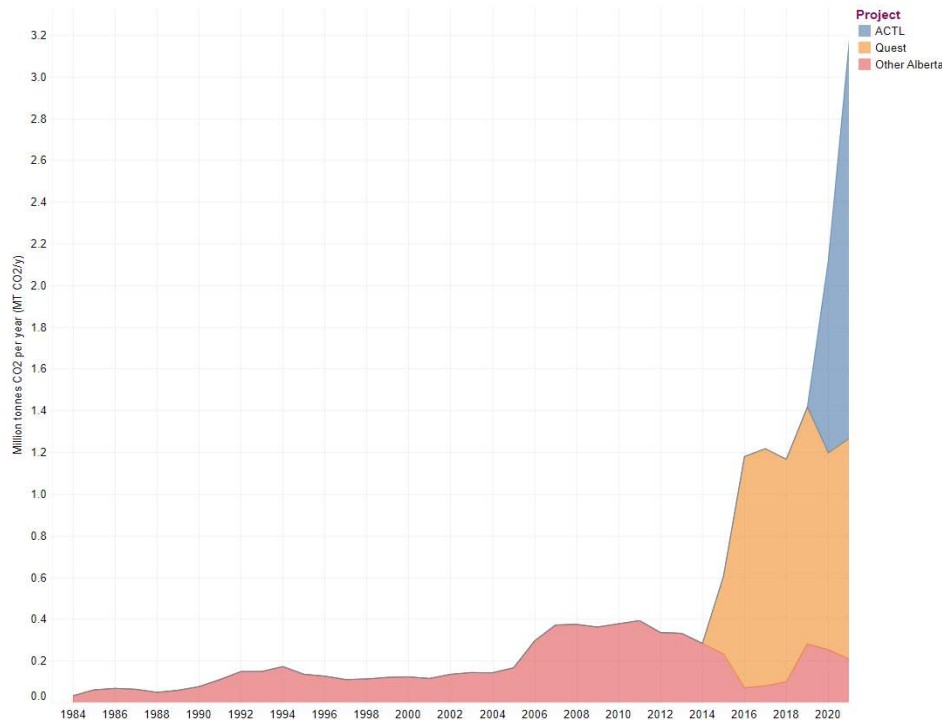


CCUS Challenges

C-FER Technologies

How Many CO₂ Pipelines?

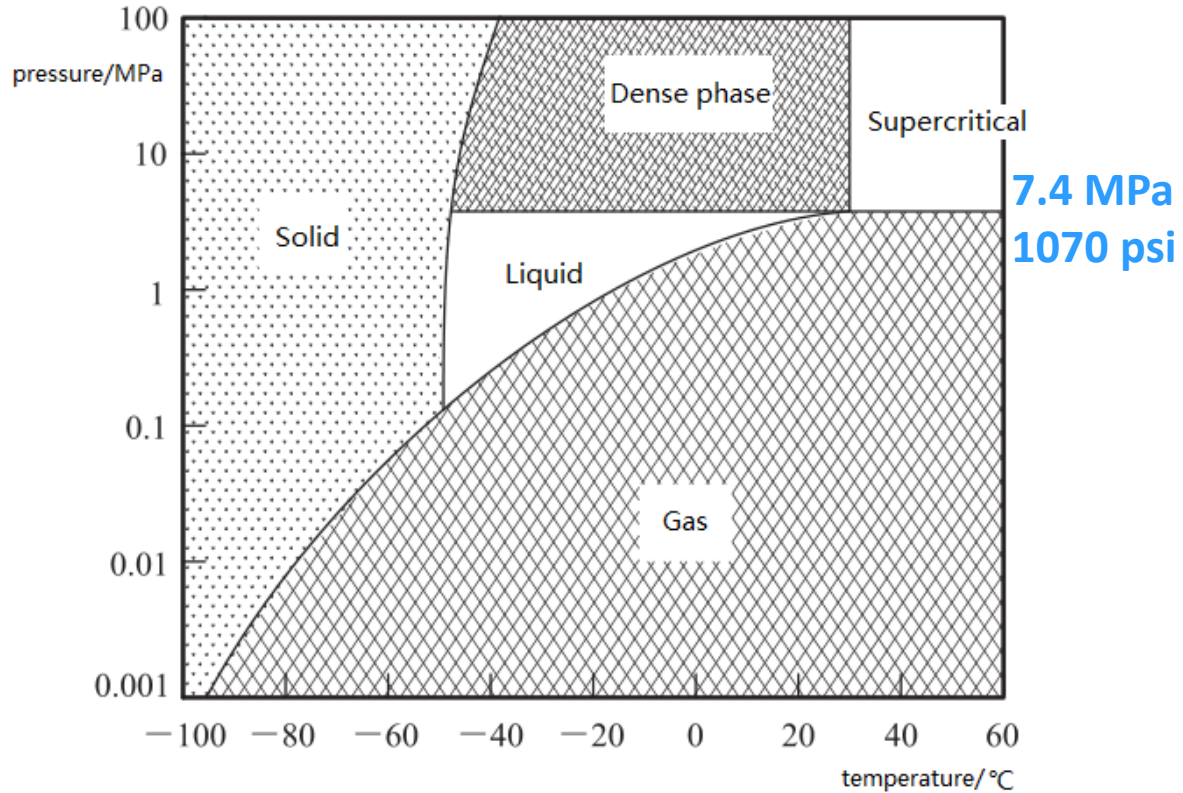
- Carbon Capture Utilization and Storage (CCUS) will be a key part of Net Zero
- USA studies suggest up to 100,000 km of new pipeline will be required
- 25 CCS projects being evaluated in Alberta



