Future Energy Systems Center

Assessment of geologic H_2 potential for sustainable energy systems: A cost and emission analysis perspective

Project Update

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Project Team

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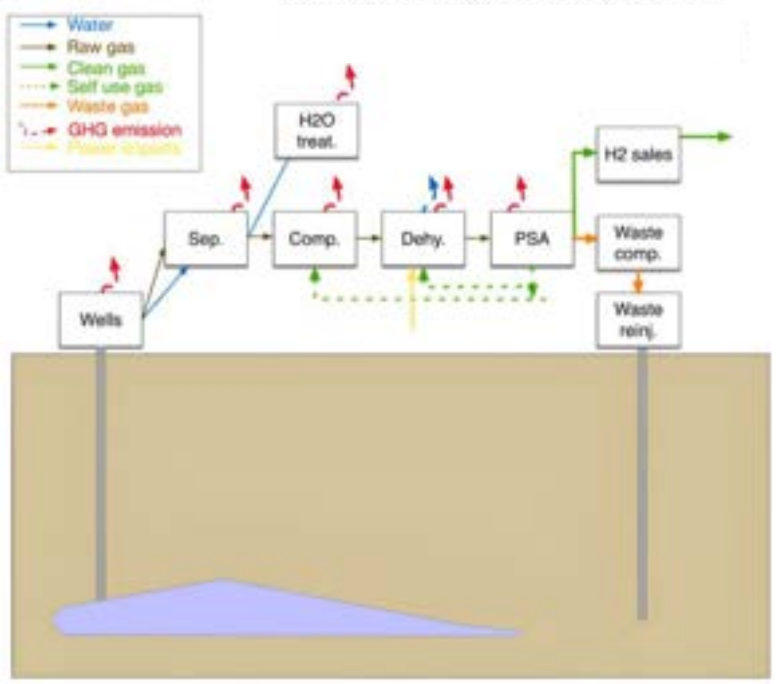
Project motivation and objectives

Motivation

- The ideal hydrogen source is low-cost and has low emission.
- Geologic hydrogen presents a promising alternative.



Processes involved in GeoH2 recovery by Brandt, Adam R. *Joule 7.8 (2023): 1818-1831.*

- **Current cost and emissions analysis on geologic hydrogen production is limited**

Objectives

1. **What are the geological characteristics and spatial distribution of hydrogen resources?**
2. **What are the cost and emissions of geological hydrogen?**
3. **What are the primary uncertainties and how do these uncertainties affect cost and emissions?**

Scope

Two validations on real-world wells

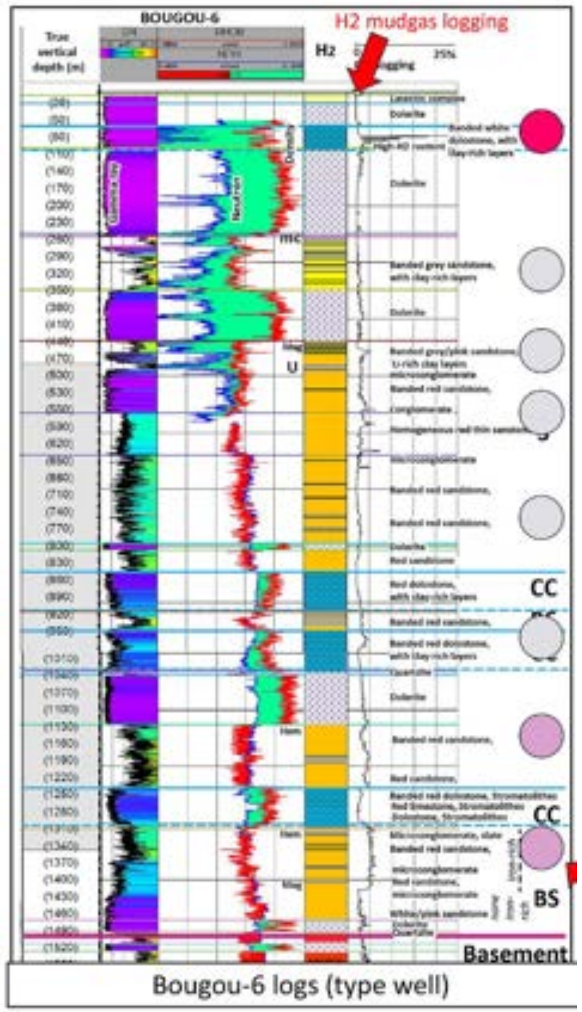
- **Spain, Monzon.** Gas cap 30 m over a 25 m water leg at 3,683 m. Default case.
- **Mali, Bougou.** Five stacked reservoirs, 62 m to 1,340 m, summed as independent tanks.
- **Both run the same analysis flow:**
  - Reservoir simulation
  - Assessment (TEA/LCA)

