



**CO<sub>2</sub>  
STORAGE**  
CONFERENCE  
2024

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

# Development of A Fit-for-Purpose CO<sub>2</sub> Injection Model for Casing And Tubing Design

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**altus**  
Well Experts, Inc.

# Agenda

- Project specifics
- Well design challenges
- CO<sub>2</sub> Injection Model (CIM)
- Tubing and Casing design/verification
- “Agile” development
- Conclusion and Future work

# Viking CCS Project Overview



**10 million tonnes CO<sub>2</sub> 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<sub>2</sub> will be stored, beneath a 'SuperSeal' of between 600 and 1,000 feet of salt.

**Over 40 year track record**

of operating infrastructure projects in the North Sea.

**up to £7 billion**

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

**Over 50 % of Humber emissions**

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



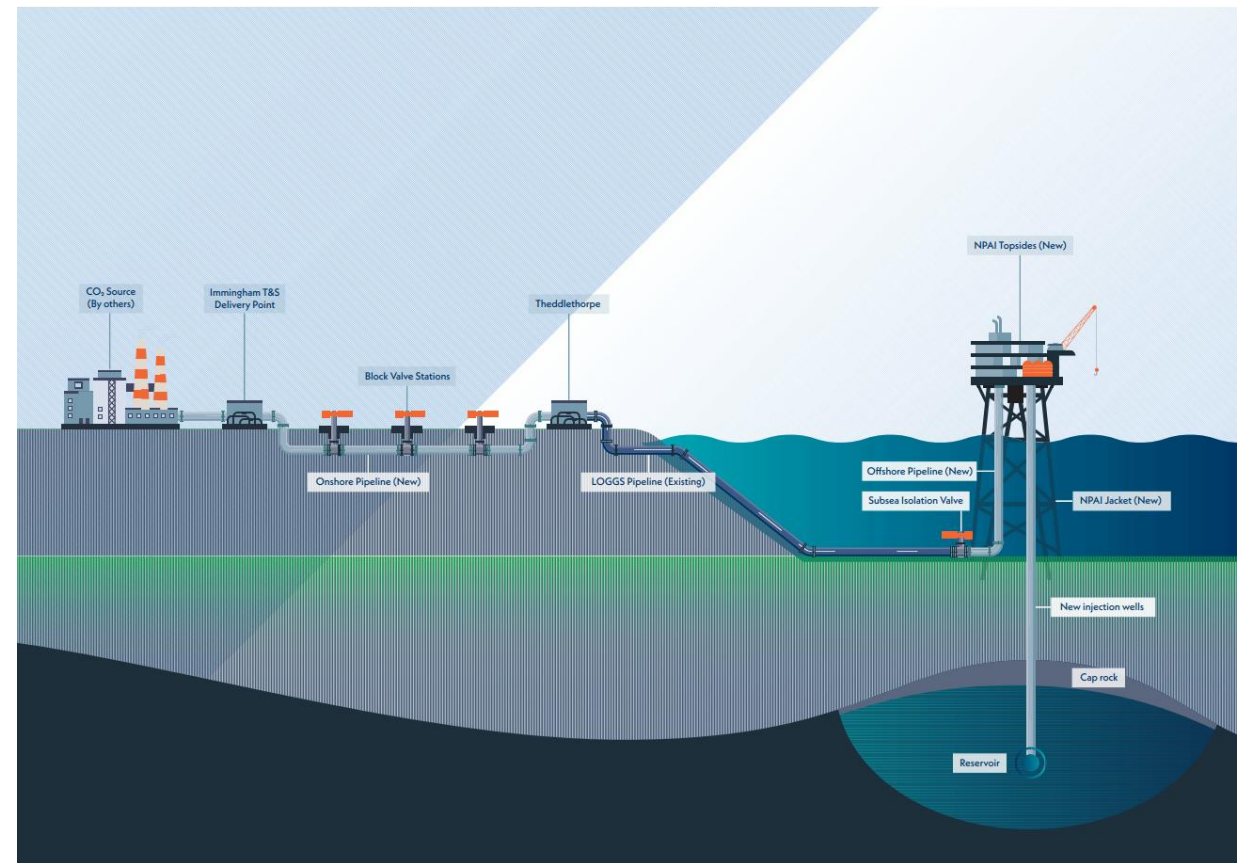
Map of UK Industrial Centres, Planned CCS Clusters and Viking CCS