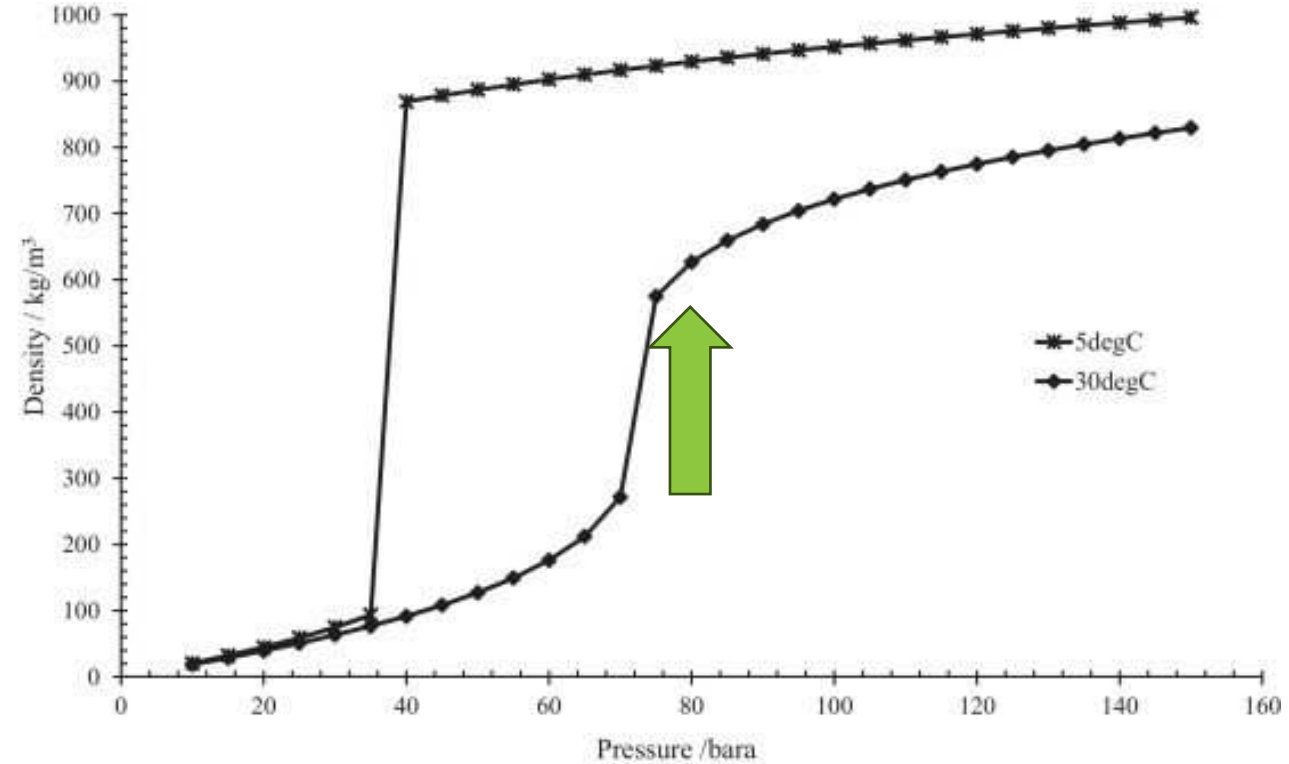
**Pathways Alliance is aiming at 22 MT/y
~ 7 times current rate of injection**