Three sensitivity studies

Baseline case: Spain Monzon reservoir

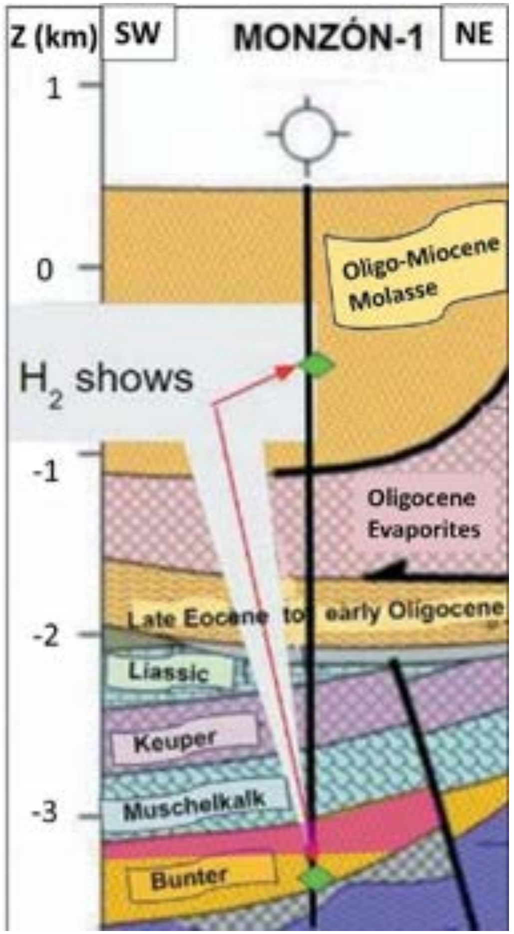
1. **Net pay thickness:** 4.8 m to 120 m of gas cap
2. **Permeability:** 0.8 to 32 millidarcy (mD)
3. **Depth:** 368 to 14,732 m
   - Pressure, porosity & permeability move together

Mali, Bougou



Bougou-6 logs (type well)

Spain, Monzon



Everts et al., Int. J. Hydrogen Energy 142 (2025) 26-39

Methodology — reservoir modelling

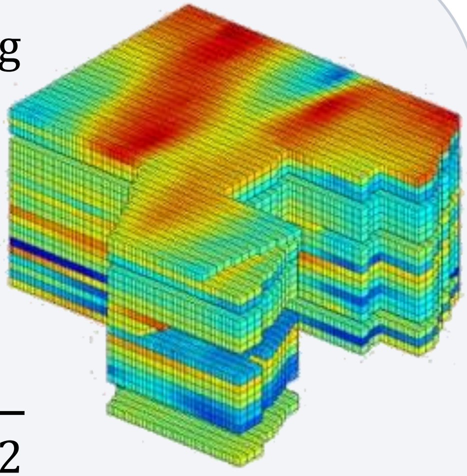
Governing equations (MATLAB MRST)

$$\frac{\partial}{\partial t}(\varphi b_\alpha S_\alpha) + \nabla \cdot (b_\alpha u_\alpha) = b_\alpha q_\alpha, \quad \alpha = \mathrm{w, g}$$

$$u_\alpha = -\frac{k k_{\mathrm{r}\alpha}}{\mu_\alpha}(\nabla p - \rho_\alpha g \nabla z)$$

$$k_{\mathrm{r}\alpha} = \left(\frac{S_\alpha - S_{\alpha \mathrm{c}}}{1 - S_{\mathrm{wirr}} - S_{\mathrm{gc}}}\right)^{n_\alpha}$$

$$\mathrm{WI} = \frac{2\pi k \Delta z}{\ln\left(\frac{r_\mathrm{e}}{r_\mathrm{w}}\right) + s}, \quad r_\mathrm{e} = 0.14\sqrt{\Delta x^2 + \Delta y^2}$$



MATLAB Reservoir Simulation Toolbox (MRST) (by SINTEF)

- Water & Gas PDE based modeling
- Permeable flow through porous media
- Water and gas extraction
- Hydrogen dissolved in the water

Assumptions

- **44.4 km^2** area for Spain case
- **Assuming 6 producers wells, 6 reinjector wells**
- **dx, dy = 30 m, dz = 15 m, dt = 2 weeks**
- **No throttling/ Constructed at yr=0 for all wells**
- **Infinite water reservoir** below lowest reservoir facing low permeable wall
- **50 years**
- **S_{gc} (critical gas saturation) = 0.1**
- **S_{wirr} (irreducible water) = 0.2**
- **Producer well's bottom hole pressure = 0.3 x initial reservoir pressure**
- **Water fully reinjected to reinjectors**
- **Commingled well** (producing gas and water from two layers)

Methodology — cost and emissions

Levelised cost of hydrogen (LCOH)

$$\text{LCOH} = \frac{CAPEX + \text{PV(OPEX)}}{\text{PV}(m)}$$

$$\text{PV}(X) = \sum_{t=1}^{N} \frac{X_t}{(1+r)^t}$$

- Discount rate r 15%, life N 50 years. PV (present value)
- **CAPEX:** well construction + surface equipment cost
- **OPEX:**
  - Fixed cost (labor and maintenance)
  - Variable cost (electricity and utilities)
- **Exploration:**
  - Excluded. (If include, 0.5$/MCF x EUR)*

Greenhouse gas (GHG) intensity

$$\text{CI} = \frac{E_{\text{direct}} + E_{\text{small}} + E_{\text{offsite}} + E_{\text{embodied}}}{m_{\text{H2}}}$$

