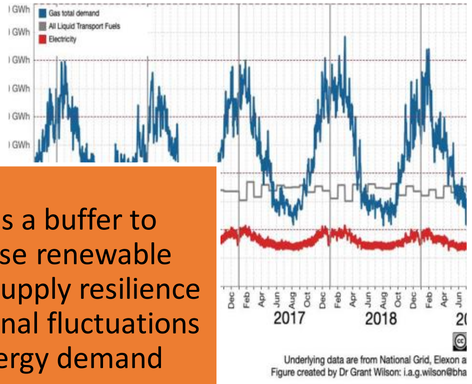
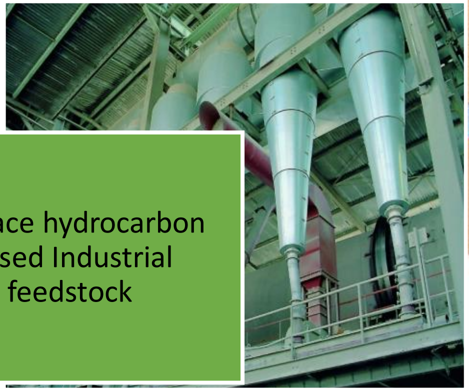
Hydrogen for Net Zero



Act as a buffer to increase renewable energy supply resilience to seasonal fluctuations in energy demand

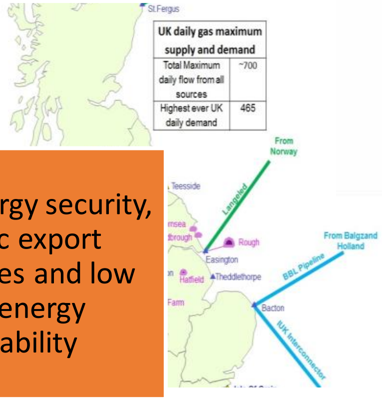
Decarbonise heat by replacing methane in the gas grid

Decarbonise aviation, road freight, rail & shipping

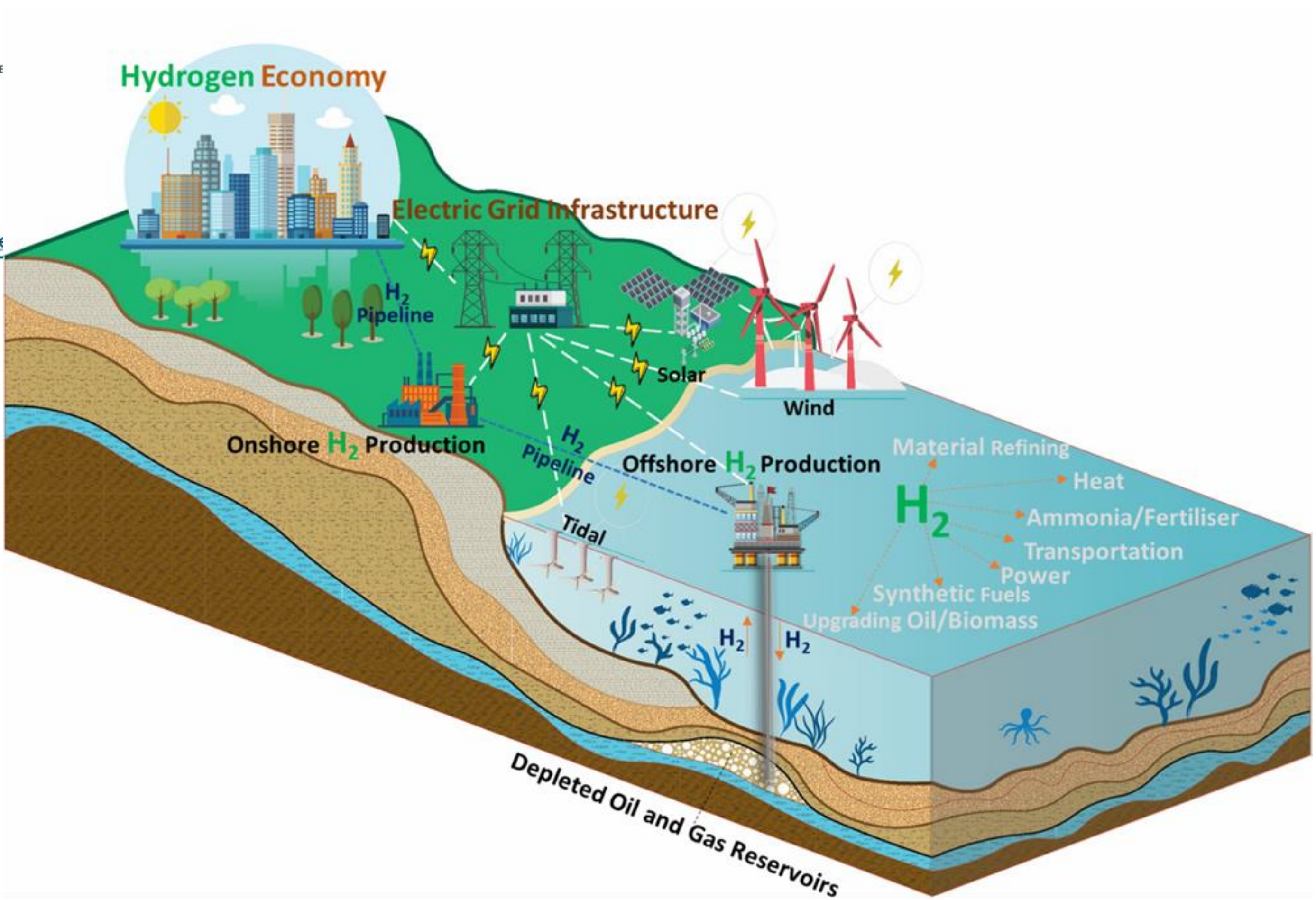


Replace hydrocarbon based Industrial feedstock

Enable large scale renewable energy integration and power generation

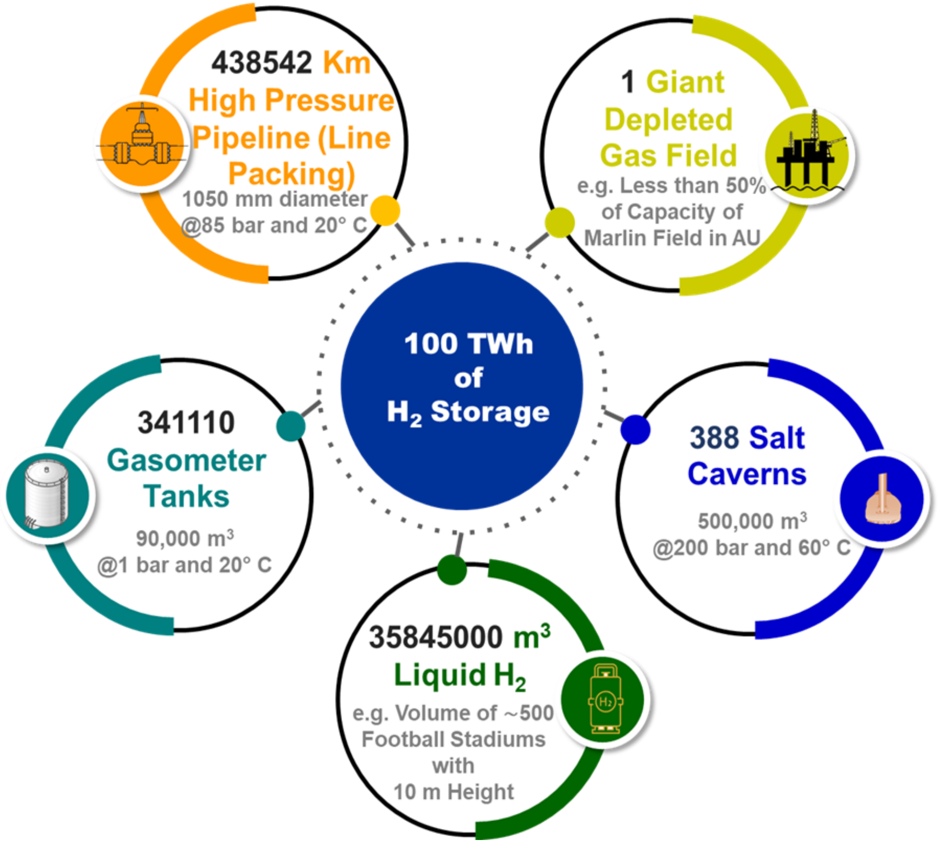


Increase energy security, economic export opportunities and low carbon energy sustainability