# Viking CCS Project Conditions and Challenges

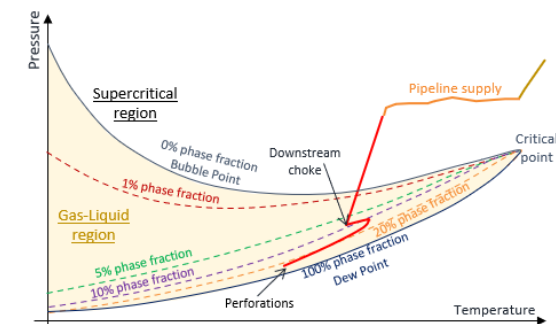
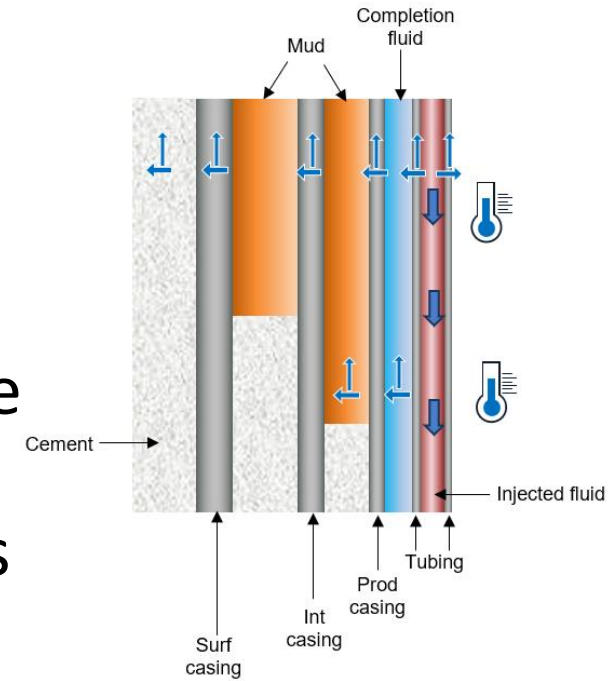
- Transportation of industrial CO<sub>2</sub> (with impurities) in dense phase
- Dedicated platform injection wells drilled in depleted gas fields
- Topsides chokes employed
- Low pressure reservoir

Viking CCS Transportation and Storage System Overview



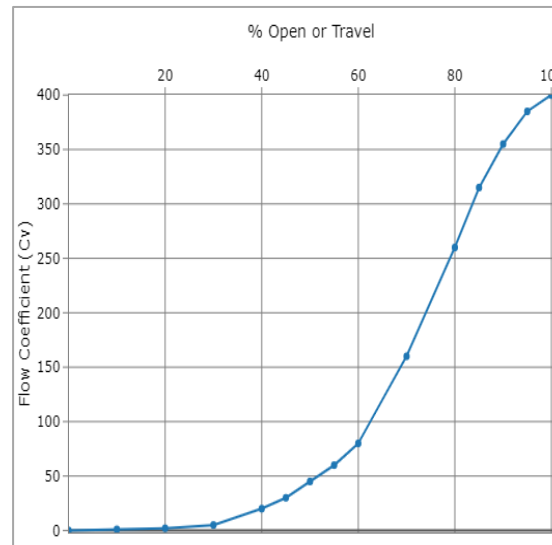
# Well Design Challenges

- Depleted Reservoir Injection → Wellbore thermal effects
- CO<sub>2</sub> 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