$$E_{\text{direct}} = E_{\text{comb}} + E_{\text{VFF}} + E_{\text{drill}}$$

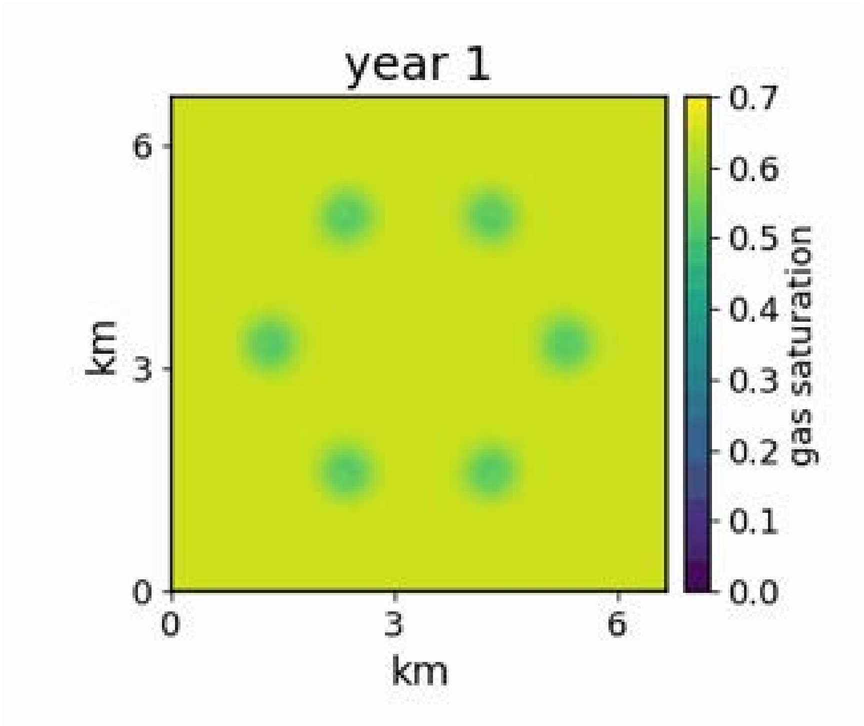
$$E_{\text{small}} = 0.10 E_{\text{direct}}$$

- **CI:** carbon intensity, kg carbon dioxide equivalent per kg hydrogen
- **Direct:** flaring, venting, fugitive leaks, drilling diesel
- **Small sources:** a 10% uplift on direct**
- **Offsite:** grid electricity for water
- **Embodied**: steel & cement (pipe and surface equipment)
- **Hydrogen GWP:** assuming 5kgCO2e/kg-H2**

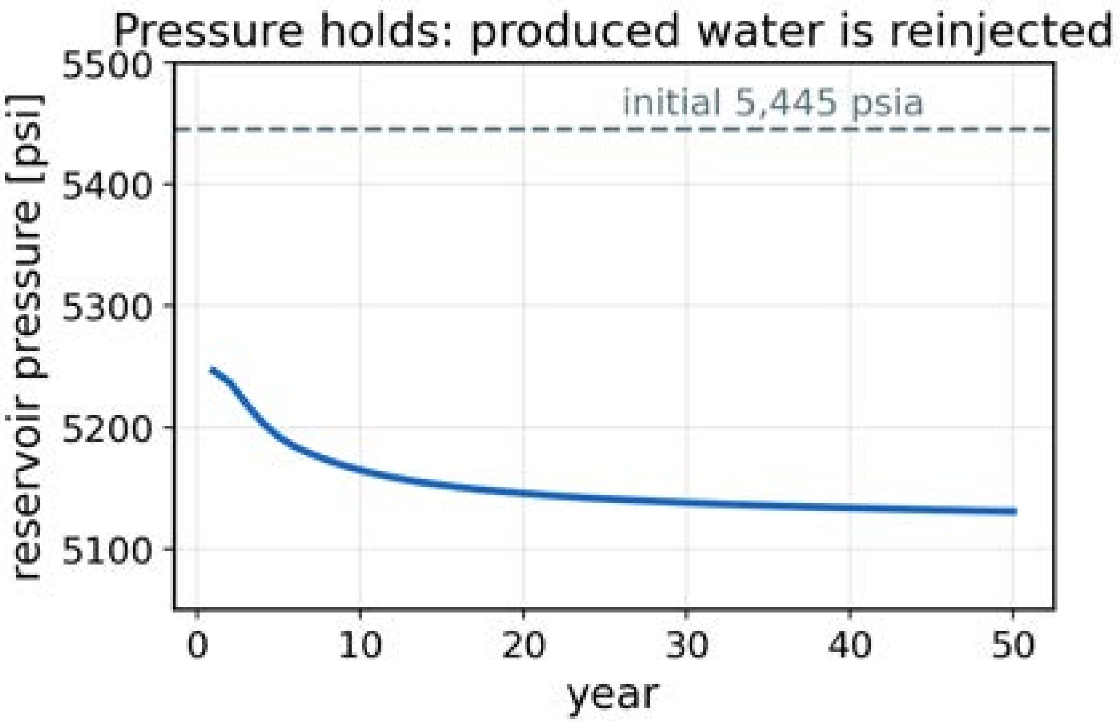
* IEA (2019)
** OPGEE Model

Results: reservoir simulation (Spain case)