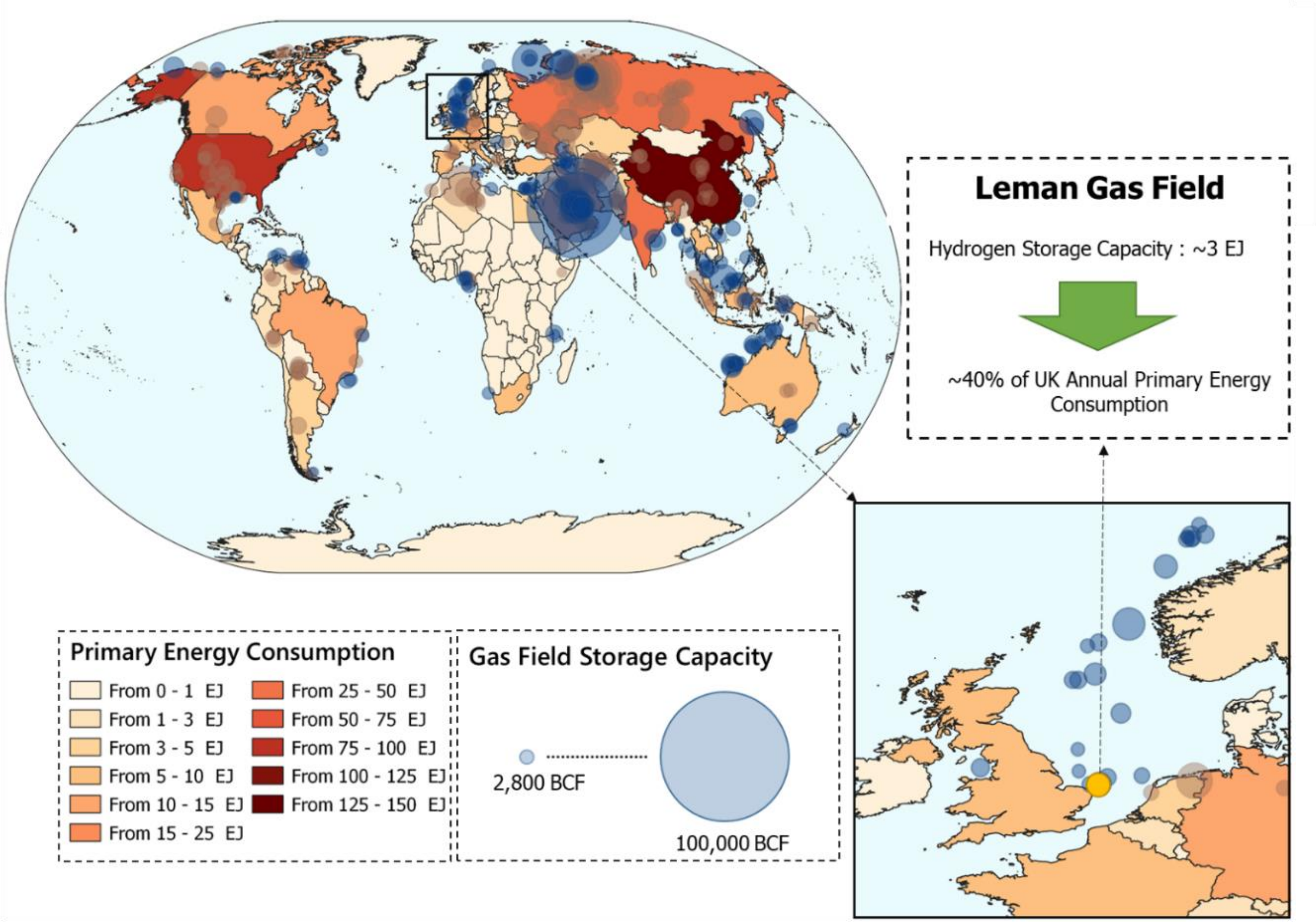


Hassanpouryouzband *et al.* (2021), doi.org/10.1021/acsenergylett.1c00845

Scales of hydrogen storage



Aftab *et al.* (2021), doi.org/10.1021/acs.iecr.1c04380



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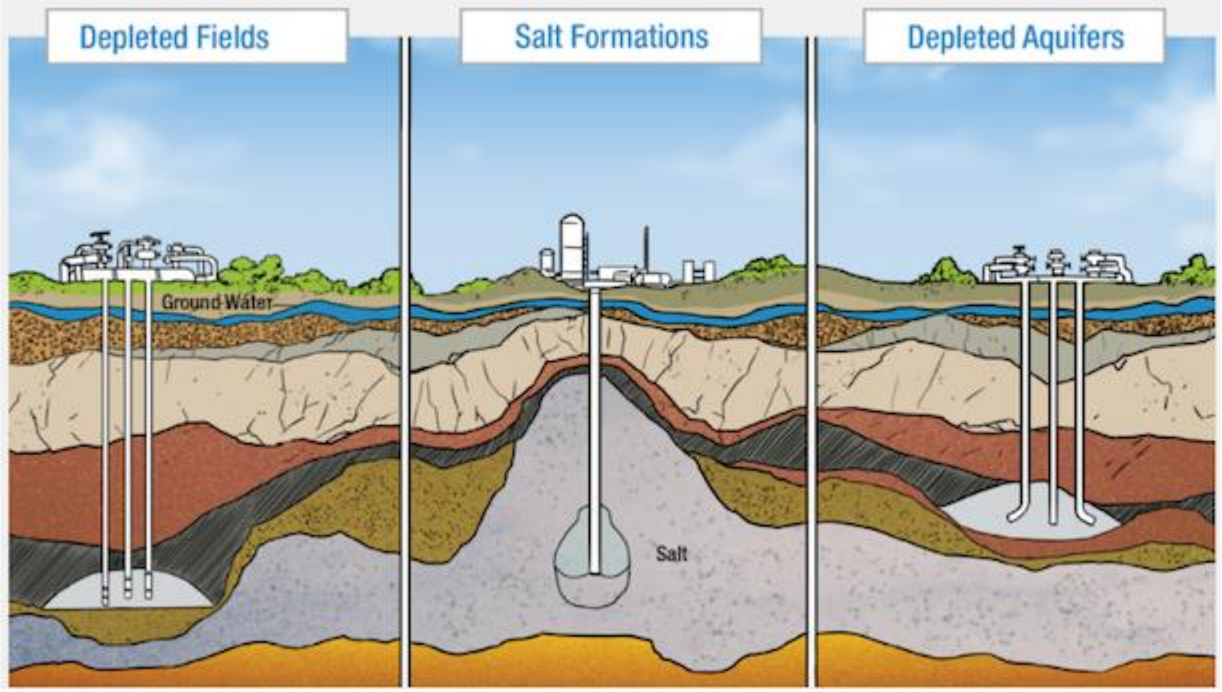
Storage Sites

Criteria	Compressed			
	Storage vessels			Geological storage
	Wind turbine tower	Pressure vessels	Underground pipes	
Storage size (GWh)	Up to 0,031 per 82 m tall WT	0,034	2,15	>10-100 Depends on the site nature
Cost	■ (green)	■ (dark blue)	■ (light blue)	■ (yellow)
Technology maturity For NG	N/A	✓	✓	✓
Technology maturity For H_2	×	✓	Exist but not on large scale	×
	Lowest ← ■ (yellow) ■ (green) ■ (light blue) ■ (dark blue) → Highest			

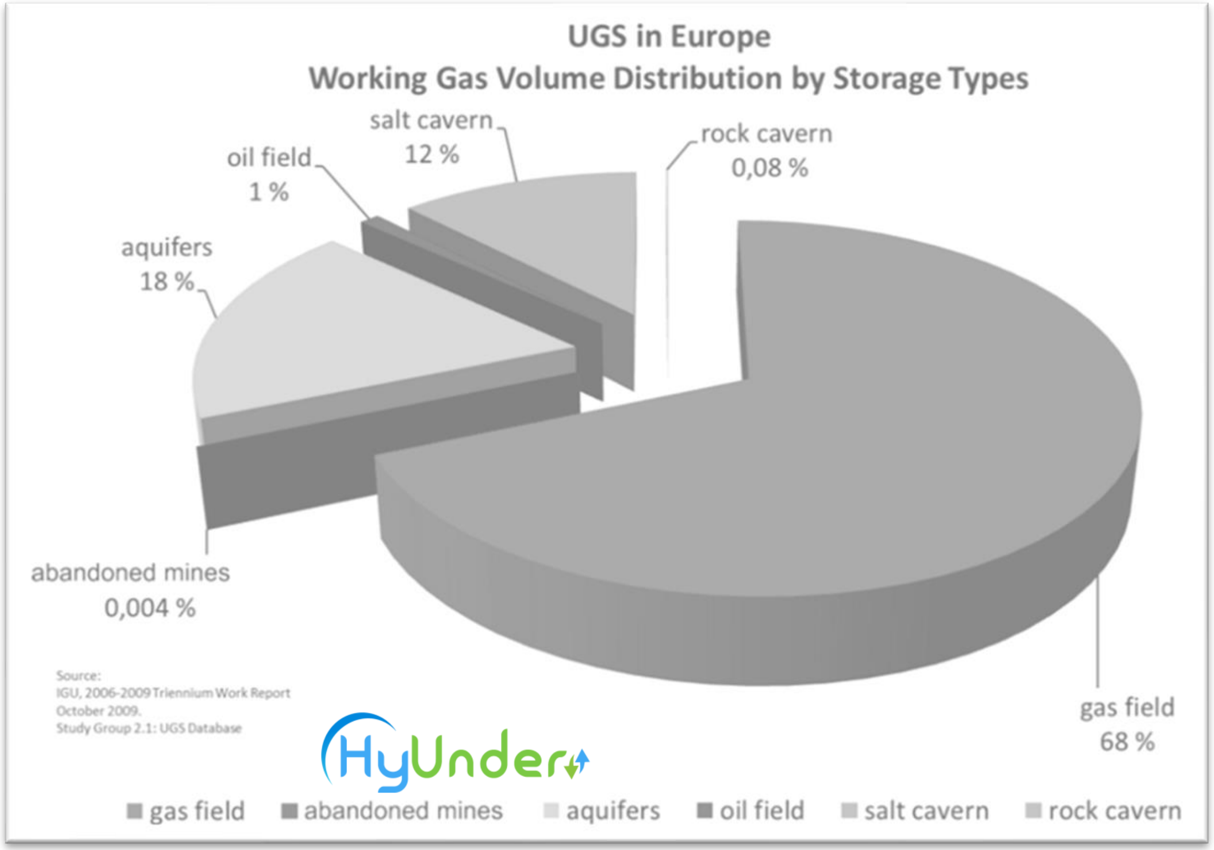
Elberry, A.M. et al. (2021)