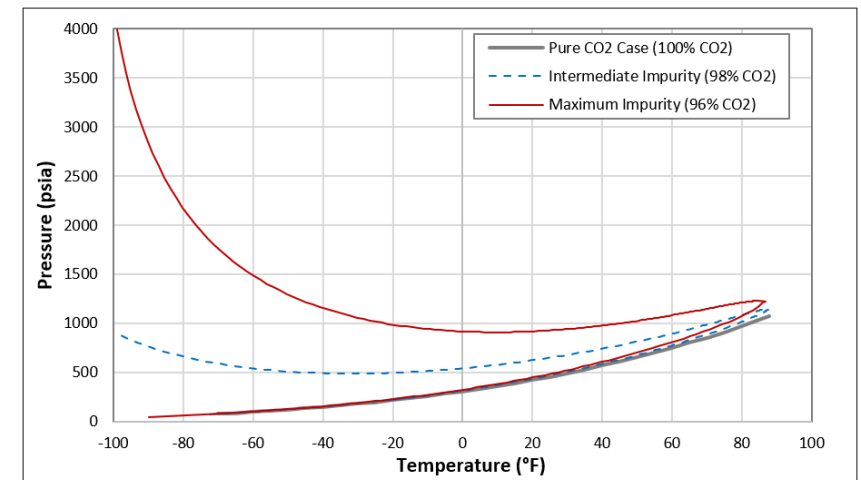


# CO<sub>2</sub> Injection Model (CIM)

- **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)

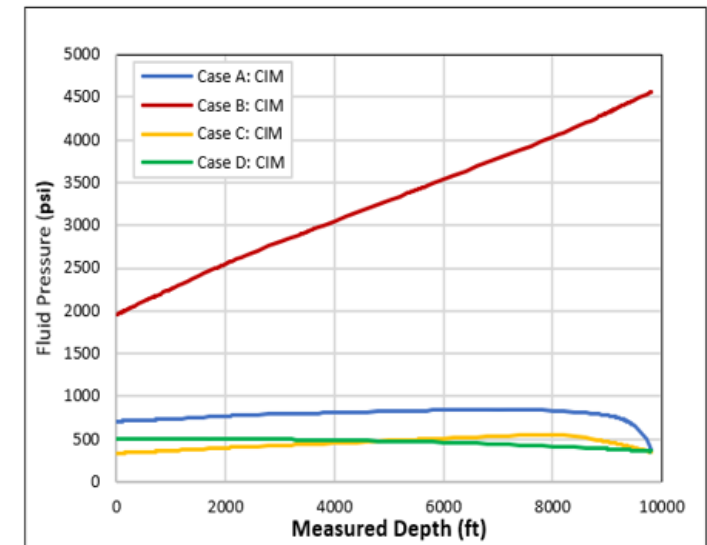
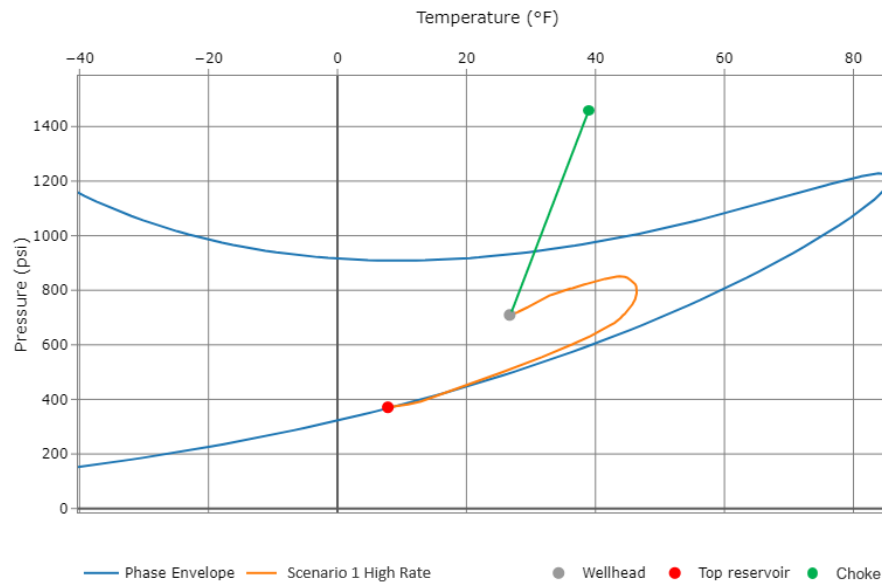
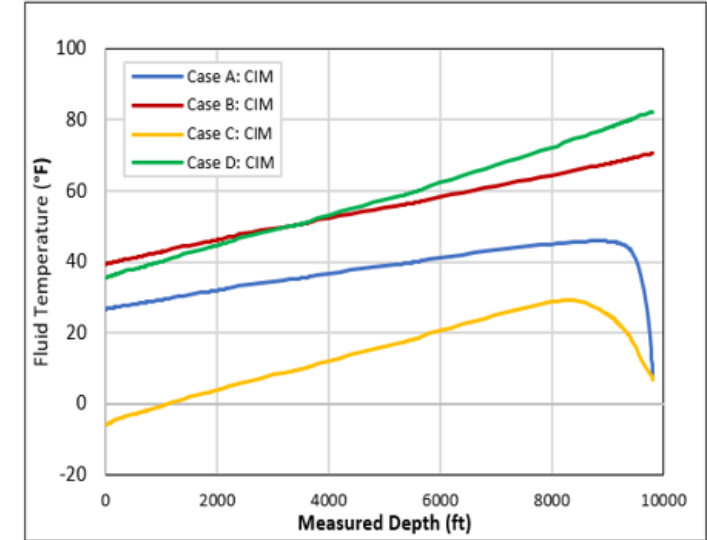