Gas saturation in the gas-cap layer

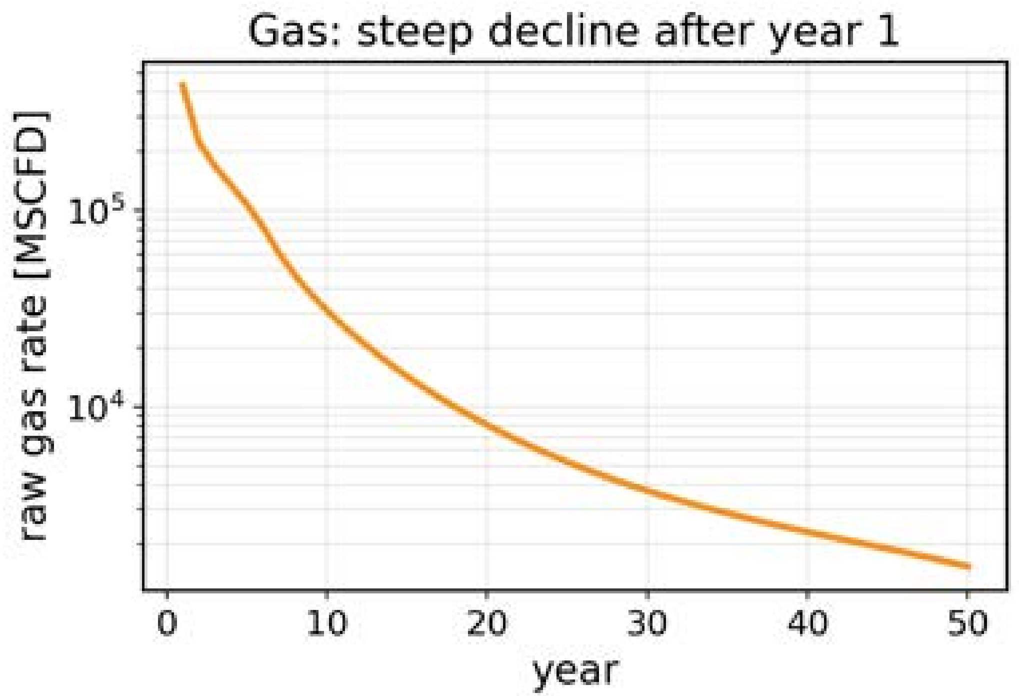


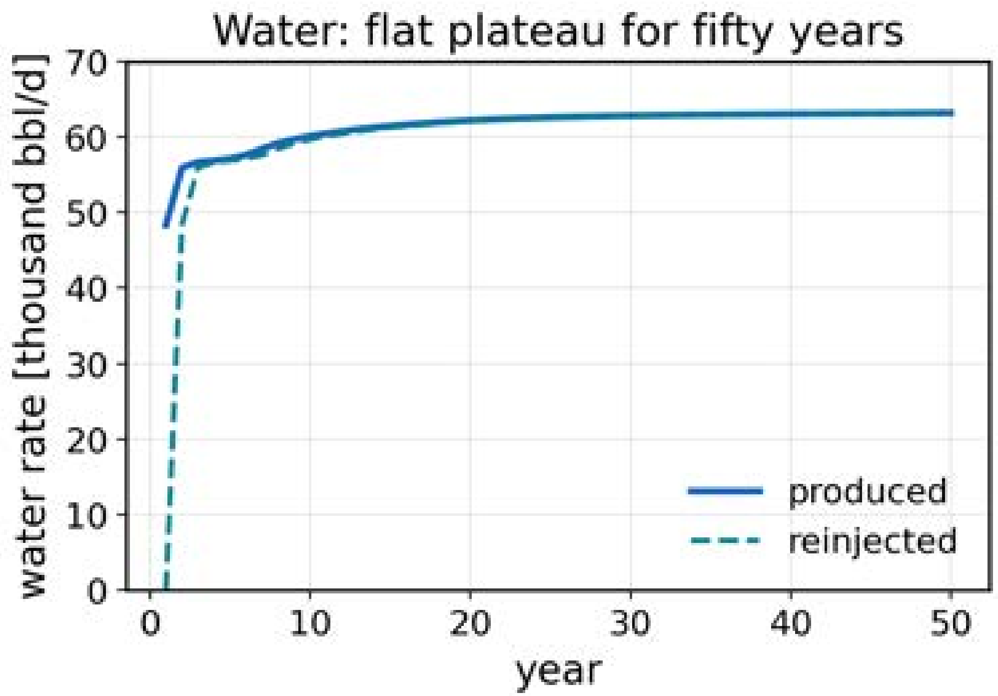
Field pressure



- Six producer wells produces gas and water simultaneously
- Gas and water extraction and flow behavior modelled
- Produced water is reinjected same amount 1yr later
- Producing well pressure decrease and converging

