Carbon Storage and Management

3–4 SEPTEMBER 2024 | KUALA LUMPUR, MALAYSIA

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) and validation
- Tubing and Casing design/verification
- “Agile” development
- Conclusion
- 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

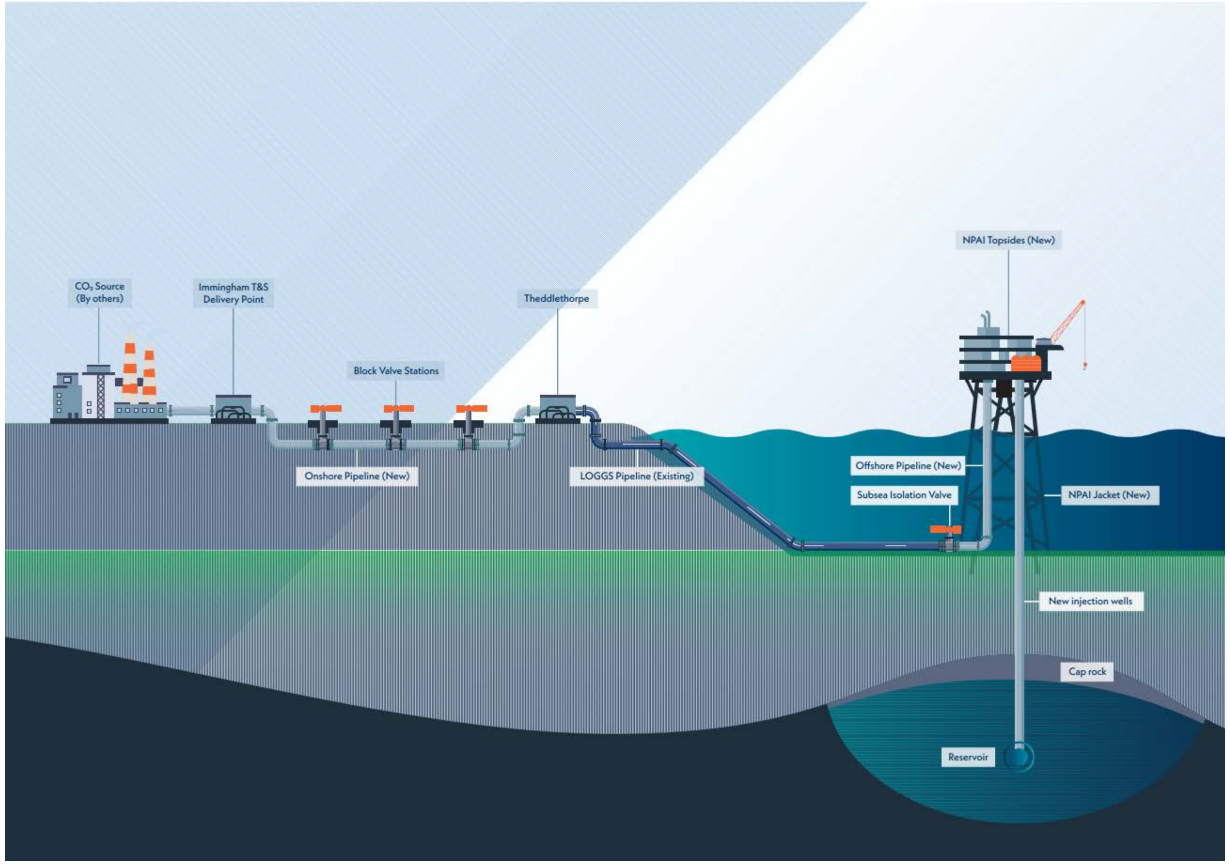
will be captured, transported, and securely stored by our project.

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

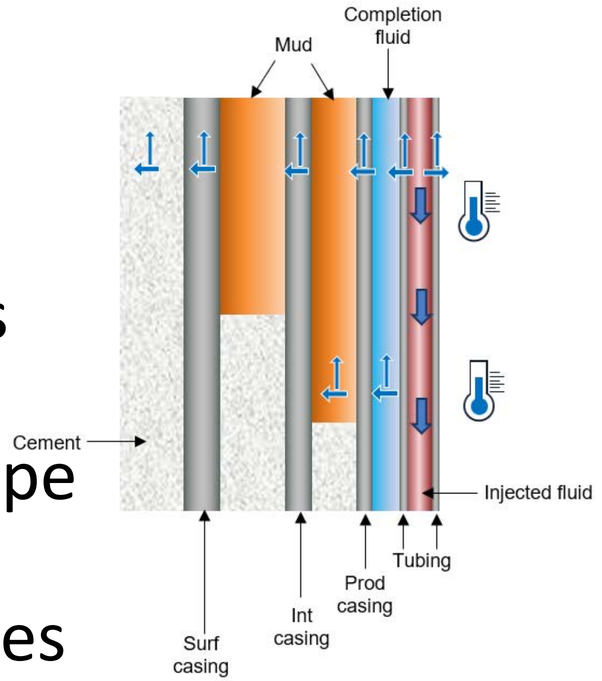
Viking CCS Project Conditions and Challenges

