1-2 October 2024 – Chester Hotel, Aberdeen, UK

Development of A Fit-for-Purpose CO_2 Injection Model for Casing And Tubing Design

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Agenda

- Project specifics
- Well design challenges
- CO_2 Injection Model (CIM)
- Tubing and Casing design/verification
- “Agile” development
- Conclusion and Future work

Viking CCS Project Overview

Harbour Energy | VikingCCS | bp

10 million tonnes CO_2 in emissions

is what we are committing to capture per year by 2030.

300 million tonnes

of storage capacity in our depleted Viking gas fields in the Southern North Sea.

2,700 m below the seabed

is where the CO_2 will be stored, beneath a 'SuperSeal' of between 600 and 1,000 feet of salt.

up to £ 7 billion

investment from 2025 to 2035 across the CCS value chain including capture and storage.

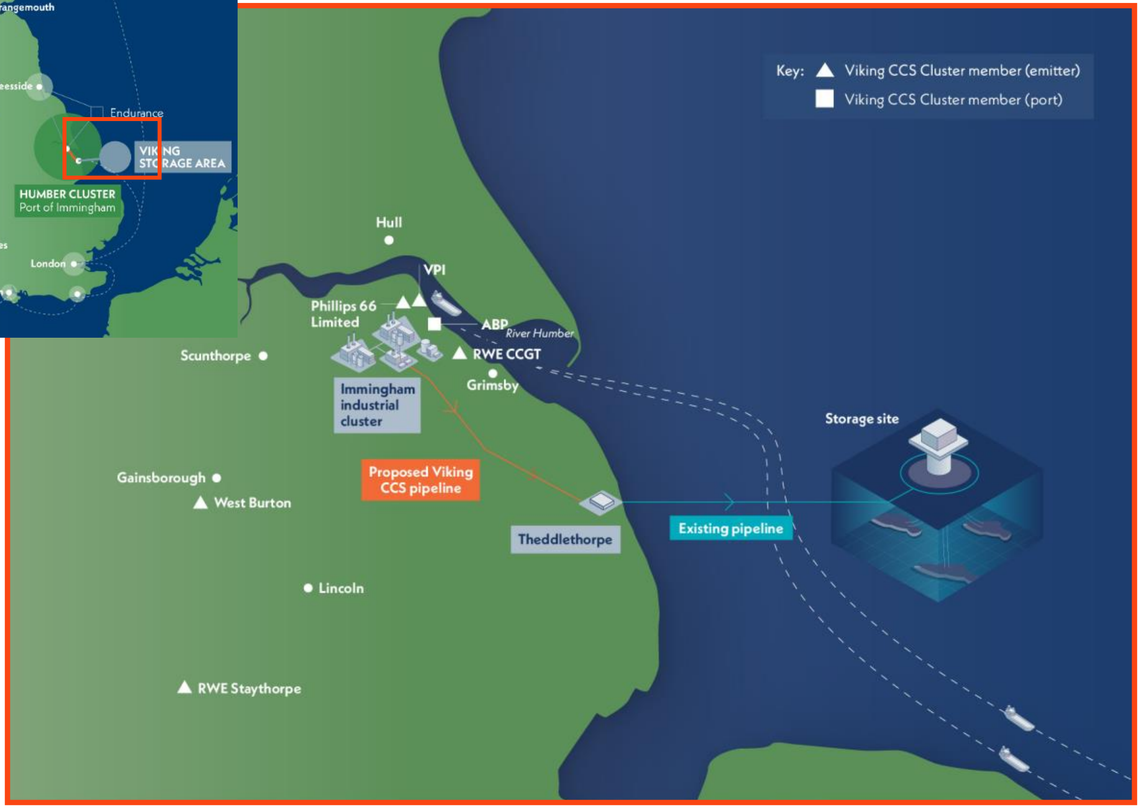
Over 40 year track record

of operating infrastructure projects in the North Sea.

Over 50 % of Humber emissions

will be captured, transported, and securely stored by our project.