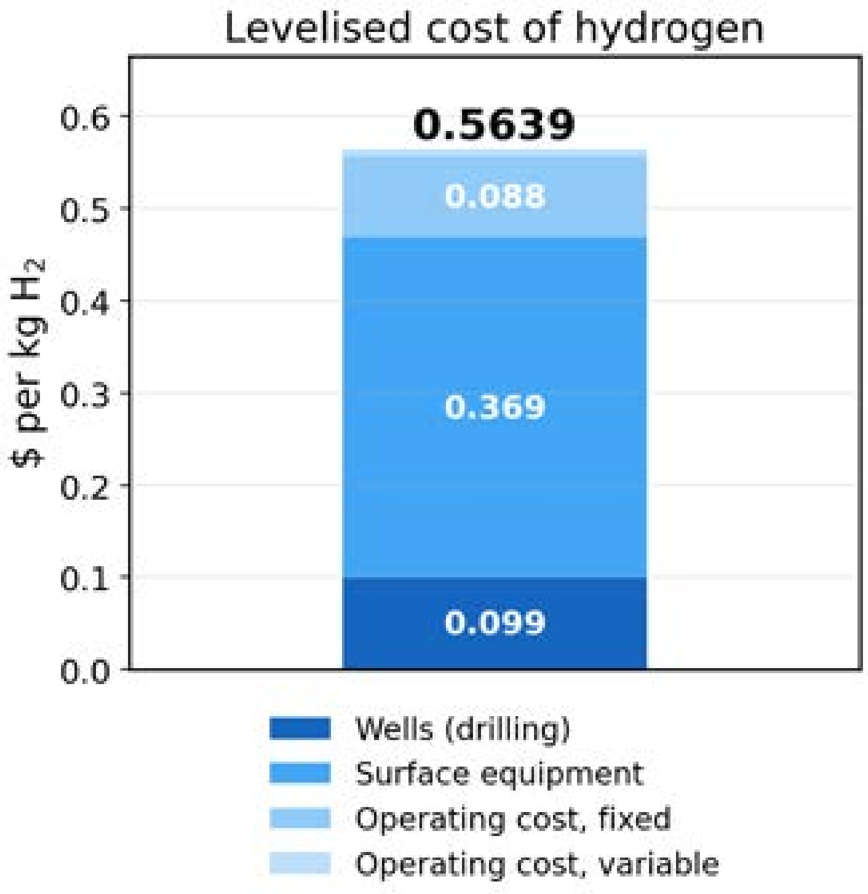
Results: production profiles





- Gas: Peak at 1st year (432,700) down to 50th year (1,540 MSCFD)
- Water: Producing up to 63,000 bbl/d within a few years, then flat
- Reinjection: from year 2 the field puts back the previous year's water (Assuming 1% loss)

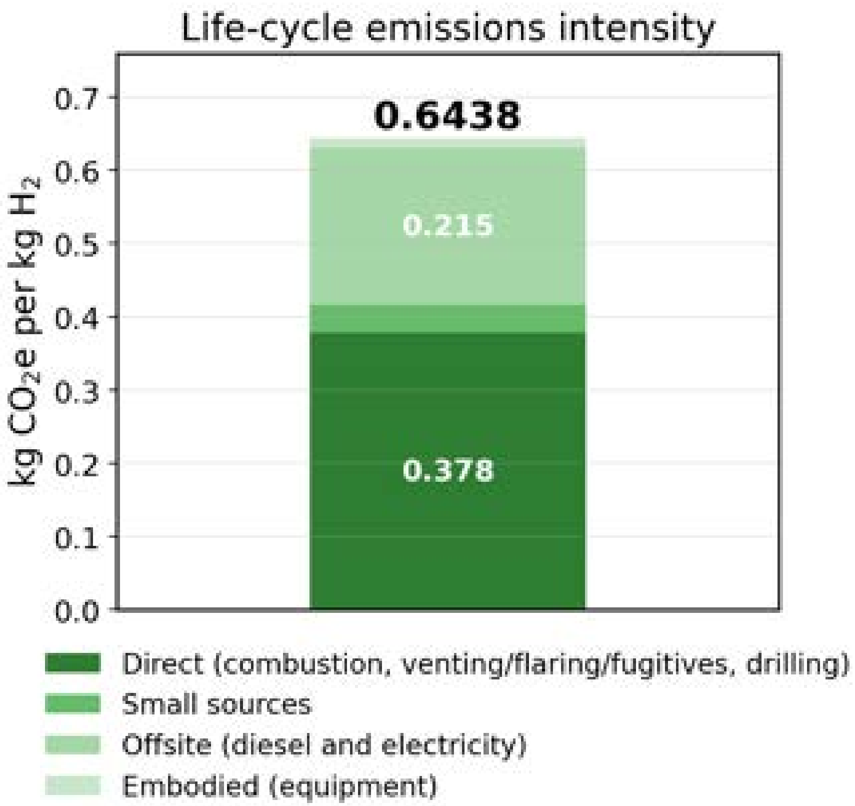
Results: techno-economic analysis



TEA results

- **$0.5639/kgH$_2$.** 1.26 million tonnes over fifty years.
- **Surface equipment 65%:** sized by peak gas and water treatment equipment
- **Drilling 18%:** twelve wells at $3.0 million each
- **Operating 17%:** mostly fixed charges on installed equipment
- **If Exploration included**: $0.20 per kg
- **Hydrogen from water:** 4.4% of total hydrogen produced