- 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

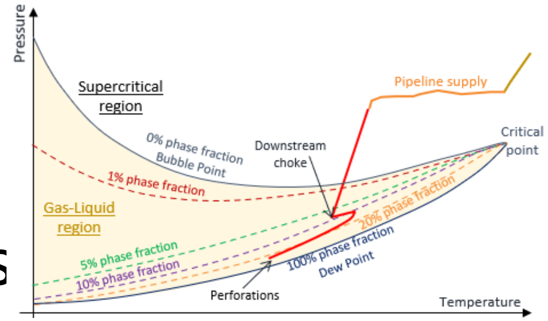
Viking CCS Transportation and Storage System Overview



Well Design Challenges



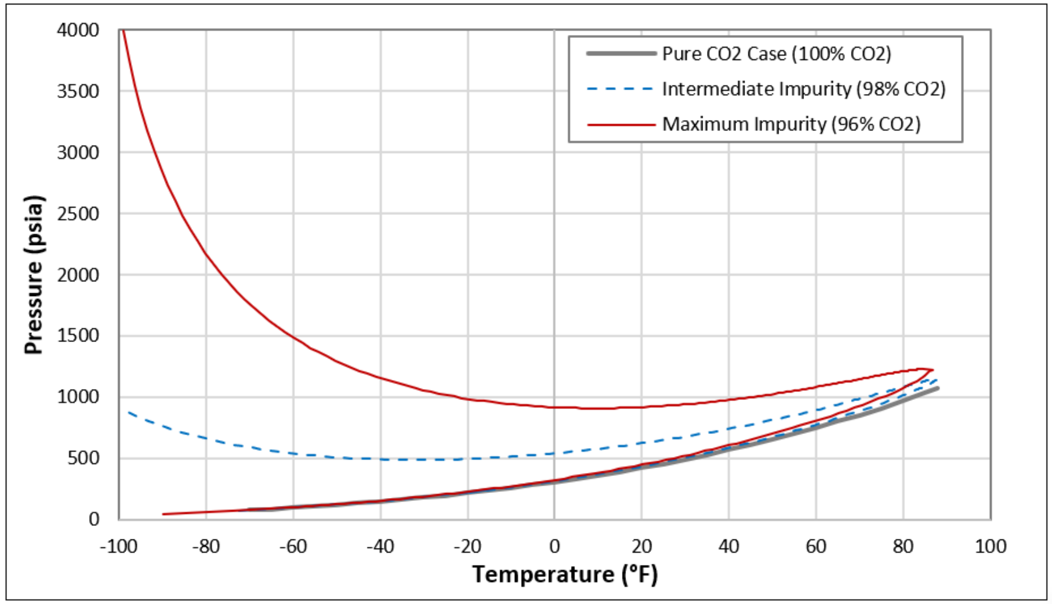
- Depleted Reservoir Injection → Wellbore thermal effects
- CO_2 impurities variations → Modelling, phase envelope
- Standards for tubular design → Operations and load cases
- Collaborative use of flow assurance and tubular design → Lack of single application to streamline the process



CO_2 Injection Model (CIM) – Equation Of State (EOS)

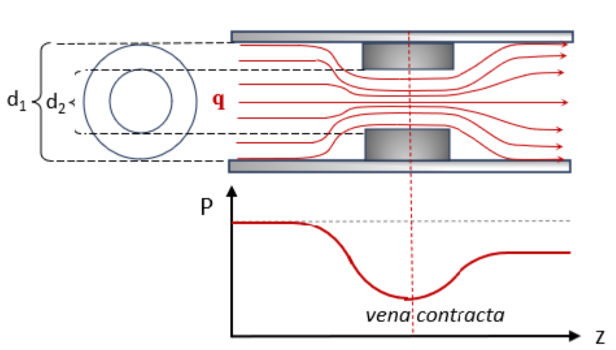
- Equation of State (EOS) critical to handle impurities
- Limited EOS options for CCS: SRK, Peng-Robinson, CPA, SAFT, GERG-2008
- **CIM Selection of GERG-2008:** ongoing efforts for robust EOS in developing CCS technology

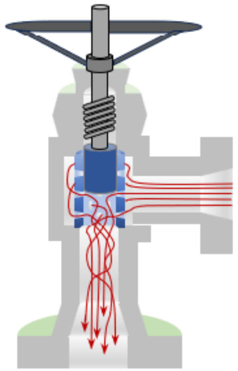
Component	Composition (Molar %)		
	Maximum Impurity Case	Intermediate Impurity Case	Pure Case
CO_2	96.000	98.0276	100.0
H_2	2.000	0.6177	0.0
N_2	1.500	0.3936	0.0
CH_4	0.490	0.2843	0.0
H_2O	0.005	0.0037	0.0
H_2S	0.002	0.0004	0.0
Ar	0.002	0.6724	0.0
O_2	0.001	0.0003	0.0
Total	100.000	100.0000	100.0