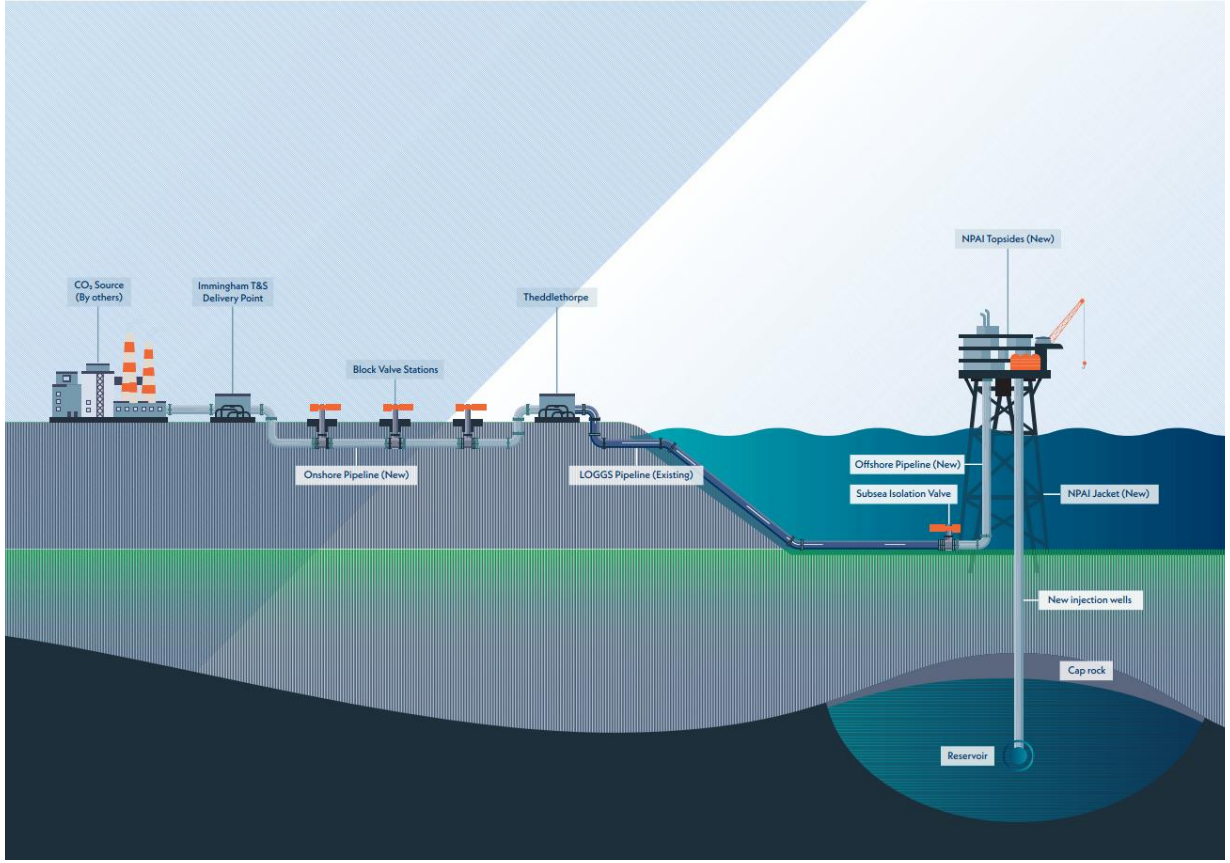
Map of UK Industrial Centres, Planned CCS Clusters and Viking CCS



Viking CCS Project Conditions and Challenges

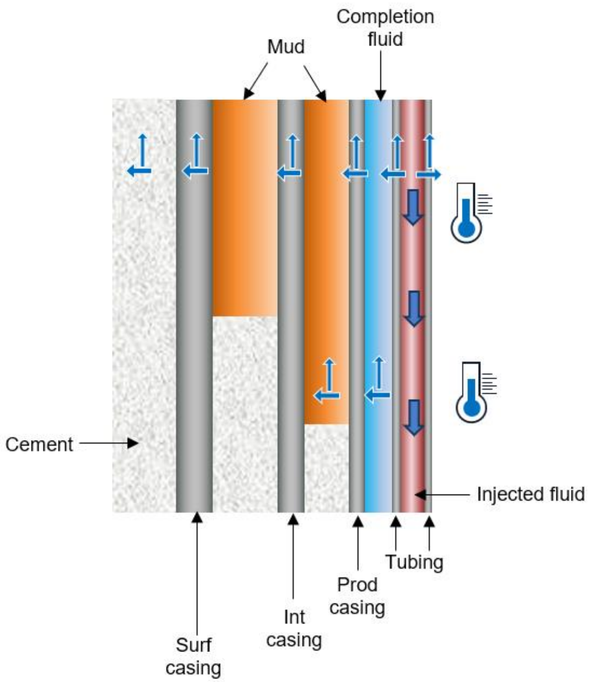
- Transportation of industrial CO_2 (with impurities) in dense phase
- Dedicated platform injection wells drilled in depleted gas fields
- Topsides chokes employed
- Low pressure reservoir