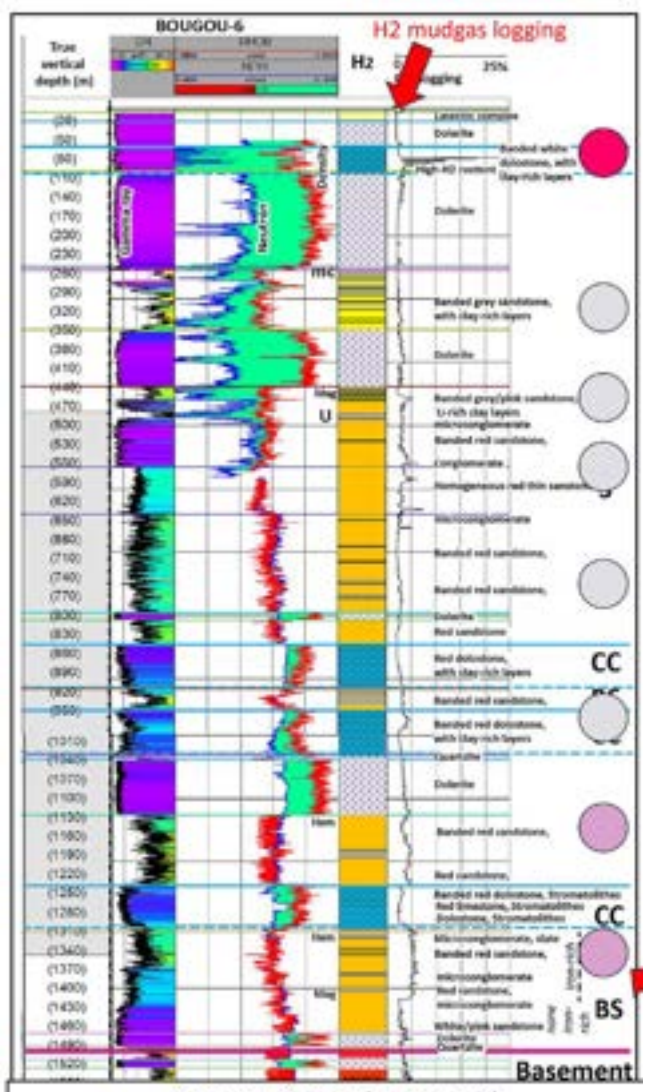
Results: life-cycle emissions



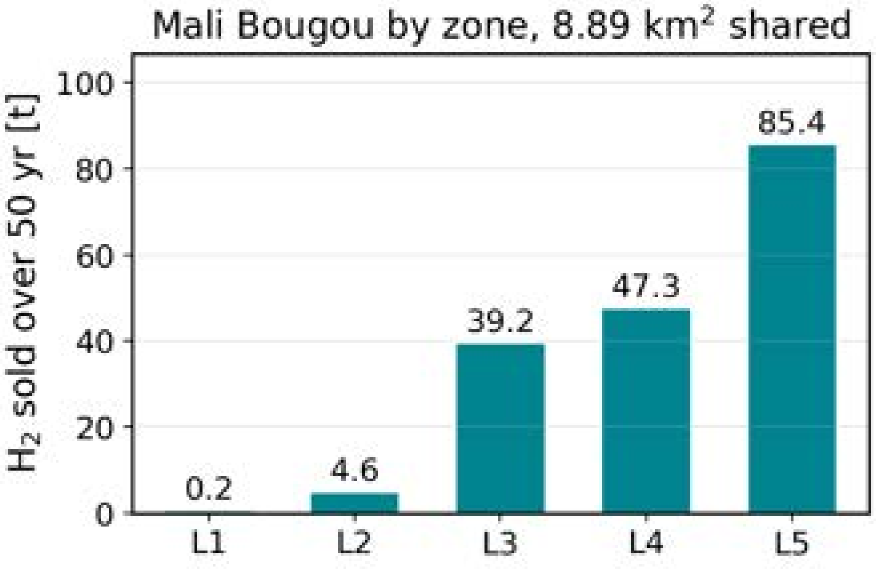
Where the emissions sit

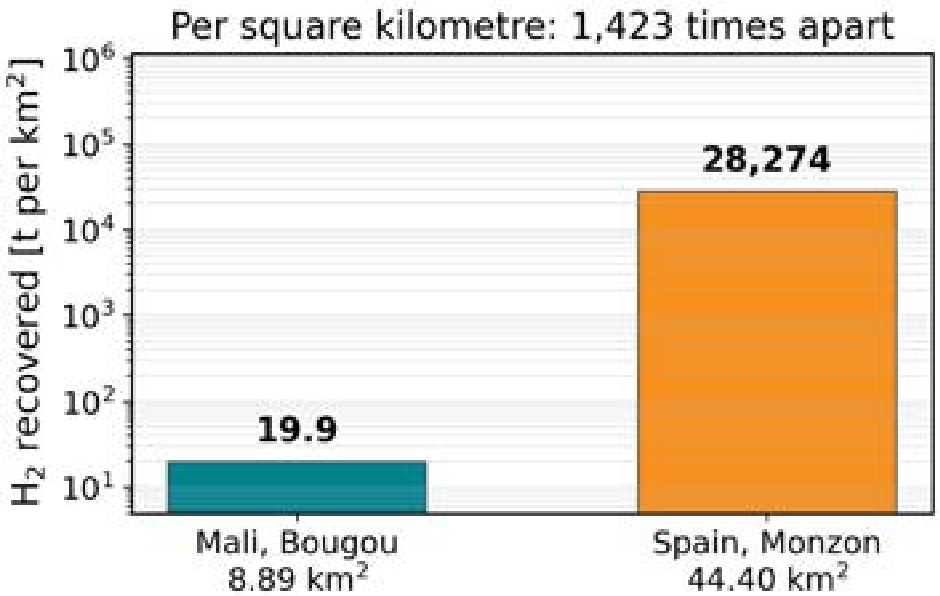
- **0.644 kgCO_2e/kgH_2** for Baseline case
- **Direct 59%:** flaring(47%), venting+fugitive leaks(10%), drilling diesel (~2%)
- **Offsite electricity 33%:** water treatment and reinjection pumping
- **Embodied steel/cement 2%:**
- **Cost/GHG result from Spain Monzon case is competitive compared to conventional H_2**

Mali case result



Bougou-6 logs (type well)