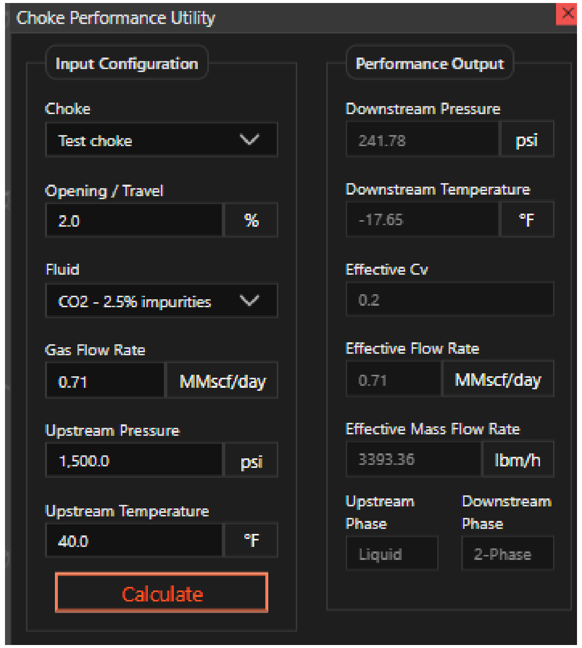
CO_2 Injection Model (CIM) – Choke modelling

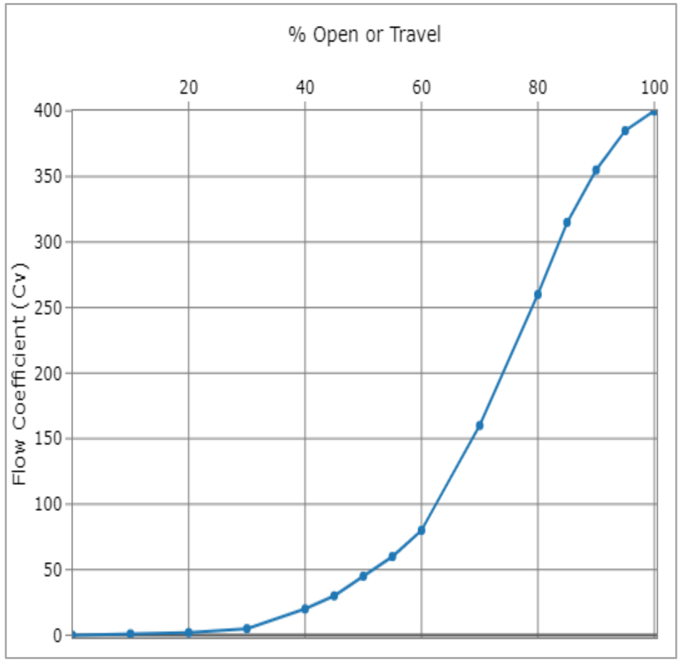
- Pressure Drop and Temperature Effects Across Choke:
  - o Temperature drop due to Joule-Thomson cooling
  - o Single-phase dense fluid flashes to multi-phase conditions downstream