1.23$/kg US$ 1.61$/kg US$1.29/kg



Pfeiffer, W.T. et al.(2017)

Underground gas storage



Aquifer storage of hydrogen

- Ketzin, Germany (62% hydrogen town gas – now closed)
- Beynes, France (50% hydrogen town gas from 1956-1972)
- Lobodice, Czech Republic (50% hydrogen town gas from 1965, now used for natural gas storage)

Salt cavern storage of hydrogen

- Teeside, UK (active since 1959 storing 95% hydrogen)
- Kiel, Germany (62% hydrogen, now operating with natural gas)
- Spindletop, US (95% hydrogen storage)
- Clemens Dome, US (95% hydrogen storage)
- Moss Bluff, US (95% hydrogen storage)

Hydrogen storage for biomethane production

- Hychico, Argentina (10% hydrogen storage in a depleted gas reservoir)
- Underground Sun Storage, Austria (10% hydrogen storage in a depleted gas reservoir from 2015)

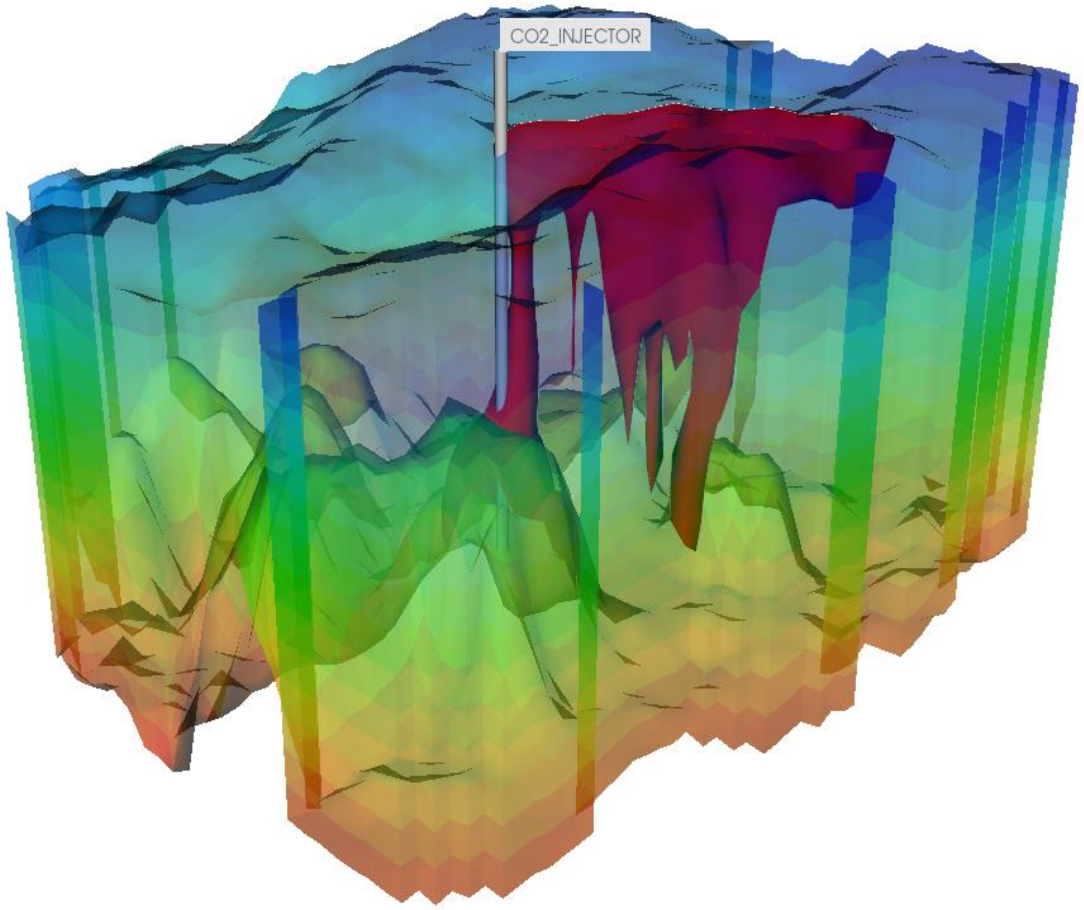
Hydrogen storage in engineered rock caverns