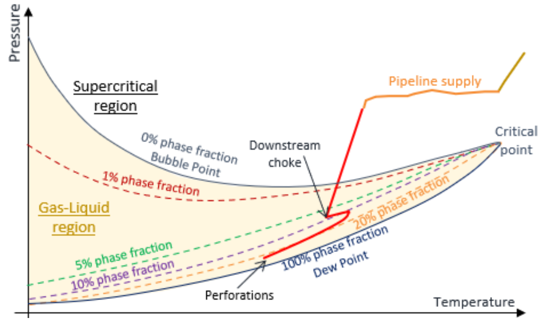
Viking CCS Transportation and Storage System Overview



Well Design Challenges

- Depleted Reservoir Injection → Wellbore thermal effects
- CO_2 impurities variations → Modelling, phase envelope
- Standards for tubular design → Operations and load cases
- Collaborative use of flow assurance and tubular design → Lack of single application to streamline the process

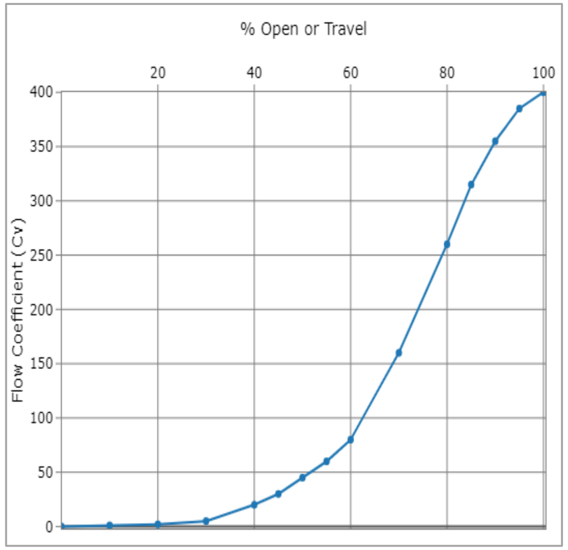




CO_2 Injection Model (CIM)

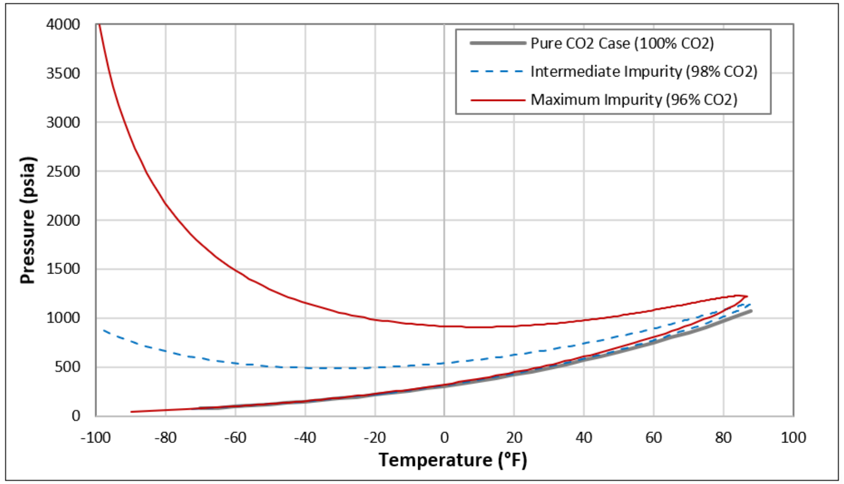
- **CIM Selection of GERG-2008:** ongoing efforts for robust EOS in developing CCS technology

- **Choke functionality:**
  - temperature loss
  - fluid vaporization across the choke
  - pressure loss
  - fluid phase at outlet
  - Flow coefficient Cv



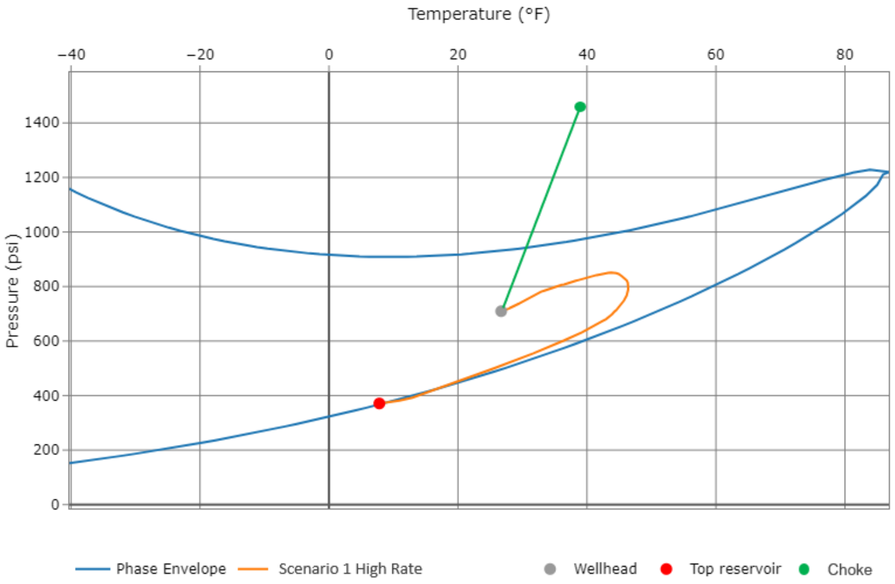
- Comparison of CIM with Industry Flow Assurance (FAM)