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



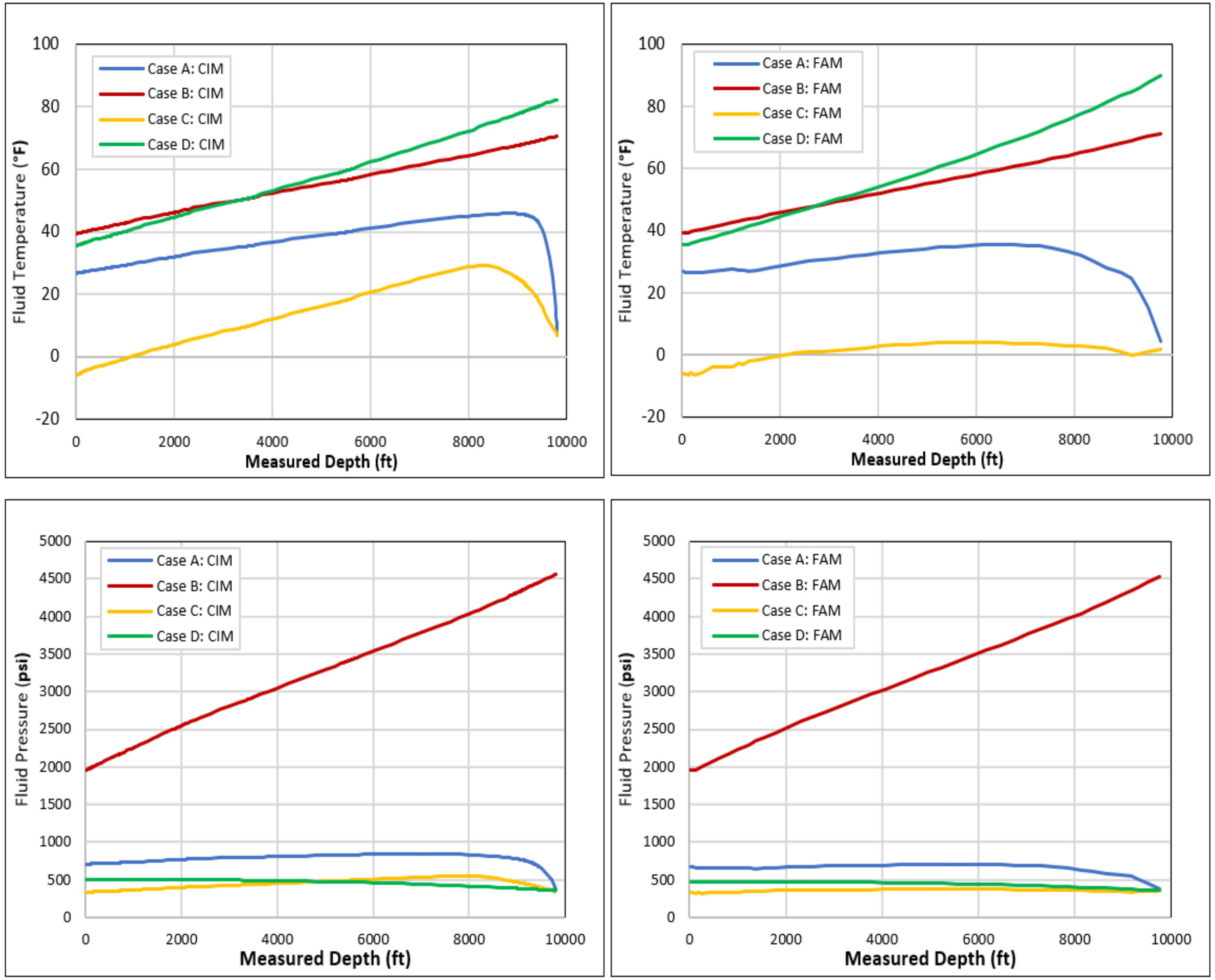


CO_2 Injection Model (CIM) – Validation

- Comparison of CIM with Industry Flow Assurance Model (FAM)
- Both use GERG-2008 EOS for CCS fluid thermodynamics
- Injection operations based on max impurity CO_2 fluid mixture composition
- Consistent BHFP and WHFT values for both models

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%

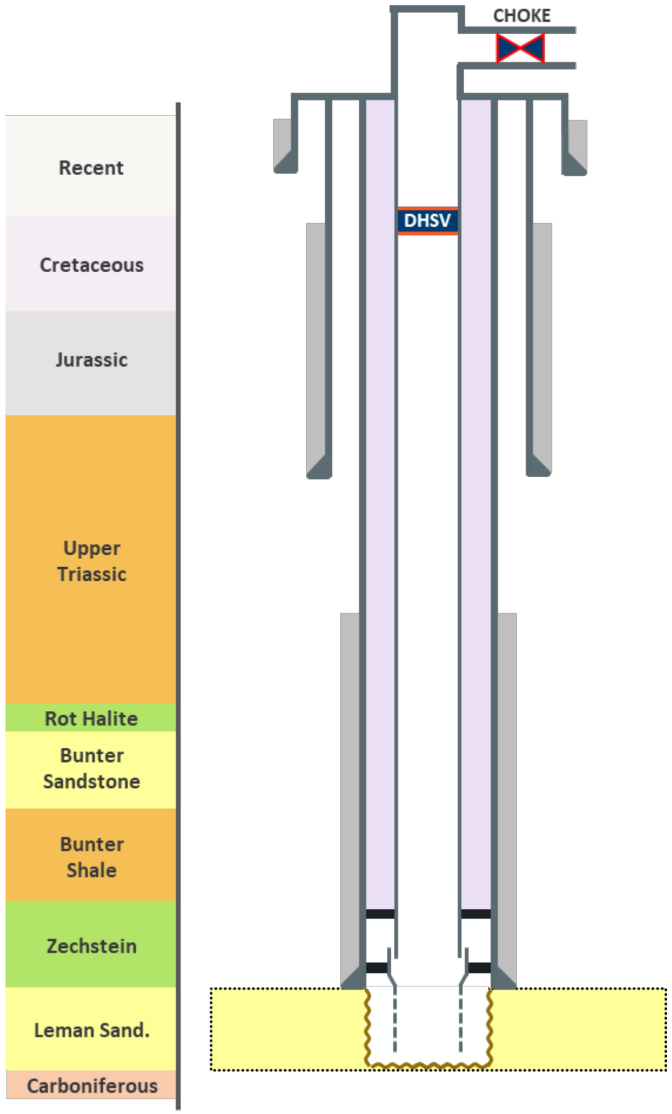
CO_2 Injection Model (CIM) – Validation



- Overall good agreement between CIM and FAM
- Some divergence in multi-phase flow, possibly due to assumptions in wellbore heat transfer
- Variances in mid-well temperatures attributed to differences in liquid holdup behavior