Component	Composition (Molar %)		
	Maximum Impurity Case	Intermediate Impurity Case	Pure Case
CO <sub>2</sub>	96.000	98.0276	100.0
H <sub>2</sub>	2.000	0.6177	0.0
N <sub>2</sub>	1.500	0.3936	0.0
CH <sub>4</sub>	0.490	0.2843	0.0
H <sub>2</sub> O	0.005	0.0037	0.0
H <sub>2</sub> S	0.002	0.0004	0.0
Ar	0.002	0.6724	0.0
O <sub>2</sub>	0.001	0.0003	0.0
<b>Total</b>	<b>100.000</b>	<b>100.0000</b>	<b>100.0</b>



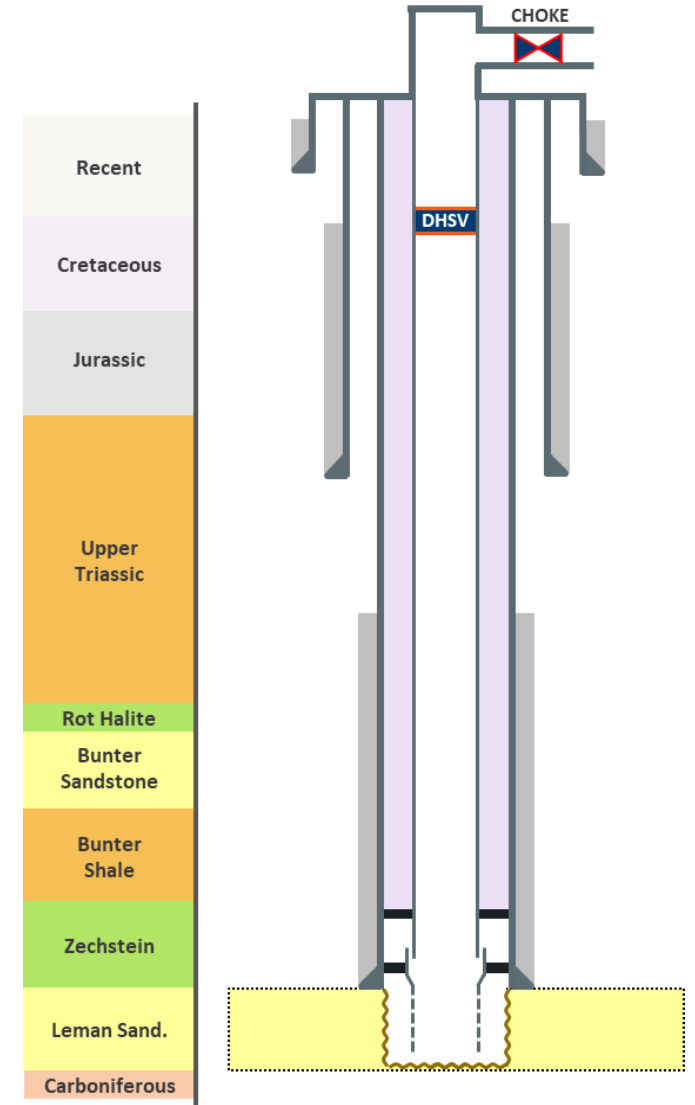
# CO<sub>2</sub> Injection Operations

Case	Input			Result						
	Mass Flow	BHFP	WHFT	Phase	WHFP			BHFT		
		(psi)	(°F)		(psi)			(°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