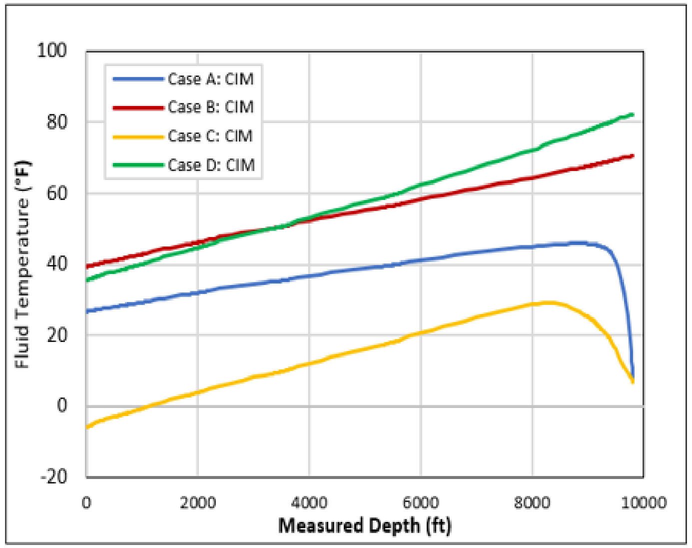
Component	Composition (Molar %)		
	Maximum Impurity Case	Intermediate Impurity Case	Pure Case
CO_2	96.000	98.0276	100.0
H_2	2.000	0.6177	0.0
N_2	1.500	0.3936	0.0
CH_4	0.490	0.2843	0.0
H_2O	0.005	0.0037	0.0
H_2S	0.002	0.0004	0.0
Ar	0.002	0.6724	0.0
O_2	0.001	0.0003	0.0
Total	100.000	100.0000	100.0

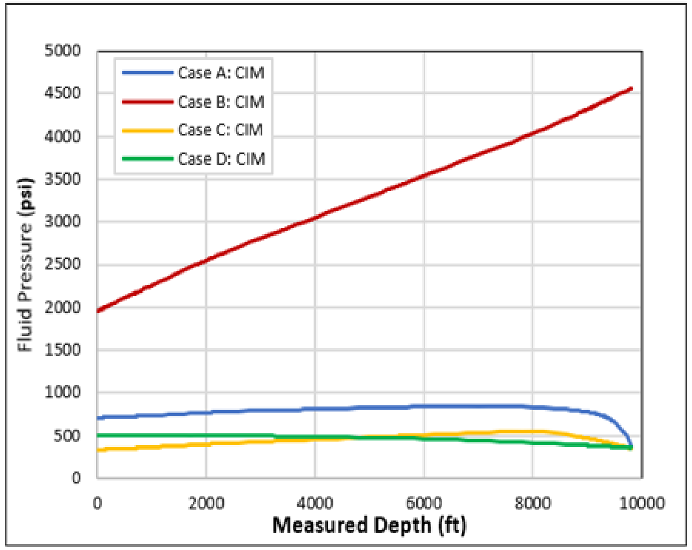


CO_2 Injection Operations

Case	Input			Result						
	Mass Flow	BHFP (psi)	WHFT (°F)	Phase	WHFP (psi)			BHFT (°F)		
					FAM	CIM	% Dev	FAM	CIM	% Dev*
A	High	340	26.7	2-Phase	670	710	5.6%	4.5	7.1	3.0%
B	High	4500	39.4	Dense	1960	1960	0.0%	71.3	70.6	0.9%
C	Medium	340	-6.0	2-Phase	330	340	2.9%	1.9	6.9	5.7%
D	Low	340	35.5	Gas	470	500	6.0%	90.1	82.3	8.8%