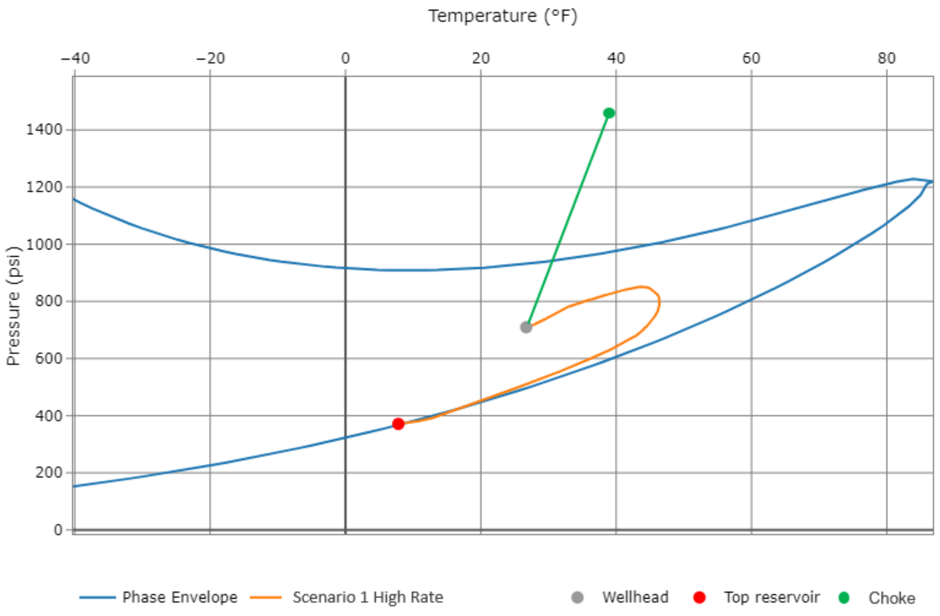
Well Design – Viking CCS

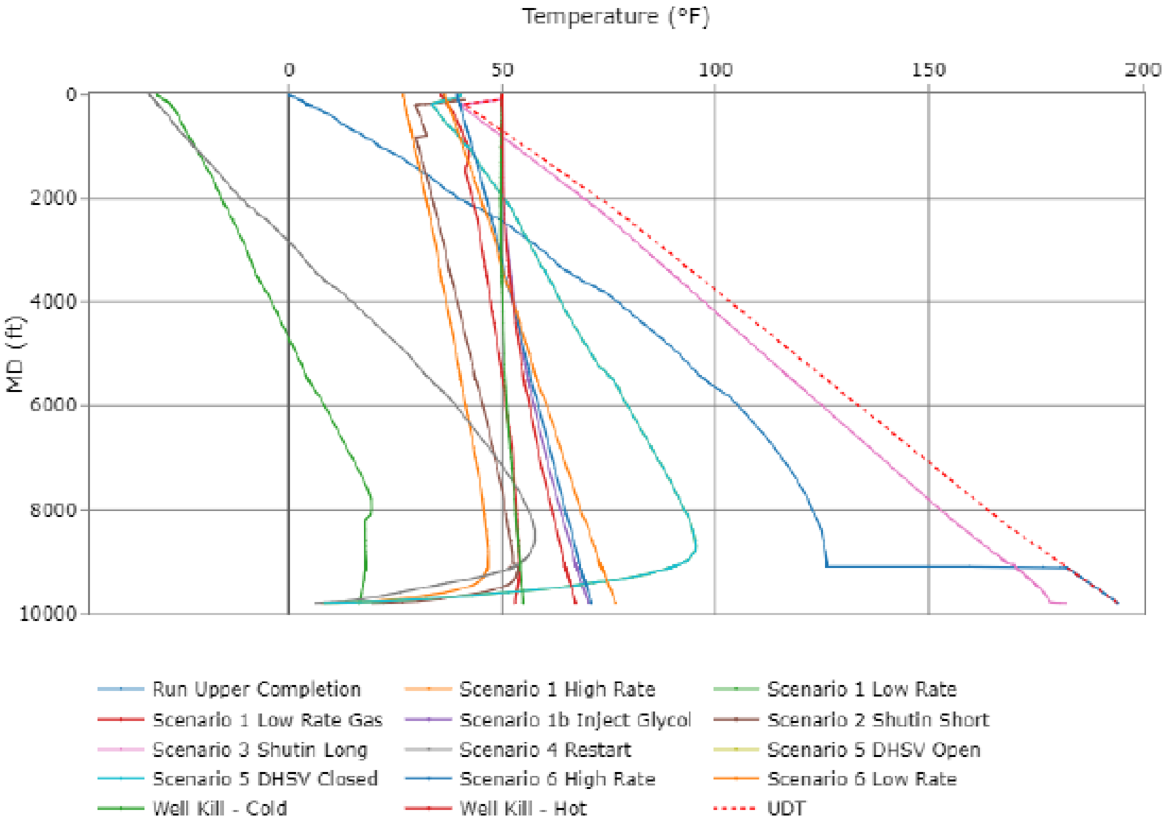
- 3 string architecture, open hole lower completion
- Injection via surface Christmas tree with choke control
- Tubing Run Down Hole Safety Valve (TRDHSV) for catastrophic damage isolation
- Fit-for-purpose TSA application needed due to limitations in legacy software for modeling CO_2 injection operations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