- HYBRIT, Sweden for 100% decarbonised steel production

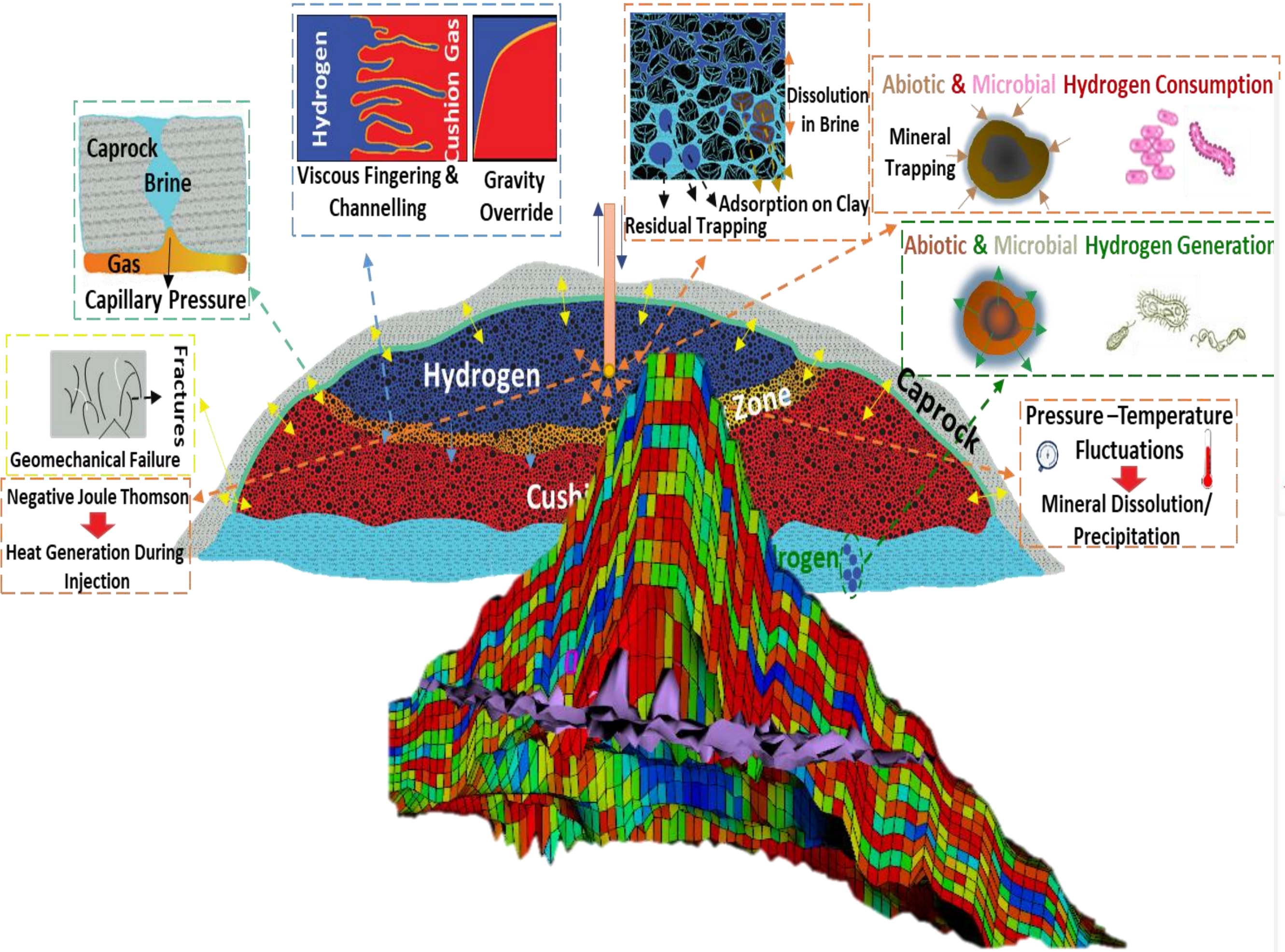
Numerical Modelling Tools

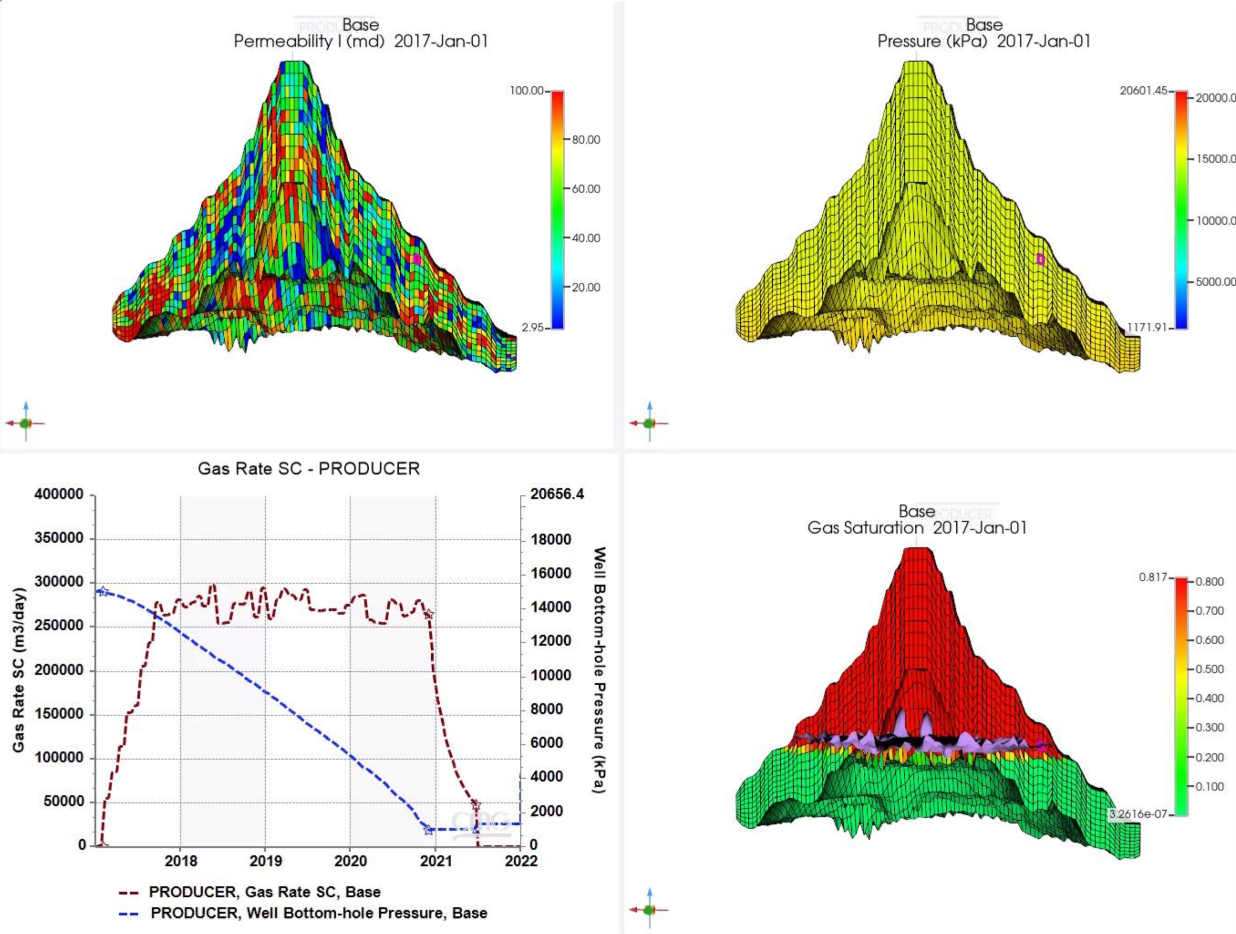
A compositional simulator with many relevant advanced physics and thermodynamics:

Relative permeability hysteresis	Gas phase trapping
Gas solubility in aqueous phase	Henry's law based K-Value based **Diffusion**
H_2O Vaporization	During gas injection
Reactions	Chemical equilibrium Arrhenius Mineral dissolution and precipitation
Geomechanics	Change in porosity and permeability Cap rock integrity
Thermal Option	Reservoir temperature could change with time



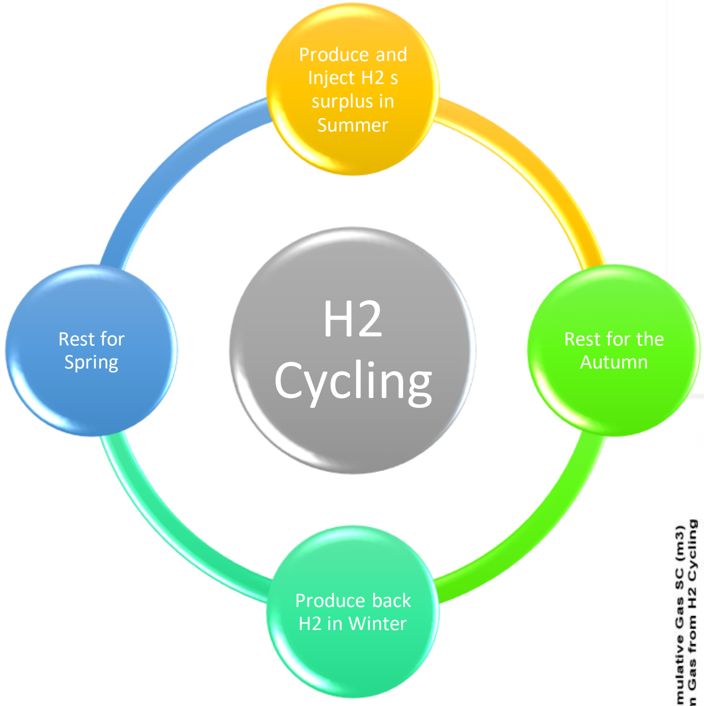
Case Study: Depleted Gas Reservoir

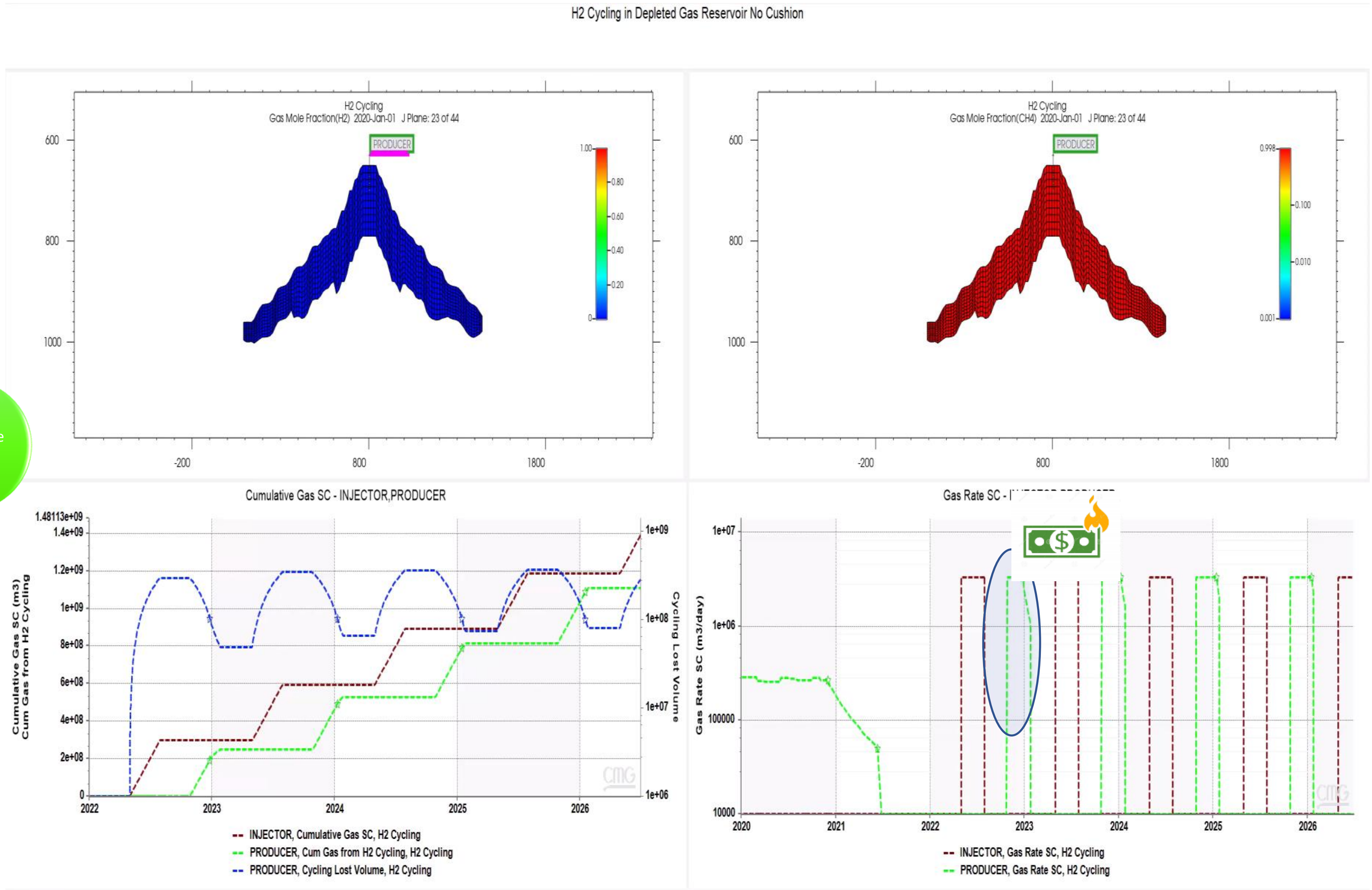




Hassanpouryouzband et al. "Offshore Geological Storage of Hydrogen: Is This Our Best Option to Achieve Net-Zero?." ACS Energy Letters 6 (2021): 2181-2186. doi.org/10.1021/acsenergylett.1c00845