CER - Market Snapshot: New projects in Alberta could add significant carbon storage capacity by 2030

CO₂ Pipeline Hydraulics



A Review of Pipeline Transportation Technology of Carbon Dioxide (Wang et al 2019)



The Effect of CO₂ Purity on the Development of Pipeline Networks for Carbon Capture and Storage Schemes (Wetenhall et al 2014)

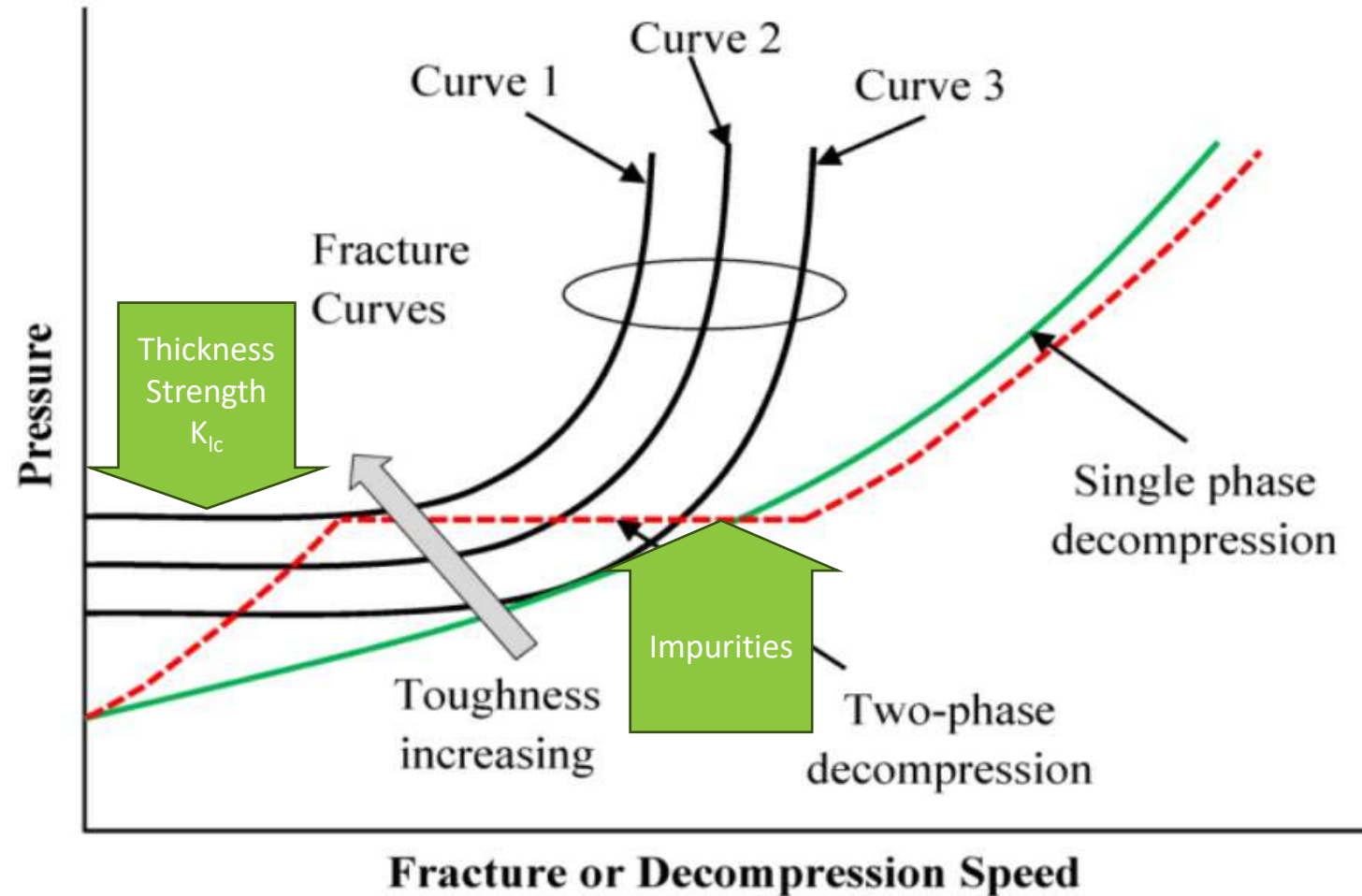
- Best economics when operating in dense phase
- Impurities (H₂, H₂O, H₂S, CO, CH₄, NO_x, SO_x,...)
 - Increase compressibility
 - Initiate corrosion