Well Design – Operating Scenarios

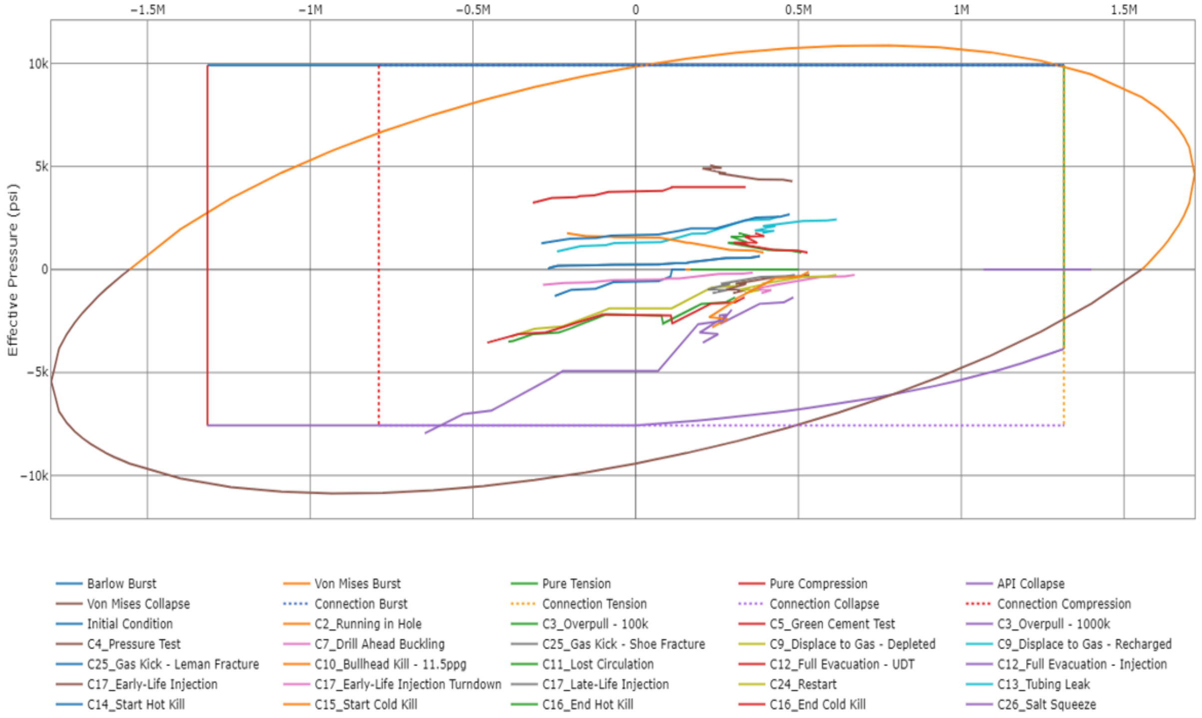
Scenario	Well Phase	Description
Scenario 1	Early-Life	Steady-state injection – Gas, multi-phase & dense-phase
Scenario 2	Early-Life	Short-term shut-in after injection
Scenario 3	Early-Life	Long-term shut-in after injection
Scenario 4	Early-Life	Startup/restart after shut-in
Scenario 5	Early-Life	Surface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