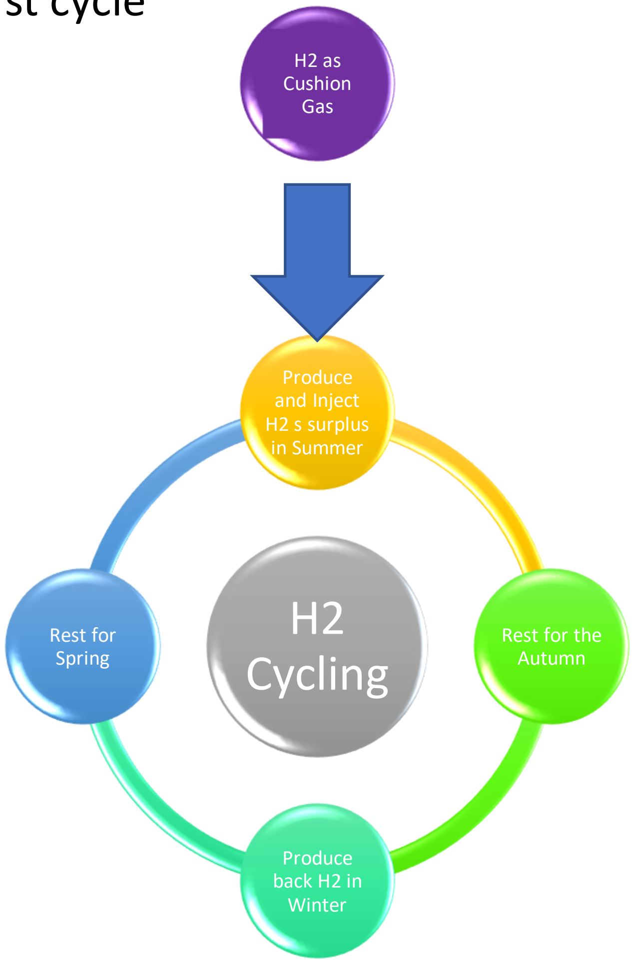
Case Study: H2 Standard Cycling

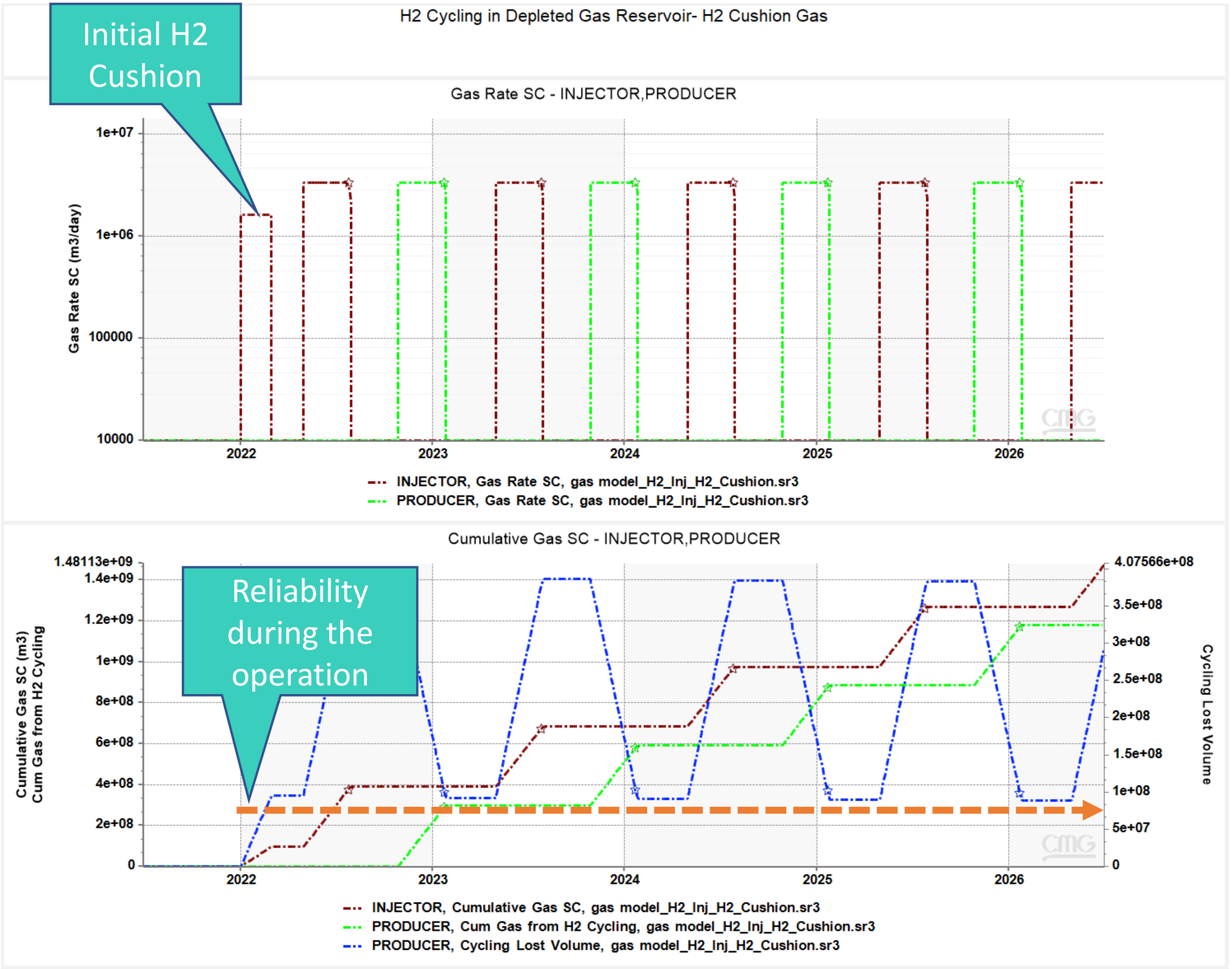




H2 Cycling with initial H2 cushion gas

Pre-inject 95 Million m^3 is H2 volume that is going to be trapped largely during the first cycle

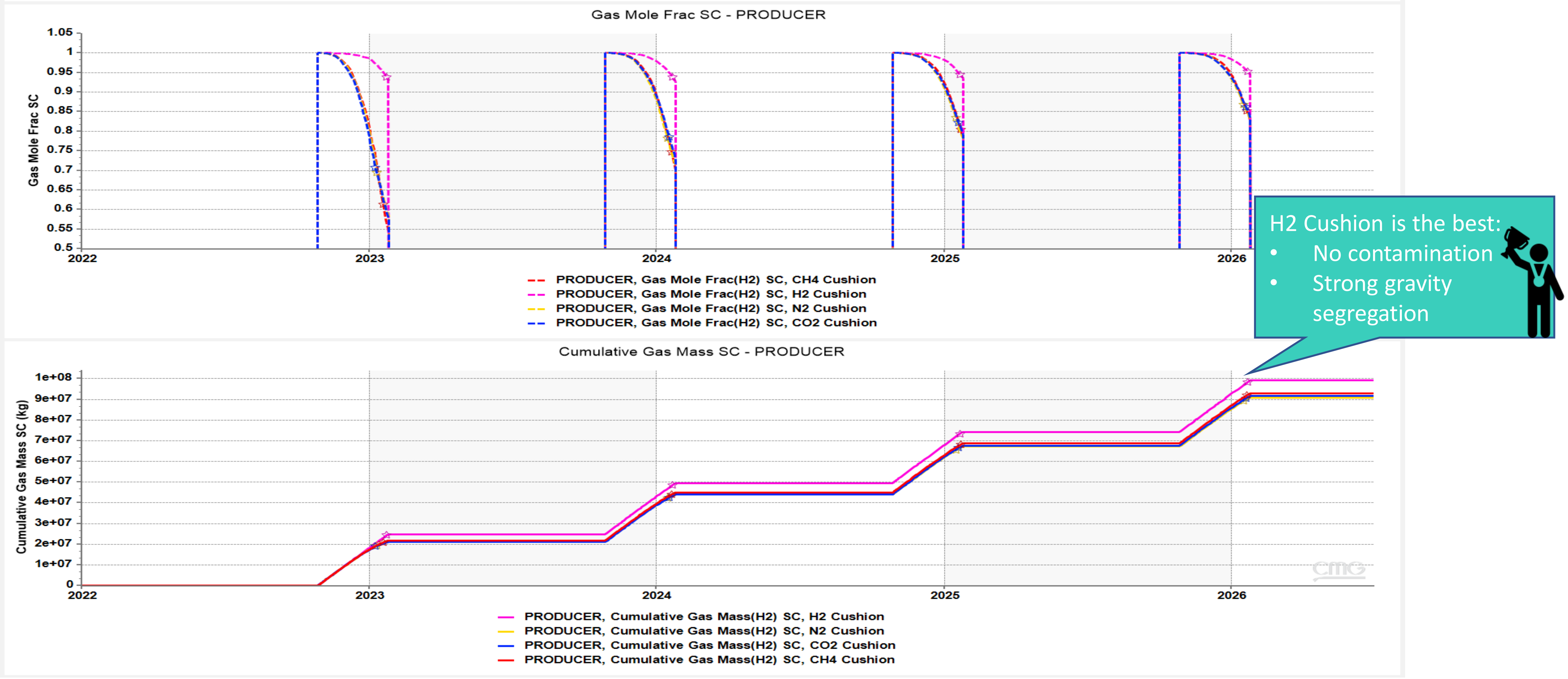




H2 Cycling with initial N2/CO2/CH4 as cushion gas

How other gases perform under similar circumstances:

- N2 is 10x cheaper than H2
- CH4 is almost free.
- CO2 sequestration is a positive overall element for the project