Spadeadam, UK (Cooper & Barnet, 2016)

Full-scale tests generally required to confirm sufficient fracture toughness for planned operating conditions

Fracture Propagation



(Decompression wave speed in CO₂ mixtures: CFD modelling with the GERG-2008 equation of state. Elshahomi et al. 2015)

Release Modeling

Outflow

- Estimate rate of gas release for large leaks & ruptures
- Requires complex transient analysis
- Consider valve closures
- Complicated by impurities effects on compressibility

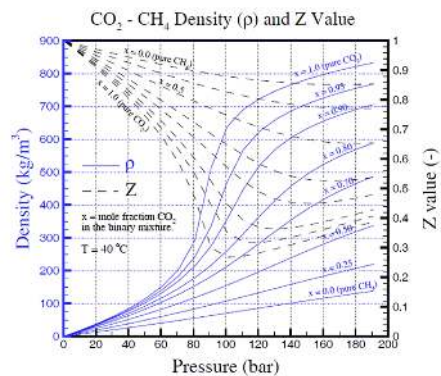


Figure 3. Density and Z value of CO₂-CH₄ mixtures at T = 40 °C (source: Magee et al., 1994; NIST, 1997).

Dispersion

- Estimate where dense gas cloud goes
- Requires complex transient analysis
- Consider terrain & wind
- Complicated by impurities effects on density



CO₂ Release at DNV Spadeadam

Toxicity

- Evaluate life safety impact
- Requires complex exposure analysis
- Consider occupancy & escape scenarios
- Complicated by impurities effects on toxicity

| Gas | 8-hour Exposure Limit (ppm) (AB OHS) |
|------------------|--------------------------------------|
| CO ₂ | 5,000 |
| CO | 25 |
| H ₂ S | 10 |
| SO ₂ | 2 |

CO₂ Dispersion Monitoring & Modeling

Opportunities to validate:

- Fracture arrest in pipelines
- Dispersion models that consider terrain
- Remote monitoring to identify and track large plumes



Canadian Forces Base Suffield

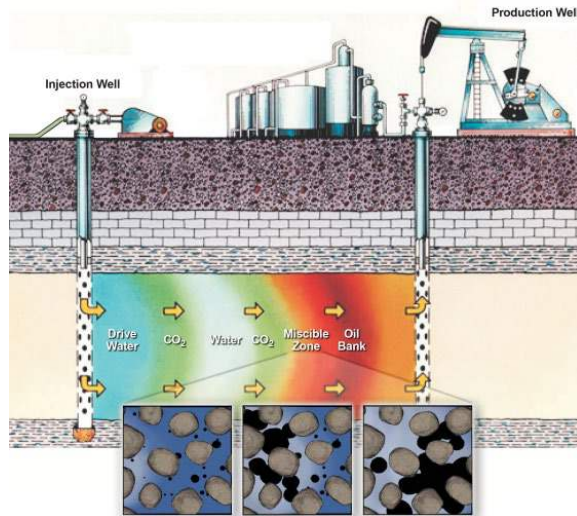
- 2,700 km²
- Restricted access
- Flat and valley terrain
- Research & Testing facilities