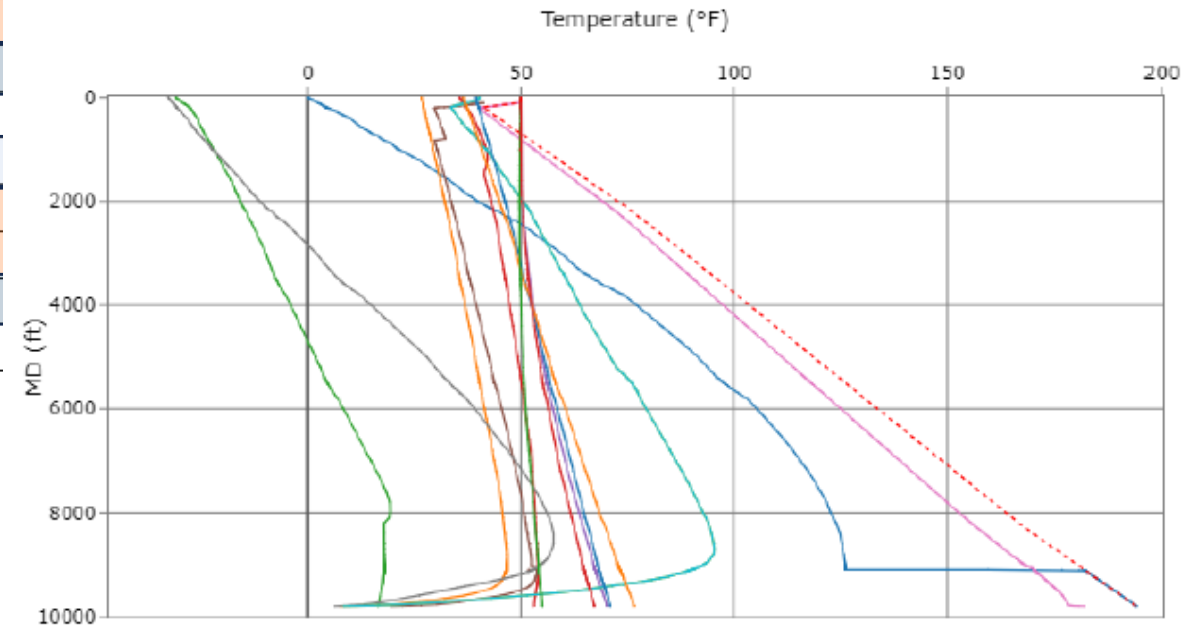
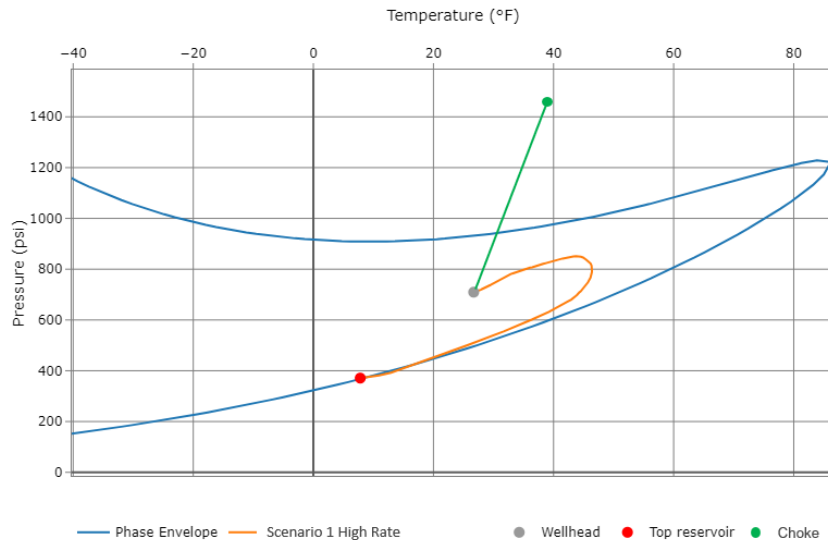
- 3 string architecture, open hole lower completion
- Injection via surface Christmas tree with choke control
- Tubing Run Down Hole Safety Valve (TRDHSV) for catastrophic damage isolation
- Fit-for-purpose TSA application needed due to limitations in legacy software for modeling CO<sub>2</sub> injection operations (into depleted reservoirs) and tubular stress analysis