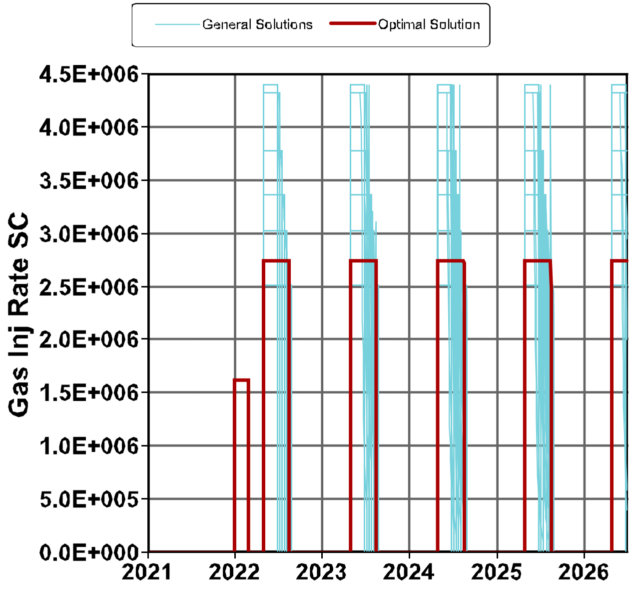
Optimisation of H2 Cycling with initial cushion gas (100 runs)

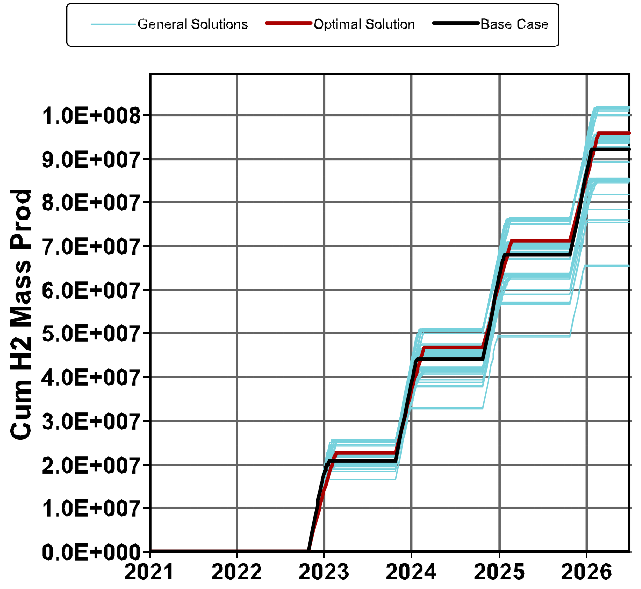
Variables

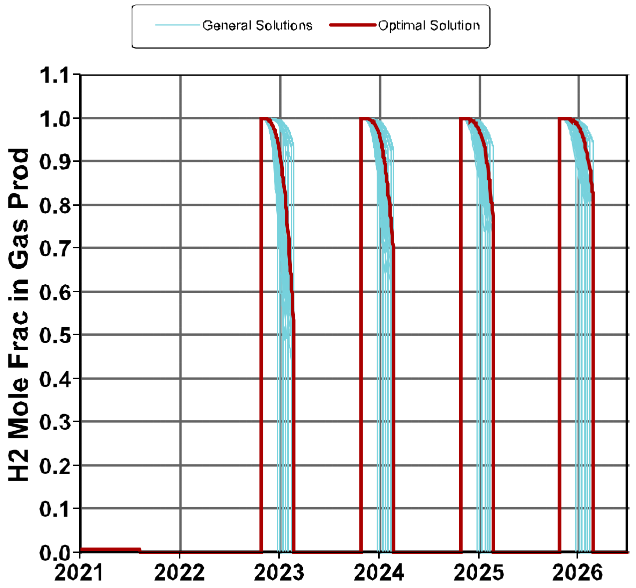
- Cushion Type (CO_2, CH_4, N_2, H_2)
- Inj Cycle Rate/Length
- Prod Cycle Rate/Length
- Autumn/Spring Rest Length
- Injecting/producing the same volumes in summer/winter varying the rates

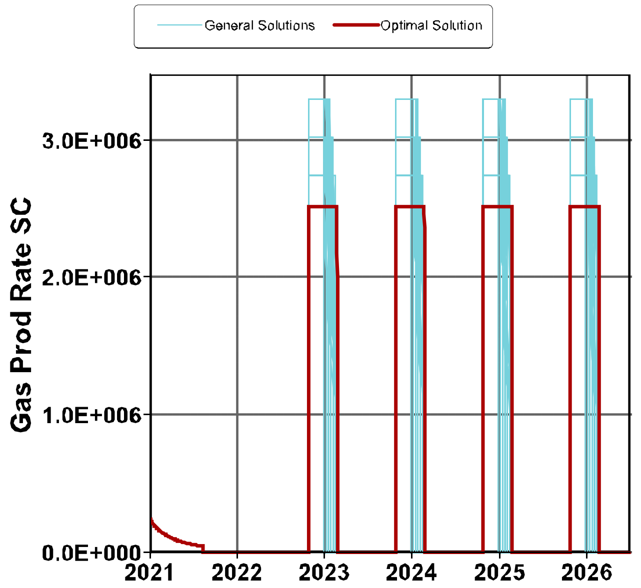
Objective FN

- Cum H2 Mass Prod after four cycles
- Cum H2 Prod after first cycle
- Length of first prod cycle
- H2 Prod Quality (Days with 0.8 H2 mole frac Pro)
- Cushion inj cost for H2&N2
- Benefit of CO_2