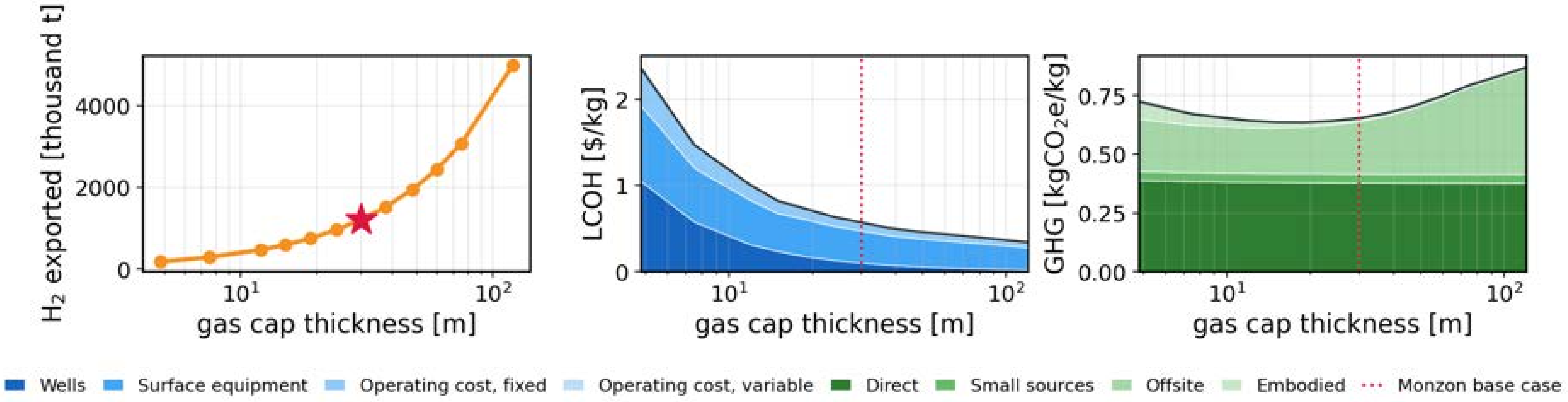




- **Mali Bougou**: five stacked zones at water saturation 0.97. Hydrogen dissolved under Henry's law, minimal free gas cap
  → Much less amount than Spain case
- **H2 In place:** 1,344 tonnes/km^2
- **EUR (for 50 years)** 19.9 tonne/km^2 → **1.5% recovery**
  - Due to minimal H2 production rate (due to low permeability and water flow)

→ **Resultingly, high LCOH & GHG**

Sensitivity: net layer thickness



- **Swept** from 0.16x to 4x (4.8m to 120 meter of gas cap)

  → H2IP/km^2 ↑ & H2IP/well ↑ → **LCOH** ↓
- Price falls from $2.37 to $0.34 per kg.
- GHG emission **almost flat** from all case but bottom at near 20 meters
  - Balance between offsite (pump electricity), embodied emission (peak gas rate), and H_2 EUR

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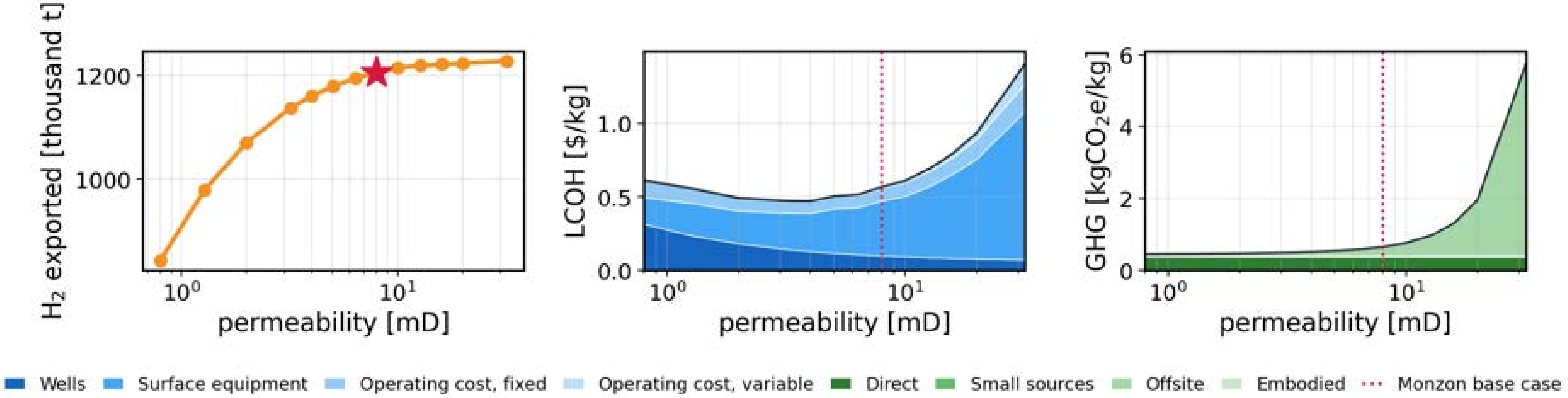
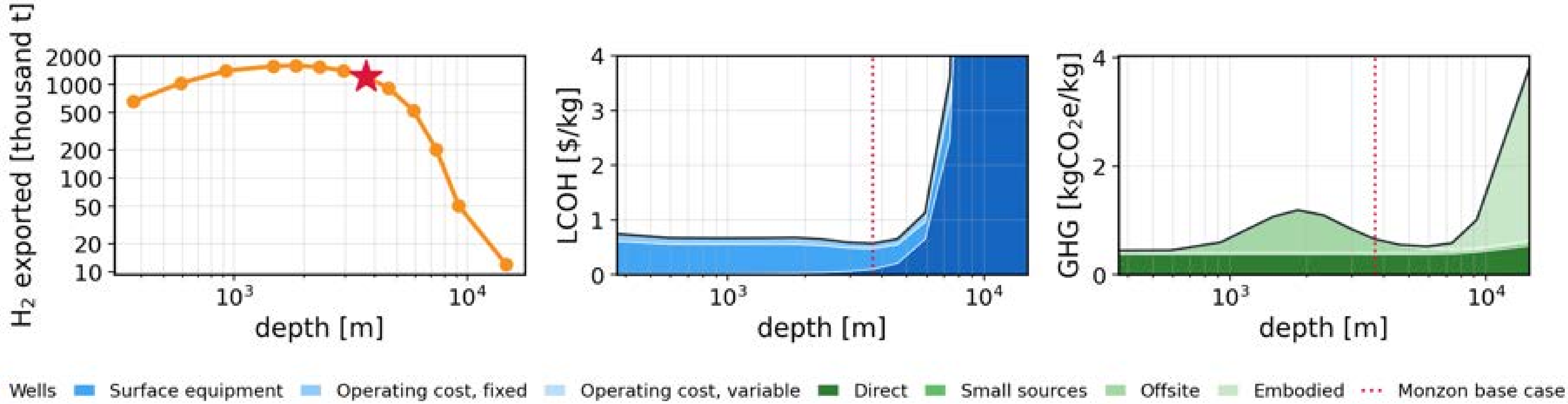
Sensitivity: permeability