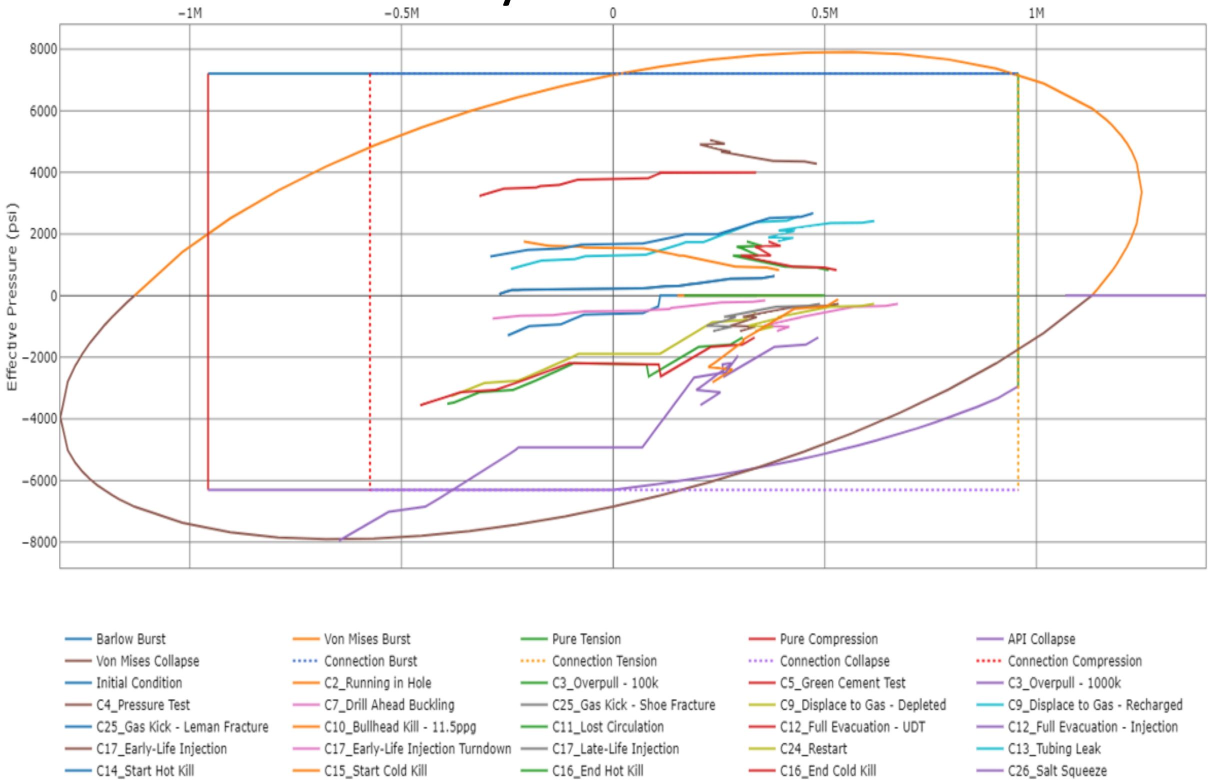


Well Design – Load Cases for Production Casing

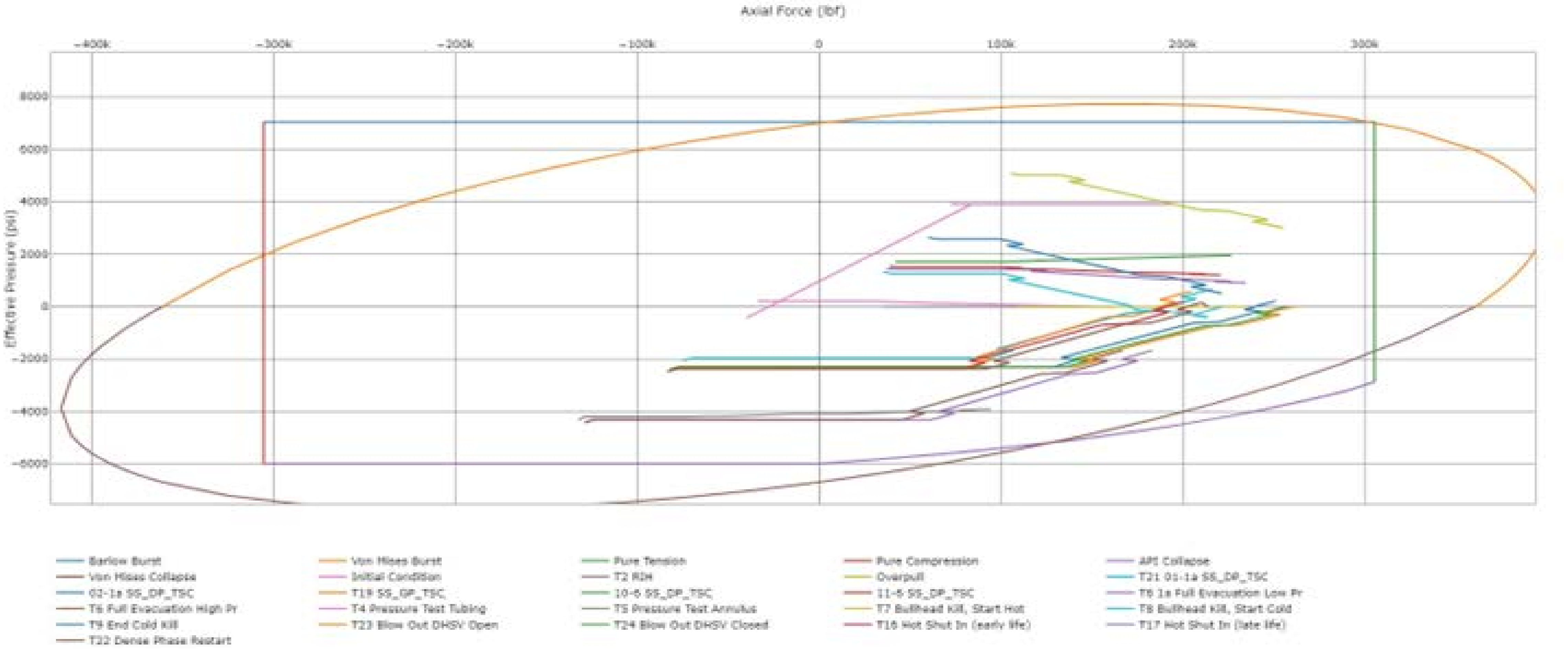
110 ksi tubular



80 ksi tubular - sensitivity

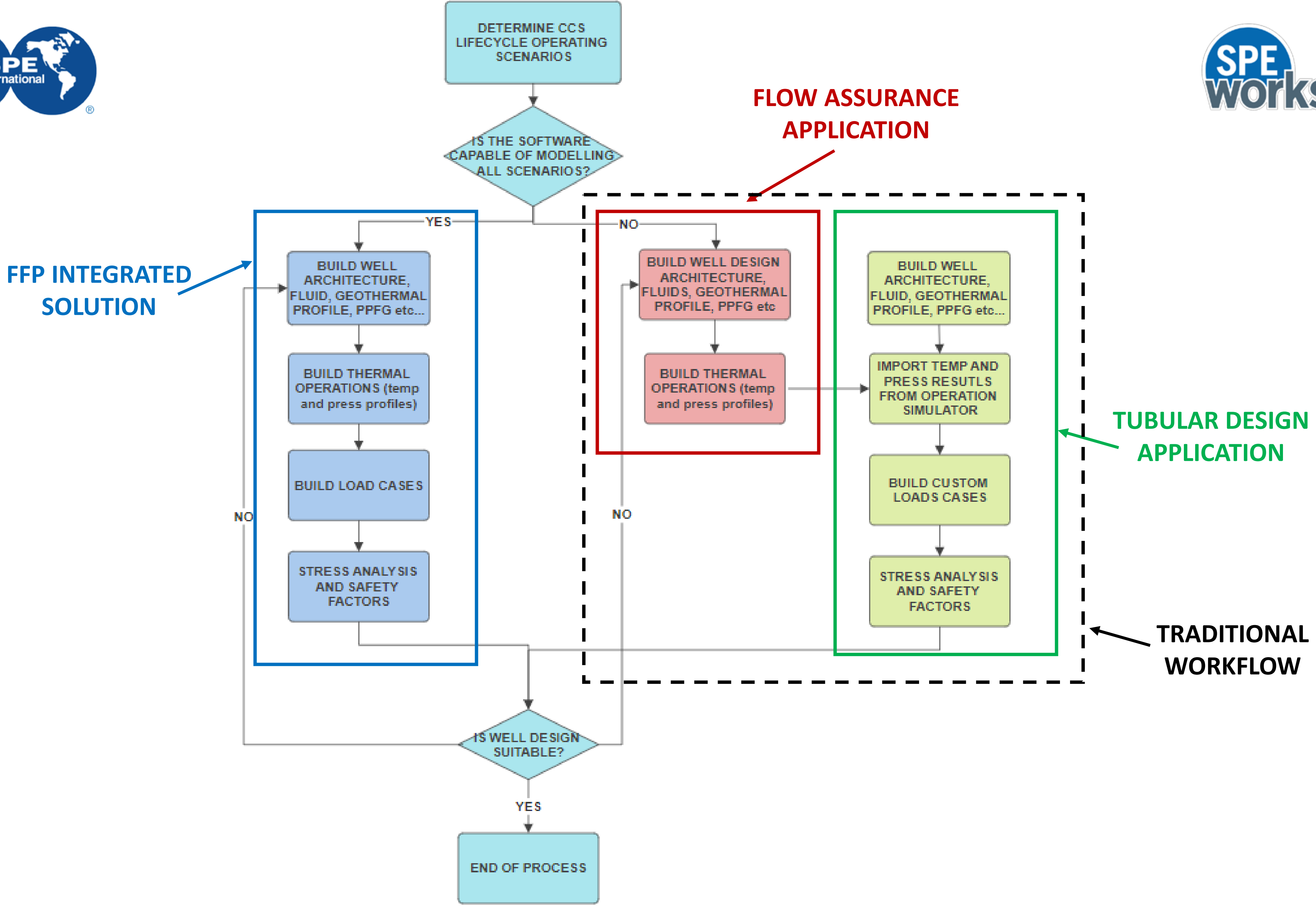


Well Design – Load Cases for Production Tubing



The experience of Agile Development

- **Fit for Purpose Solution** → model aligns with engineering objectives, accommodates common models and unique well design requirements
- **Agile development** → rapid identification & solution of specific design challenges
- **Cloud-based architecture** enhances efficiency, providing immediate access to updates and enabling direct user contribution
- Viking CCS well engineering team actively contributed to CIM software adaptation
- FFP allows multiple iterations of well path, casing/cement program, etc. for up-to-date Basis of Design assessments



DETERMINE CCS LIFECYCLE OPERATING SCENARIOS
IS THE SOFTWARE CAPABLE OF MODELLING ALL SCENARIOS?
YES
NO
FFP INTEGRATED SOLUTION
BUILD WELL ARCHITECTURE, FLUID, GEOTHERMAL PROFILE, PPFG etc...
BUILD THERMAL OPERATIONS (temp and press profiles)
BUILD LOAD CASES
STRESS ANALYSIS AND SAFETY FACTORS
FLOW ASSURANCE APPLICATION
BUILD WELL DESIGN ARCHITECTURE, FLUIDS, GEOTHERMAL PROFILE, PPFG etc
BUILD THERMAL OPERATIONS (temp and press profiles)
TUBULAR DESIGN APPLICATION
BUILD WELL ARCHITECTURE, FLUID, GEOTHERMAL PROFILE, PPFG etc...
IMPORT TEMP AND PRESS RESUTLS FROM OPERATION SIMULATOR
BUILD CUSTOM LOADS CASES
STRESS ANALYSIS AND SAFETY FACTORS
TRADITIONAL WORKFLOW
NO
NO
IS WELL DESIGN SUITABLE?
YES
END OF PROCESS

Conclusion

- CCS challenges for a traditional well design workflow
- Fit-for-Purpose solution that integrates CCS fluid modelling in tubular design application:
  - Allows swift identification of casing and tubing CCS design solutions
  - Facilitates sensitivity analysis which are crucial in CCS design
  - Agile development for rapid identifications and solutions of well design
- The 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

- CIM for flow assurance to include alternatives to GERG-2008 EOS for impurities
- FFP application to fully integrate choke functionality and injectivity functionality
- 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.

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