# Well Design – Operating Scenarios

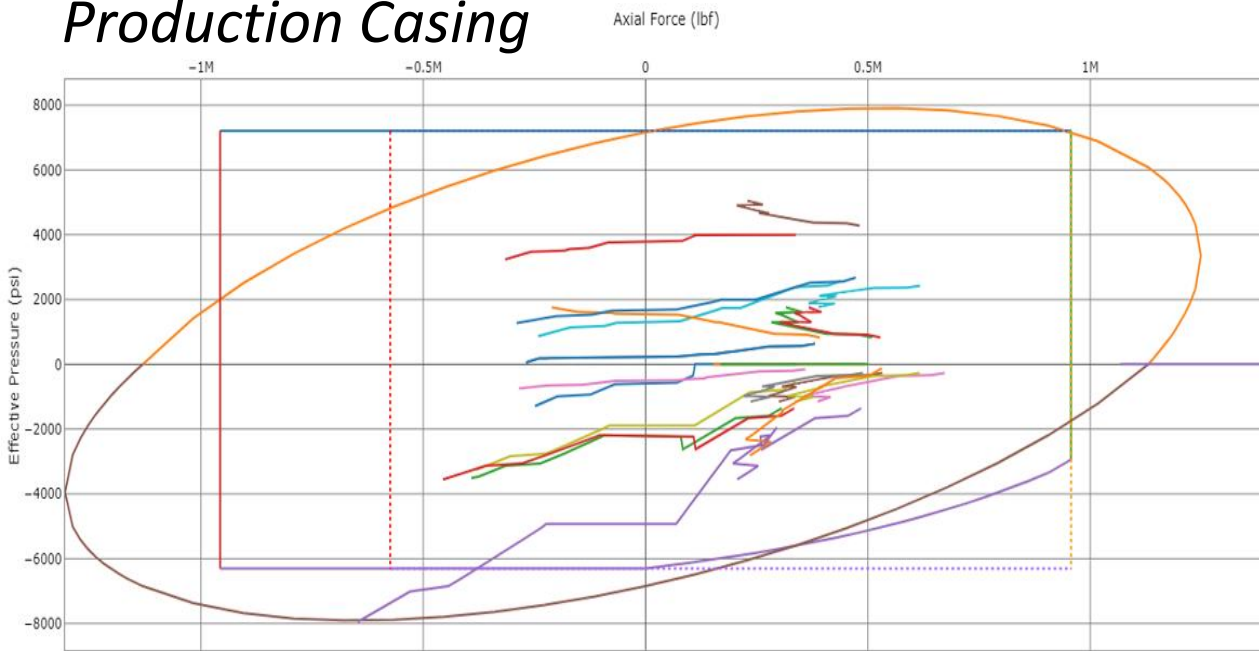
Scenario	Well Phase	Description
Scenario 1	Early-Life	Steady-state injection – Gas, multi-phase & dense-phase
Scenario 2	Early-Life	Short-term shut-in after injection
Scenario 3	Early-Life	Long-term shut-in after injection
Scenario 4	Early-Life	Startup/restart after shut-in
Scenario 5	Early-Life	Surface 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



- Run Upper Completion
- Scenario 1 High Rate
- Scenario 1 Low Rate
- Scenario 1 Low Rate Gas
- Scenario 1b Inject Glycol
- Scenario 2 Shutin Short
- Scenario 3 Shutin Long
- Scenario 4 Restart
- Scenario 5 DHSV Open
- Scenario 5 DHSV Closed
- Scenario 6 High Rate
- Scenario 6 Low Rate
- Well Kill - Cold
- Well Kill - Hot
- UDT