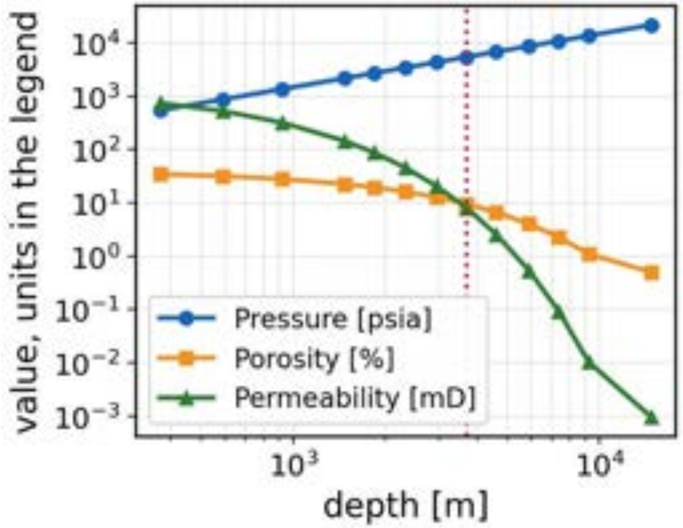


- **Swept** from 0.1x to 4x (0.8 mD to 32 mD)
  - → Flow rate ↑ & EUR converging → **LCOH ↓**
  - → Peak gas and water rate at yr=0 ↑ → Oversizing of surface equipment → **LCOH ↑**
  - → Settle point! (at ~ 4 mD)
- **GHG increase monotonically** due to oversizing of components → Importance of throttling

Sensitivity: depth, with compaction



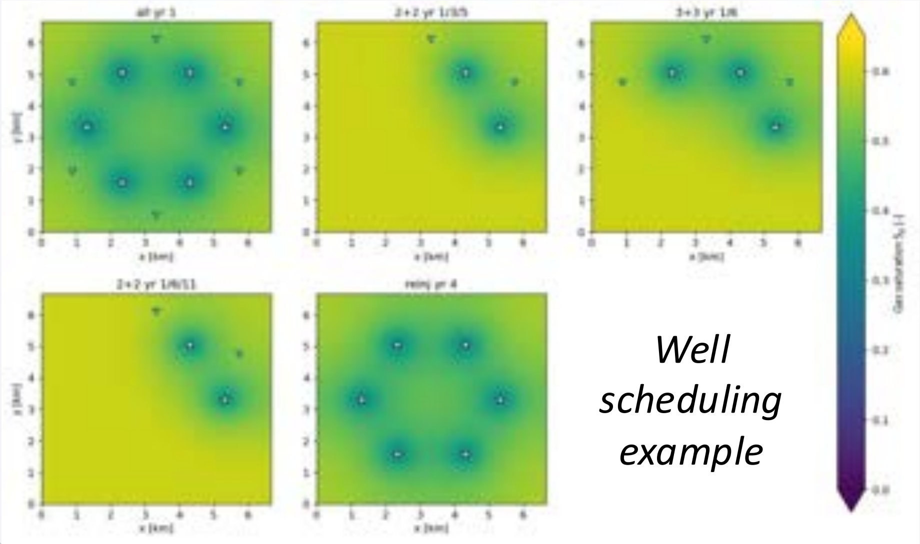
- **Swept** from 0.1x to 4x (368 to 14,732 meters)
  - → Pressure ↑ → **EUR ↑**
  - → Porosity & Permeability ↓ → **EUR ↓** → Settling point @ 1,800 meter
- LCOH moves almost flat untill 5,000 meter then increase rapidly (Due to well construction cost increase and EUR decrease (permeability))
- GHG has local peak near ~1,800 meter (due to local max water amount (offsite)
  - → Then re-increase due to deep well construction & low EUR (embodied)



Future work

Future work for the reservoir modeling

- **Additional scenario and sensitivity**
  - Well type (Water only / Gas only)
  - Throttling
  - Well construction scheduling



Next in the assessment / publication

- **Different type of well pipe shape & effect**
  - Hydrogen/High P/High T - resistive materials
- **LCA assessment for component fabrication**
- **Gas composition effect on separation burden**
- **Publication**