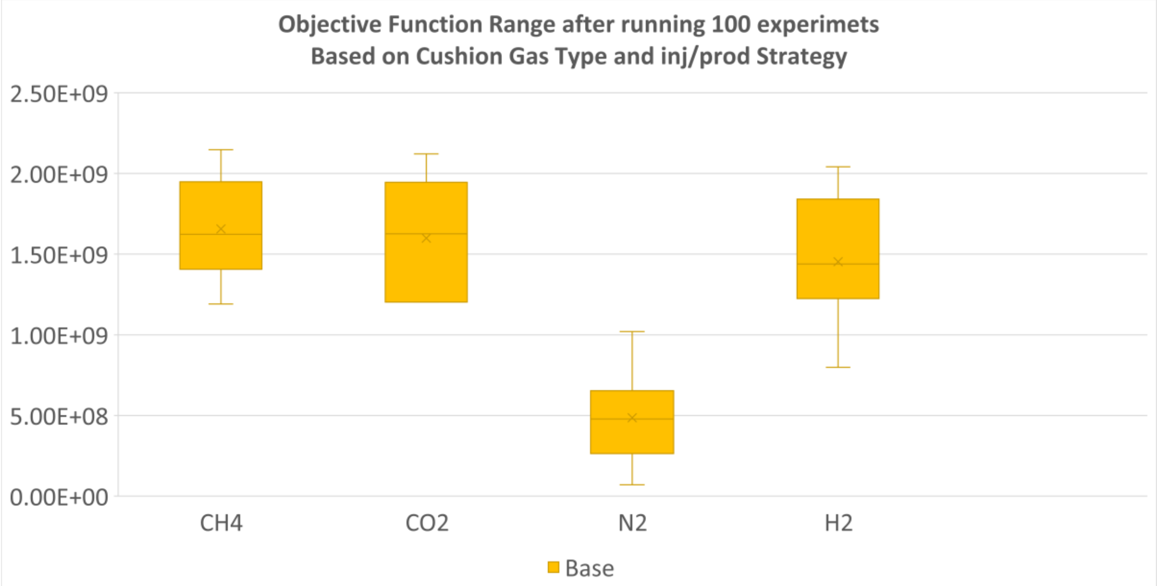


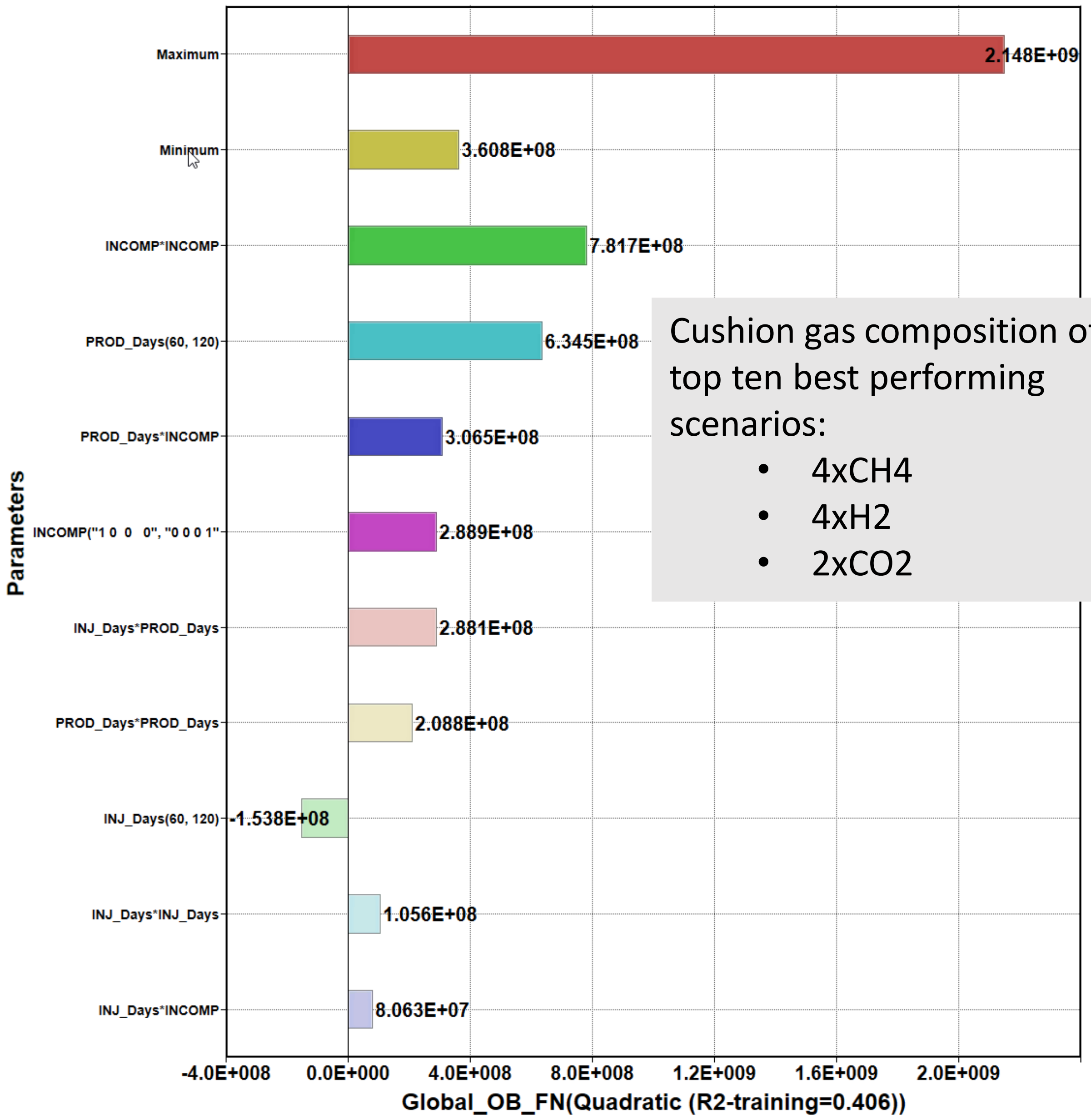




Optimisation Results

- CH4,H2 and CO2 provide better cushions.
- CH4 and H2 are native to the operation. Minimal or no contamination penalty.
- Minimal injection cost for CO2
- Better cycling efficiency with longer injection and production period (lower rates)



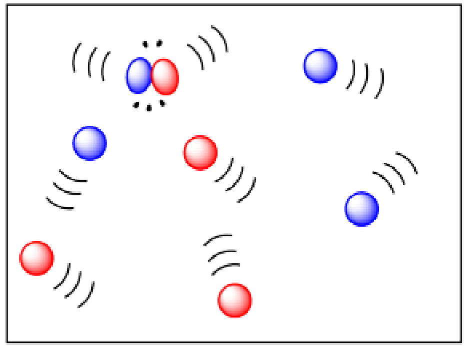


Cushion gas composition of top ten best performing scenarios:

- 4xCH4
- 4xH2
- 2xCO2

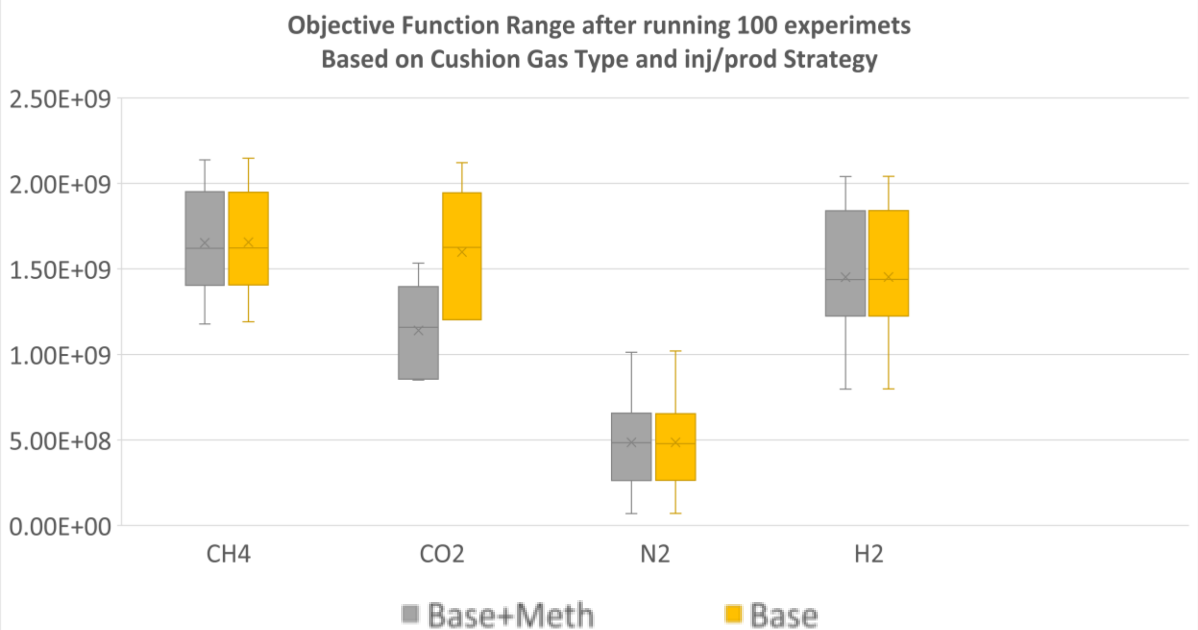
What if we use CO2 as Cushion

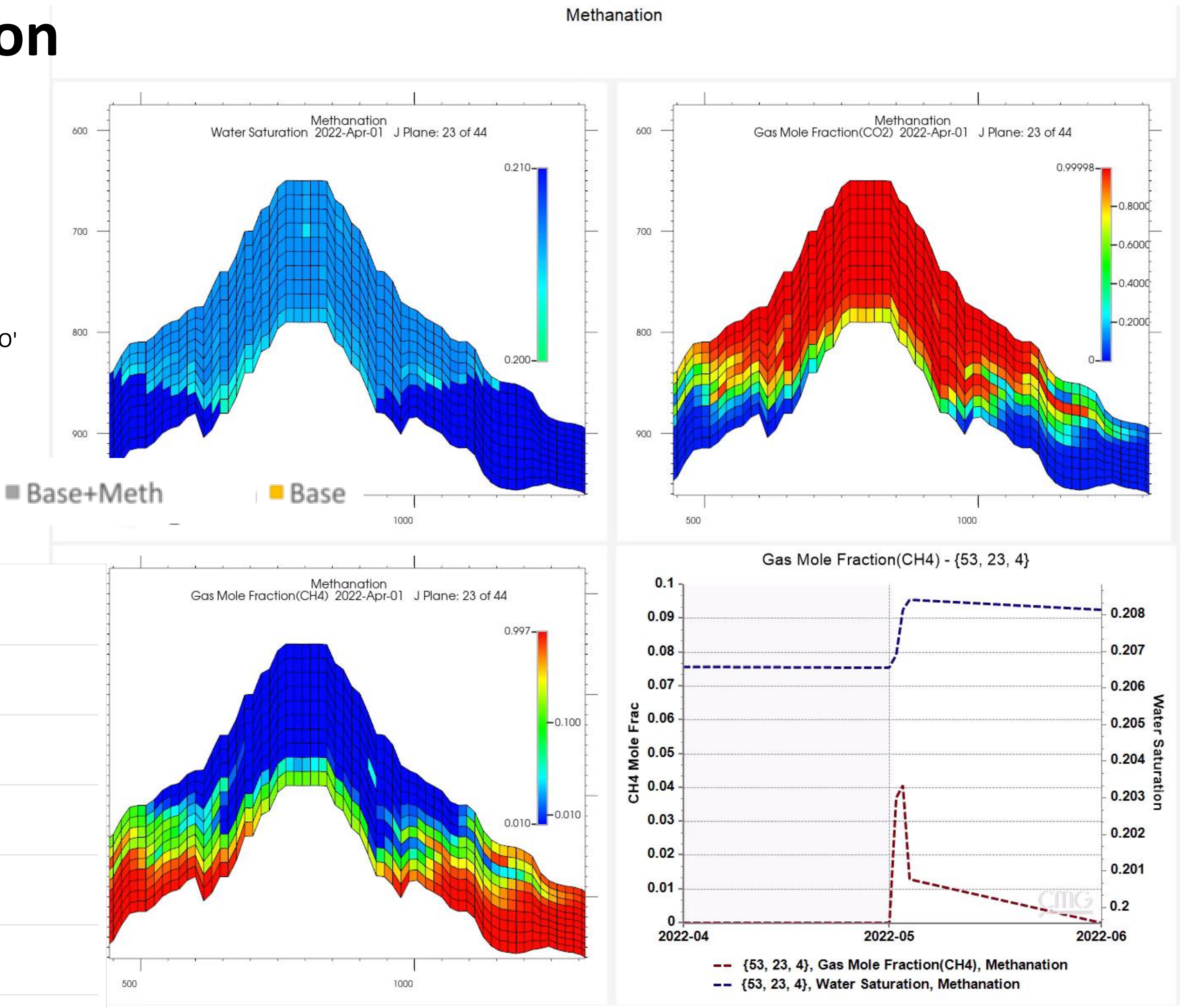
Again 100 cases are run to look for best cushion and prod/inj strategy