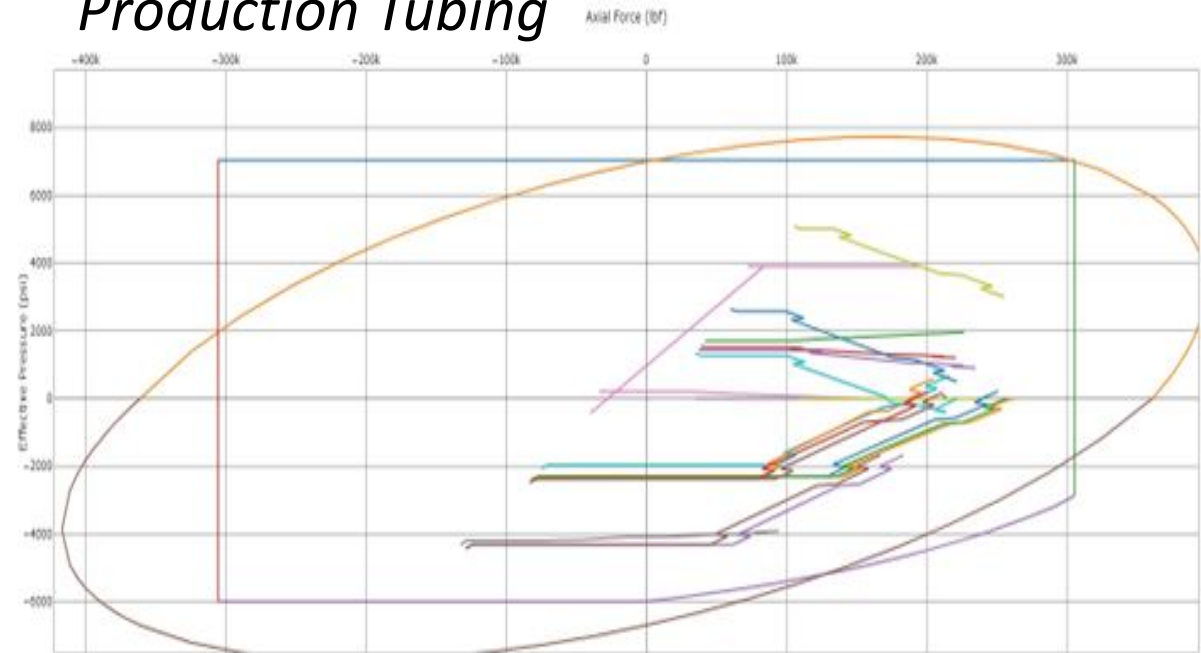
# Well Design – Load Cases for Production Casing and Tubing