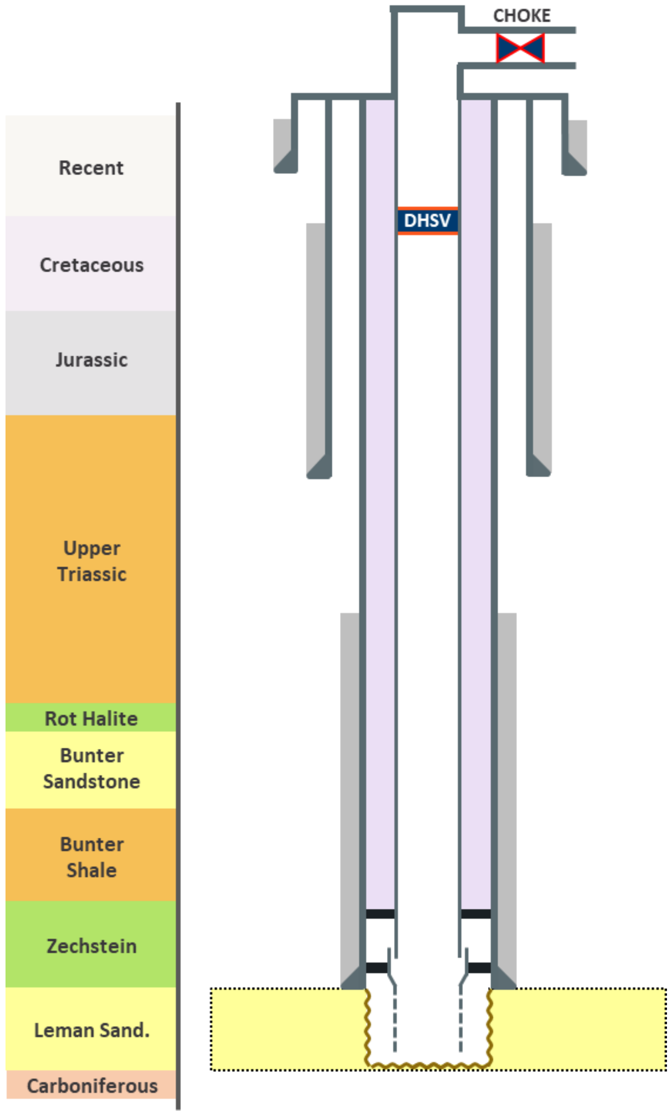






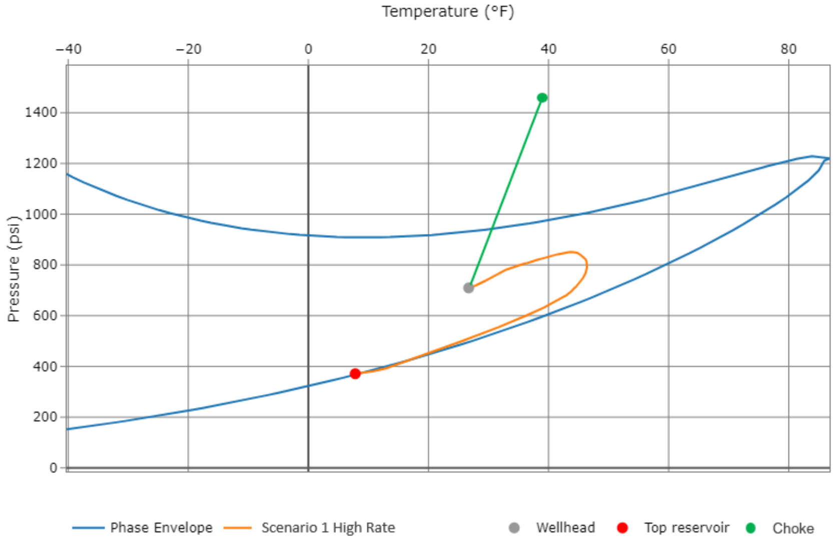
Well Design – Viking CCS

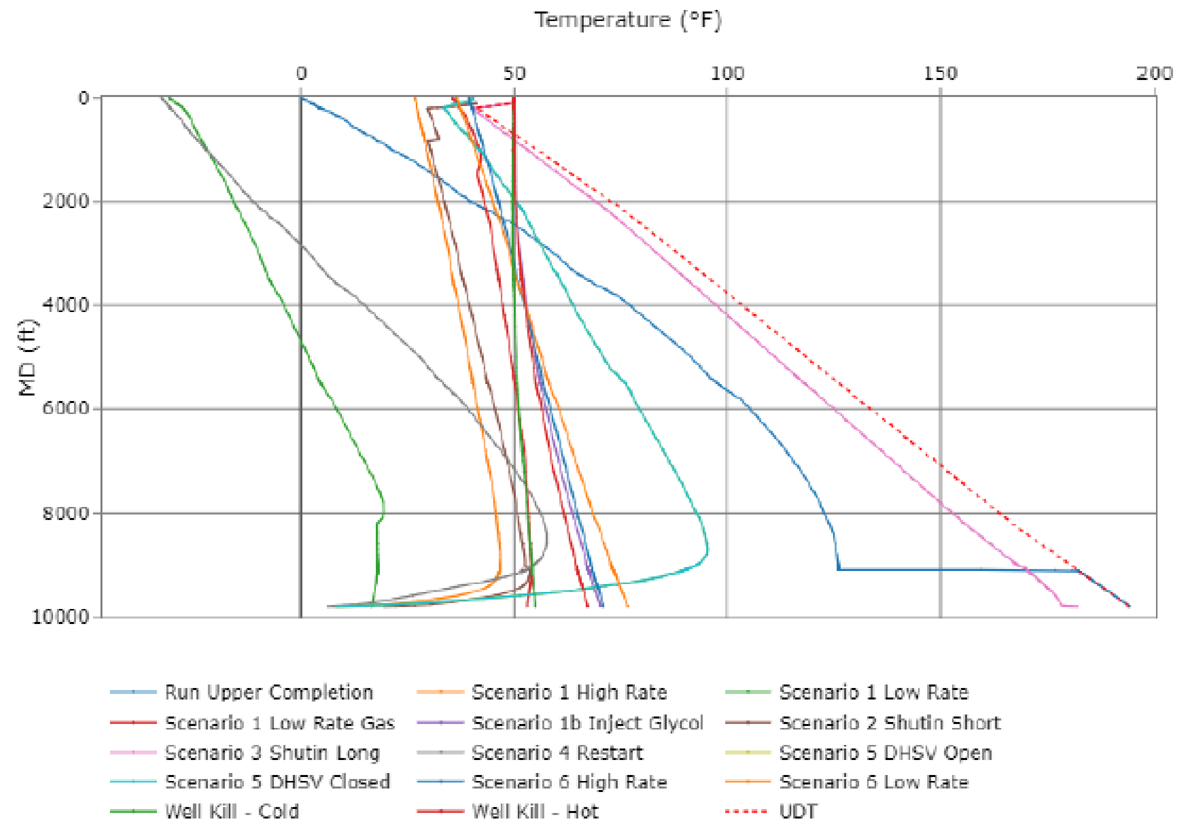
- 3 string architecture, open hole lower completion
- Injection via surface Christmas tree with choke control
- Tubing Run Down Hole Safety Valve (TRDHSV) for catastrophic damage isolation
- Fit-for-purpose TSA application needed due to limitations in legacy software for modeling CO_2 injection operations (into depleted reservoirs) and tubular stress analysis



Well Design – Operating Scenarios

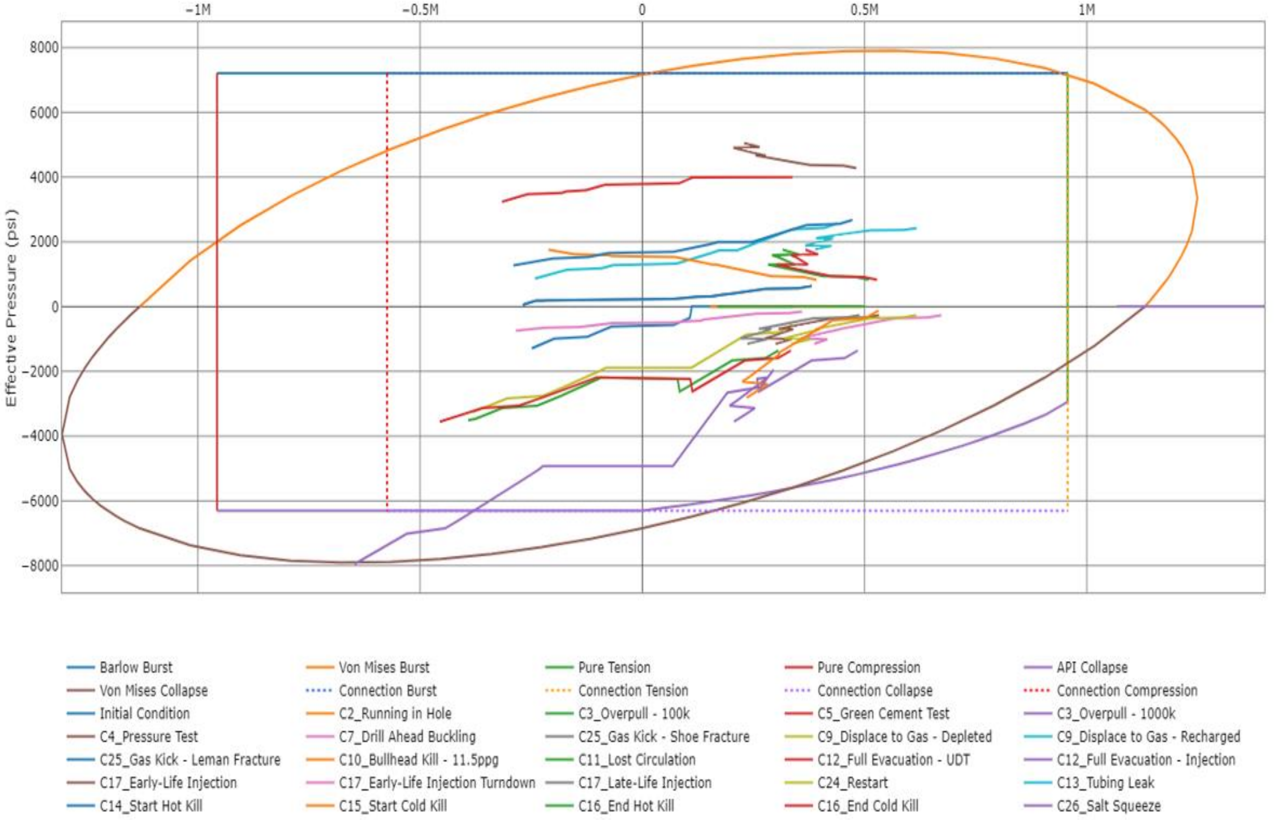
Scenario	Well Phase	Description
Scenario 1	Early-Life	Steady-state injection – Gas, multi-phase & dense-phase
Scenario 2	Early-Life	Short-term shut-in after injection
Scenario 3	Early-Life	Long-term shut-in after injection
Scenario 4	Early-Life	Startup/restart after shut-in
Scenario 5	Early-Life	Surface leak/venting
Scenario 6	Late-Life	Steady-state injection – Dense-phase
Scenario 7	Late-Life	Short-term shut-in after injection
Scenario 8	Late-Life	Long-term shut-in after injection
Scenario 9	Late-Life	Startup/restart after shut-in
Scenario 10	Late-Life	Surface leak/venting