Underground Storage

Enhanced Oil Recovery

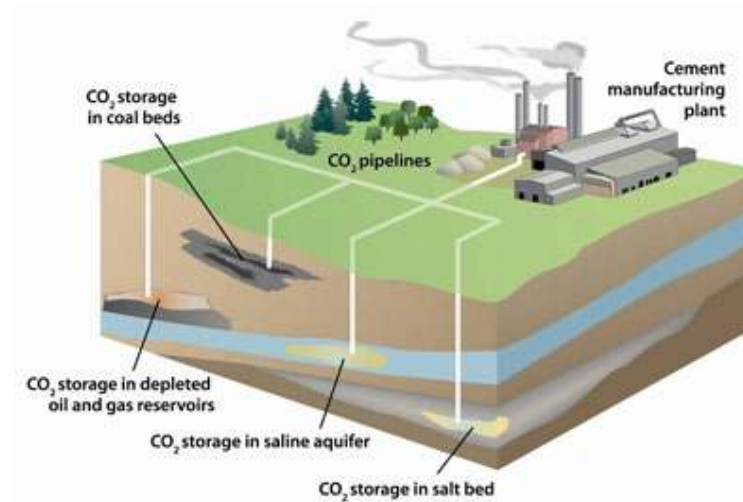
Enhance (AB) – Alberta Carbon Trunk Line
Weyburn (SK) – Boundary Dam Power Station



Carbon Dioxide Enhanced Oil Recovery, NETL

Sequestration

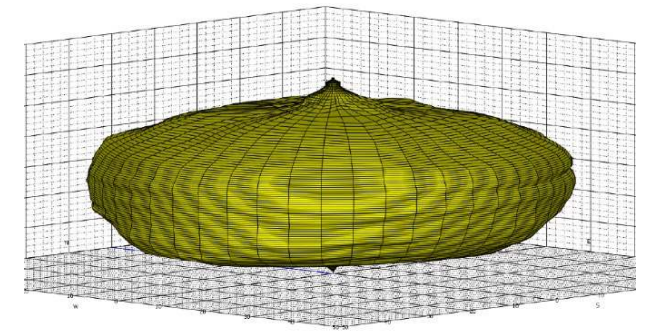
Quest (AB) – Alberta Carbon Trunk Line
Aquistore (SK) – Boundary Dam Power Station