REACTION-RATE-ARN 'CO2' + 4 'H2' = 'CH4' + 2 'H2O'
REACTION-ORDER 'CO2' 1 'H2' 1
FREQUENCY-FACTOR 1.0e-3
ACTIVATION-ENERGY 0

No more CO2 cushion gas scenario in top 10 best scenarios





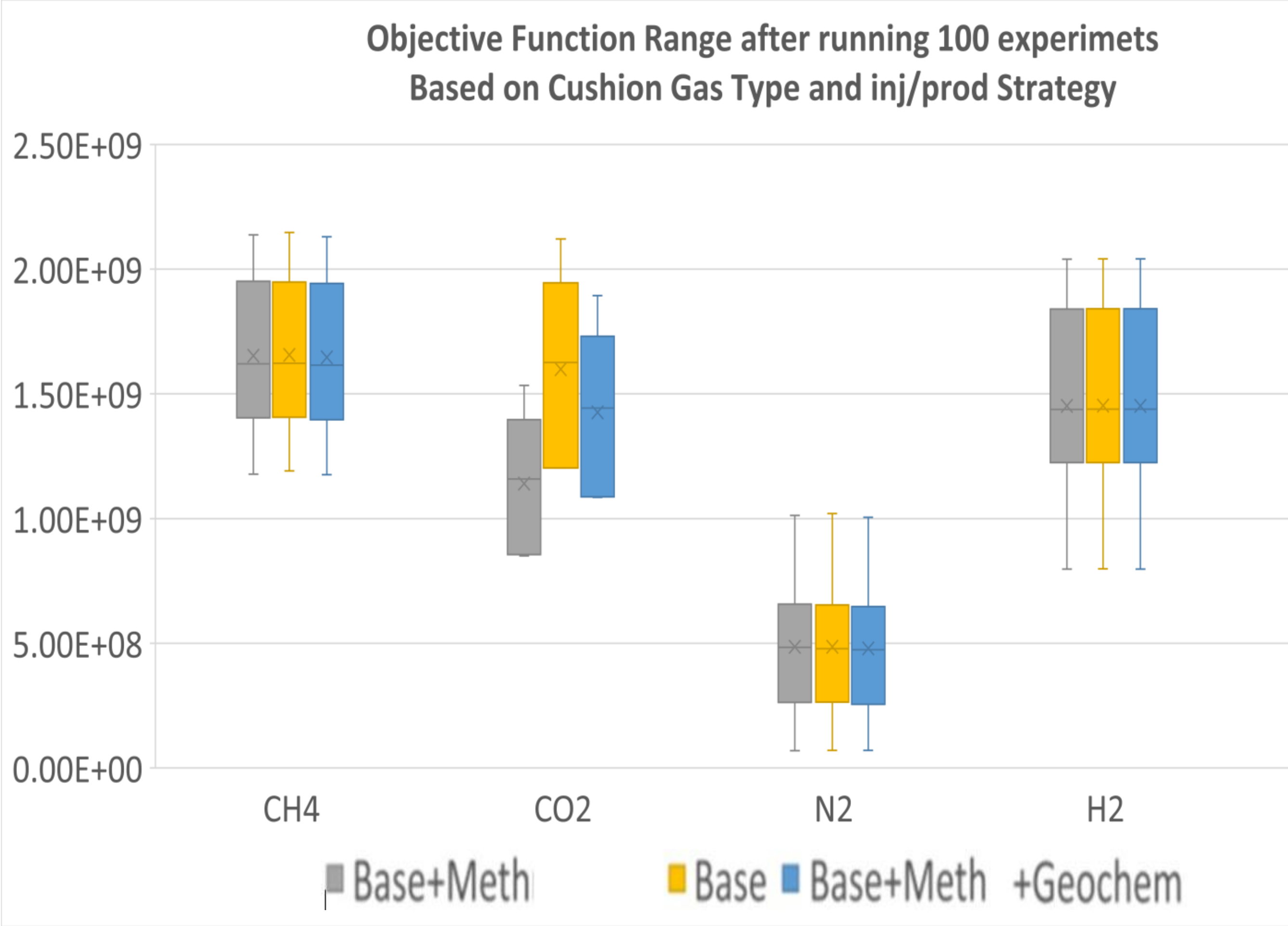
Cushion gas with methanation and geochemistry reactions

- Reactions are added using Wolery databases:
    - Aqueous
        - 'H2O' + 'CO2' = 'HCO3-' + 'H+'
        - 'OH-' + 'H+' = 'H2O'
        - 'CO3--' + 'H+' = 'HCO3-'
        - 'CaCO3' + 'H+' = 'HCO3-' + 'Ca++’
    - Mineral
        - 'Calcite' + 'H+' = 'HCO3-' + 'Ca++'
        - 'Halite' = 'Cl-' + 'Na+'

CO2:Methanation vs Geochemistry reactions

Cushion gas with methanation and geochemistry reactions

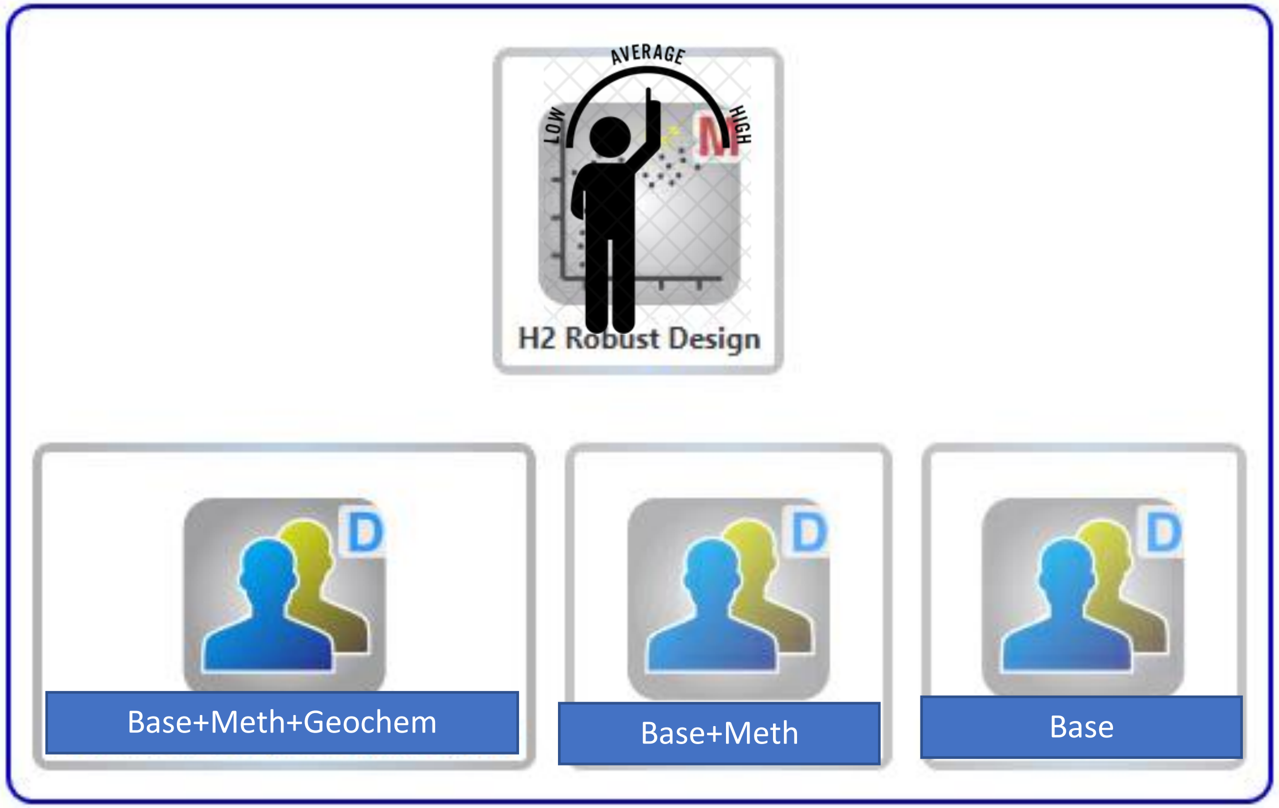
- In the case of CO_2 cushion Adding geochemistry negative effects of methanation partly decreases because:
  - A portion of CO_2 injected reacts with the carbonate reservoir rock increasing por/perm
  - Reduced CO_2 results in less methanation degrading the production stream and reduce overall gas permeability



Optimisation under uncertainty

- When the actual physics is unknown, the optimal design must account for a range of possibilities.

- Any design setting including cushion type, inj/prod strategy has to be tested simultaneously in all three probable scenario. The overall score of a scenario will be a weighted average of all scenarios.



- Using CH4 and H2 cushions tend to outperform other scenarios.
- If CO2 cushion is used the overall objective function across three modelling assumption is only 3% below from the absolute best scenario.

Conclusions

Compositional simulator with the right physics can accurately predict the H2 Cycling behaviors.

The role of cushion gas is crucial for an effective H2 cycling, particularly within the first few cycling rounds

There is an economic balance between long-term savings from using cushion and immediate cost of cushion injection.

Optimal cushion type dependents on potential reactions it triggers.

Despite CO2 cushion being an attractive proposition, it might undermine cycling efficiency.

Within a complete modelling framework CO2 cushion can deliver near optimal efficiencies.

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- **CMG's Vision:**

To be the leading developer and supplier of dynamic reservoir and production technologies in the WORLD

Questions?

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