## Production Casing

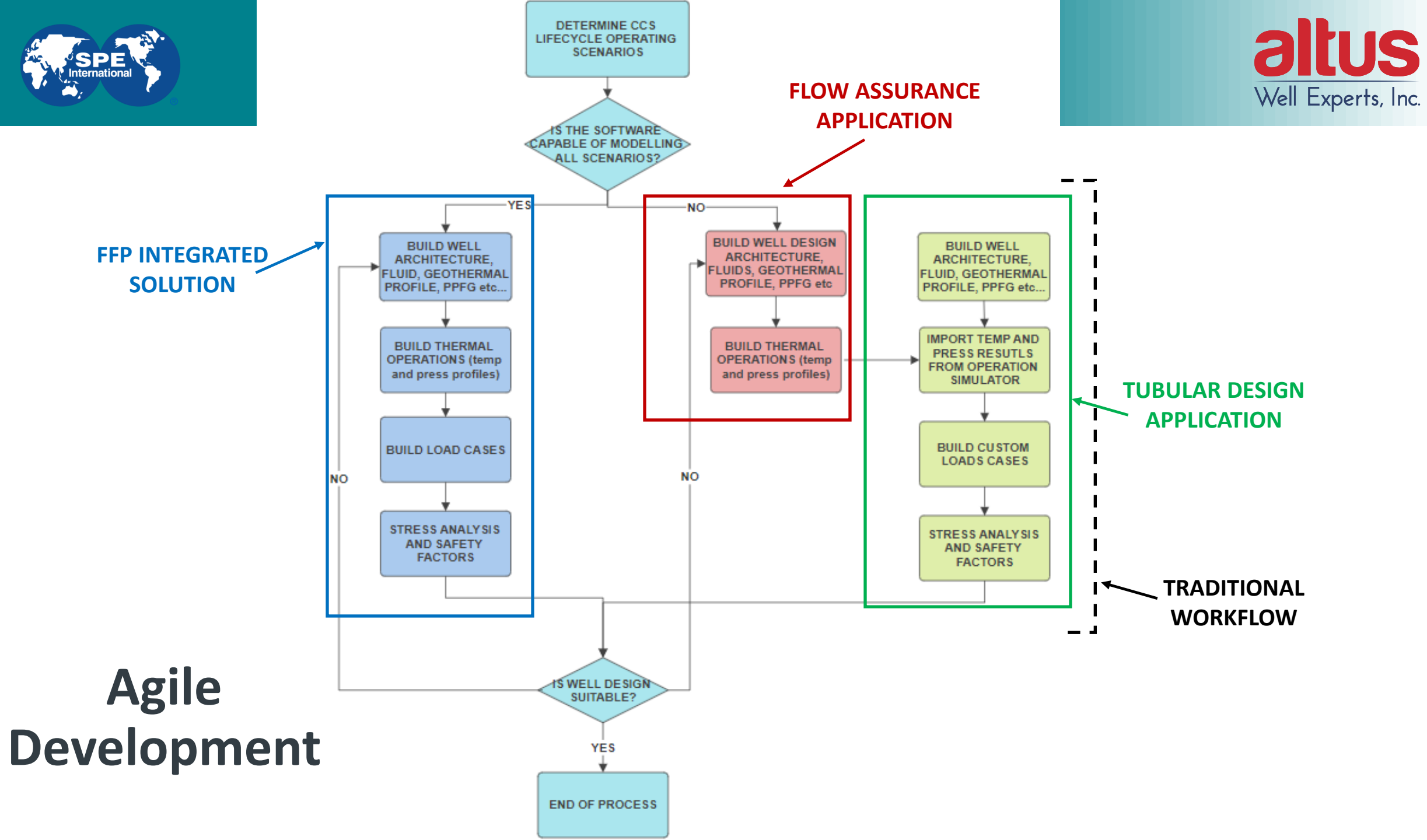


- |                               |                                   |                              |                               |                                 |
|-------------------------------|-----------------------------------|------------------------------|-------------------------------|---------------------------------|
| Barlow Burst                  | Von Mises Burst                   | Pure Tension                 | Pure Compression              | API Collapse                    |
| Von Mises Collapse            | Connection Burst                  | Connection Tension           | Connection Collapse           | Connection Compression          |
| Initial Condition             | C2_Running in Hole                | C3_Overpull - 100k           | C5_Green Cement Test          | C3_Overpull - 1000k             |
| C4_Pressure Test              | C7_Drill Ahead Buckling           | C25_Gas Kick - Shoe Fracture | C9_Displace to Gas - Depleted | C9_Displace to Gas - Recharged  |
| C25_Gas Kick - Leman Fracture | C10_Bullhead Kill - 11.5ppg       | C11_Lost Circulation         | C12_Full Evacuation - UDT     | C12_Full Evacuation - Injection |
| C17_Early-Life Injection      | C17_Early-Life Injection Turndown | C17_Late-Life Injection      | C24_Restart                   | C13_Tubing Leak                 |
| C14_Start Hot Kill            | C15_Start Cold Kill               | C16_End Hot Kill             | C16_End Cold Kill             | C26_Salt Squeeze                |

## Production Tubing



- |                            |                         |                          |                              |                              |
|----------------------------|-------------------------|--------------------------|------------------------------|------------------------------|
| Barlow Burst               | Von Mises Burst         | Pure Tension             | Pure Compression             | API Collapse                 |
| Von Mises Collapse         | Initial Condition       | T2 RM                    | Overpull                     | T21 01-14 SS_DP_TSC          |
| Initial Condition          | T18 SS_DP_TSC           | 10-0 SS_DP_TSC           | 11-0 SS_DP_TSC               | T8 1a Full Evacuation Low Pr |
| T8 Full Evacuation High Pr | T4 Pressure Test Tubing | T5 Pressure Test Annulus | T7 Bullhead Kill, Start Hot  | T8 Bullhead Kill, Start Cold |
| T9 End Cold Kill           | T23 Blow Out DHSV Open  | T24 Blow Out DHSV Closed | T16 Hot Shut In (early life) | T17 Hot Shut In (late life)  |
| T22 Dense Phase Restart    |                         |                          |                              |                              |



**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



# ACKNOWLEDGEMENTS / THANK YOU / QUESTIONS

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