Carbon Sequestration, US EPA

Temporary

Required to manage variability in capture/injection networks



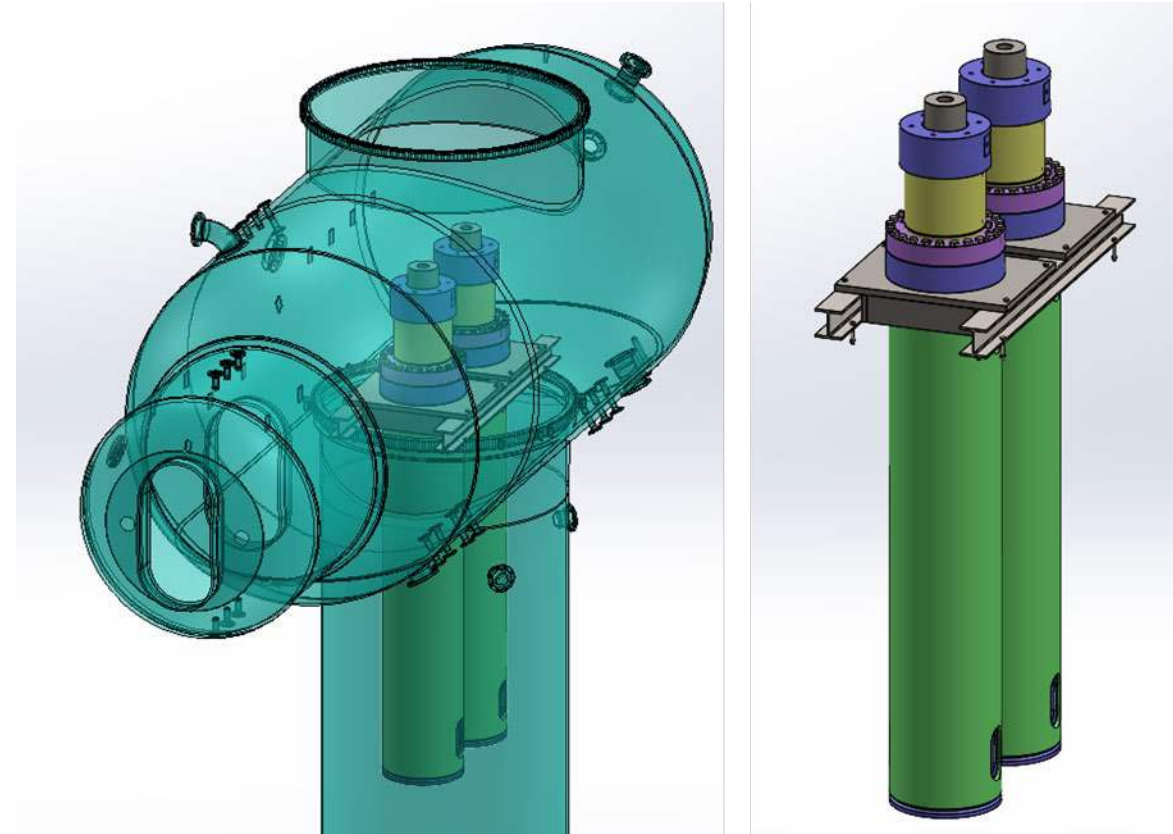
Petronim Projects, petronim.ca

Challenges

- Thermal cycling
- Leakage through neighbouring wells
- Well component degradation
- Permanence of storage

- Ensure Integrity of underground storage
 - Reservoir/cavern integrity
 - Wellbore integrity
 - Risk assessment of storage operations and well servicing
- Approach
 - Qualification of well casing connections for hydrogen sealability
 - Geomechanical modeling of reservoir and cavern stability
 - Assessment of wellbore cement sealability
 - Expand risk models for threats & release consequences

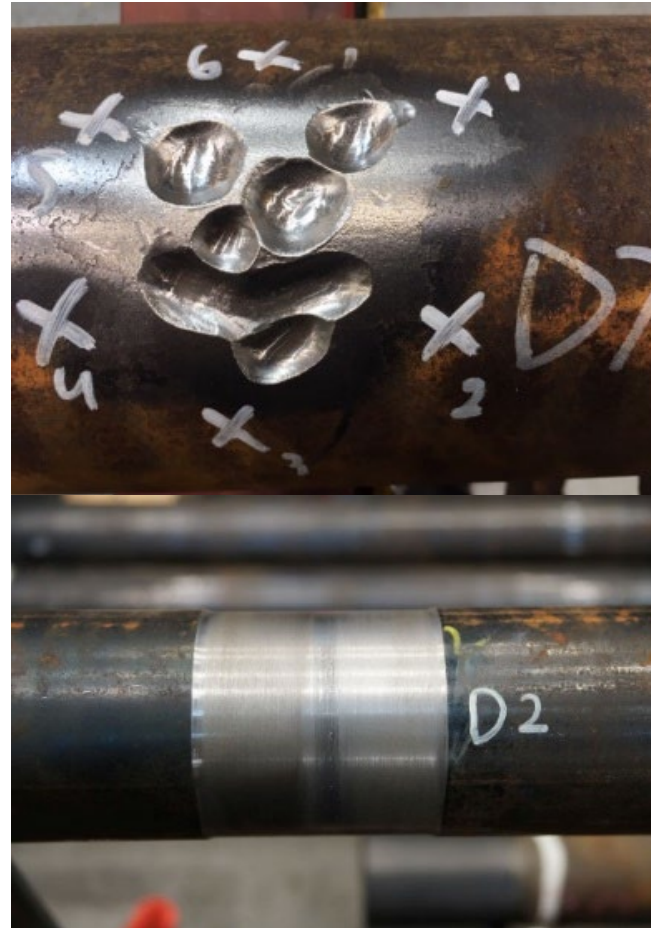
CO₂ Underground Storage



Well casing connection qualification test in hydrogen

Underground Storage Casing Inspection

- Logging tool verification
 - Corrosion wall loss
 - Leak locating
- QRA-based prioritization



CO₂ Pipelines

| Challenge | Test Type |
|---|---|
| Decompression behaviour with impurities | Shock tube test |
| Corrosion caused by impurities | Flowing critical pressure corrosion tests |
| Fracture propagation | Full-scale fracture arrest tests |

CO₂ Underground Storage

| Challenge | Test Type |
|----------------------------------|---|
| Well casing connection integrity | Connection qualification testing with CO ₂ |
| Well cement integrity | Long-term exposure |
| Well inspection log performance | Validation testing of logs in a controlled test well |
| Cavern stability | Geomechanical modeling |

CO₂ Releases

| Challenge | Test Type |
|--|-------------------------------|
| Discharge rate from storage wells or pipelines | Transient pressure modeling |
| Dispersion of releases considering terrain and obstacles | Transient dispersion modeling |
| Life-safety impact | Consequence modeling |
| Risk assessment | QRA |

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