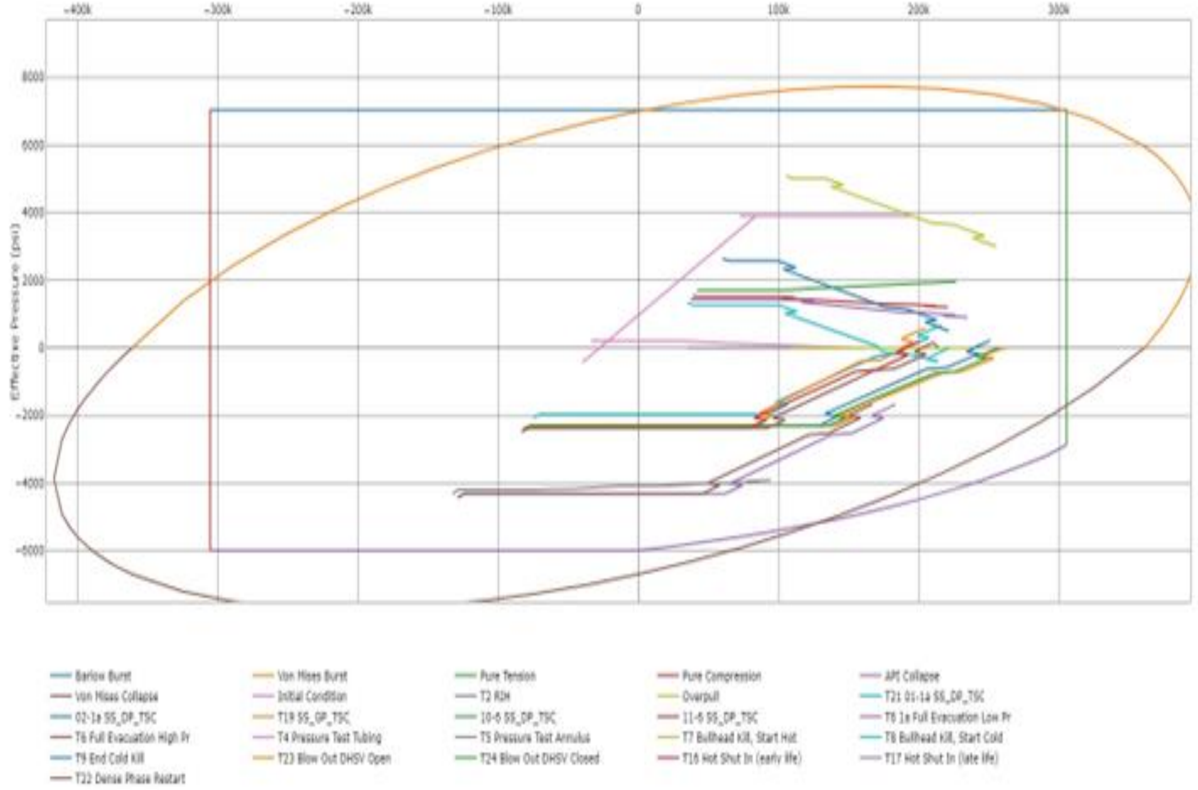


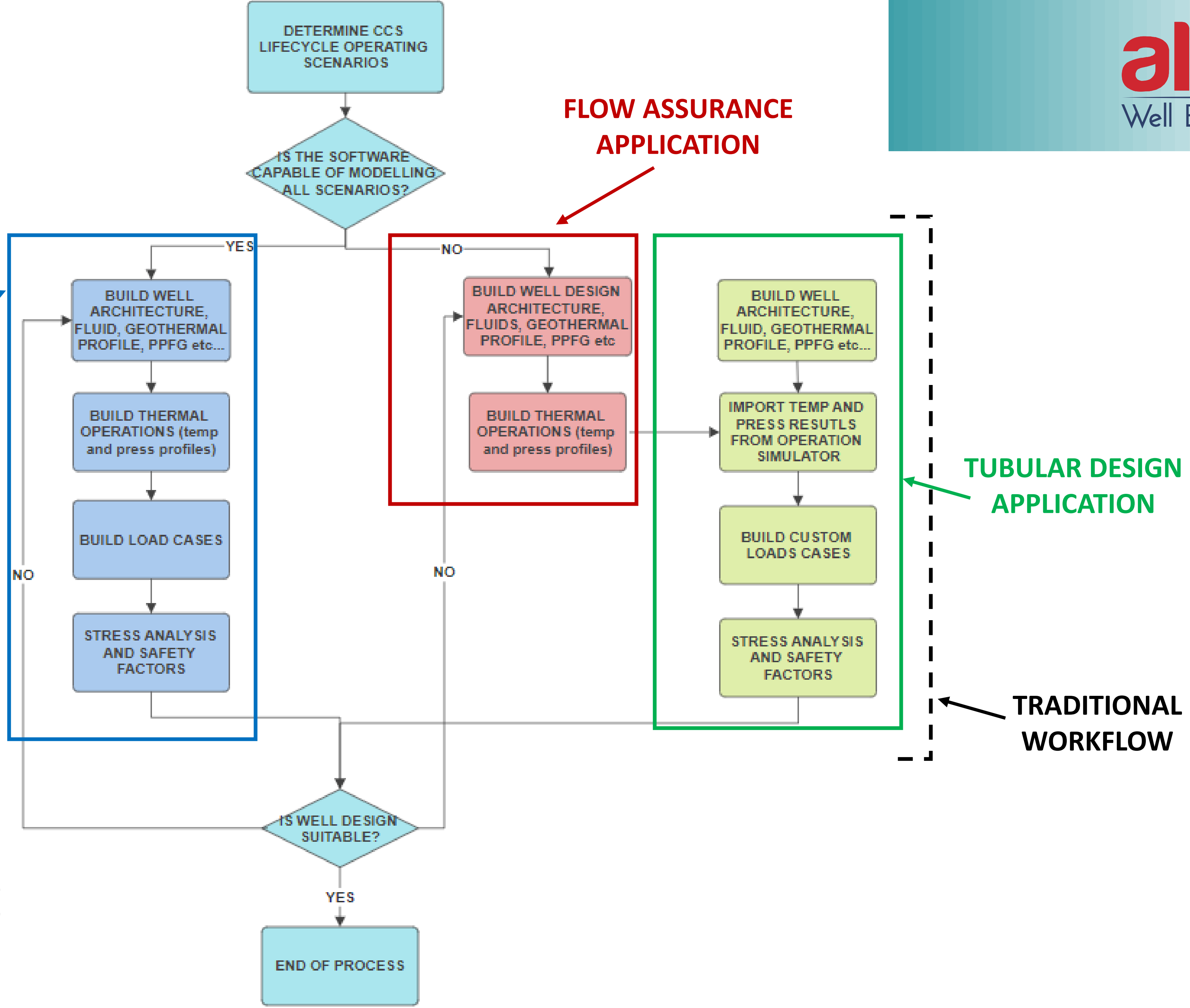
Well Design – Load Cases for Production Casing and Tubing

Production Casing



Production Tubing





Agile Development

Conclusion and Future work

- Conclusion
  - Fit-for-Purpose solution that integrates CCS fluid modelling in tubular design application advantages
  - Viking proposed well design is inherently robust, accommodating fluctuating injection rates for long-term performance
  - Ongoing development targets modeling gaps, aiming for a complete design analysis package by end-2024
- Future work:
  - Alternatives EOS with impurities alternative to GERG-2008 EOS
  - Create functionality for simulating well leaks, from small emissions to rare blowouts, to model extreme low temperatures

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Altus Well Experts, Inc.

Dr. Afif Halal