Connecting for a New Future

Fenja Development Automated Flow Assurance System and Associated Real-time Advisory Modules

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Outline

- Fenja Field Overview
- Flow Assurance Challenges in Fenja
- Fenja Digital Twin
- Operational Automated Advisors
- Integrity and Safety Automated Advisors
- Conclusions

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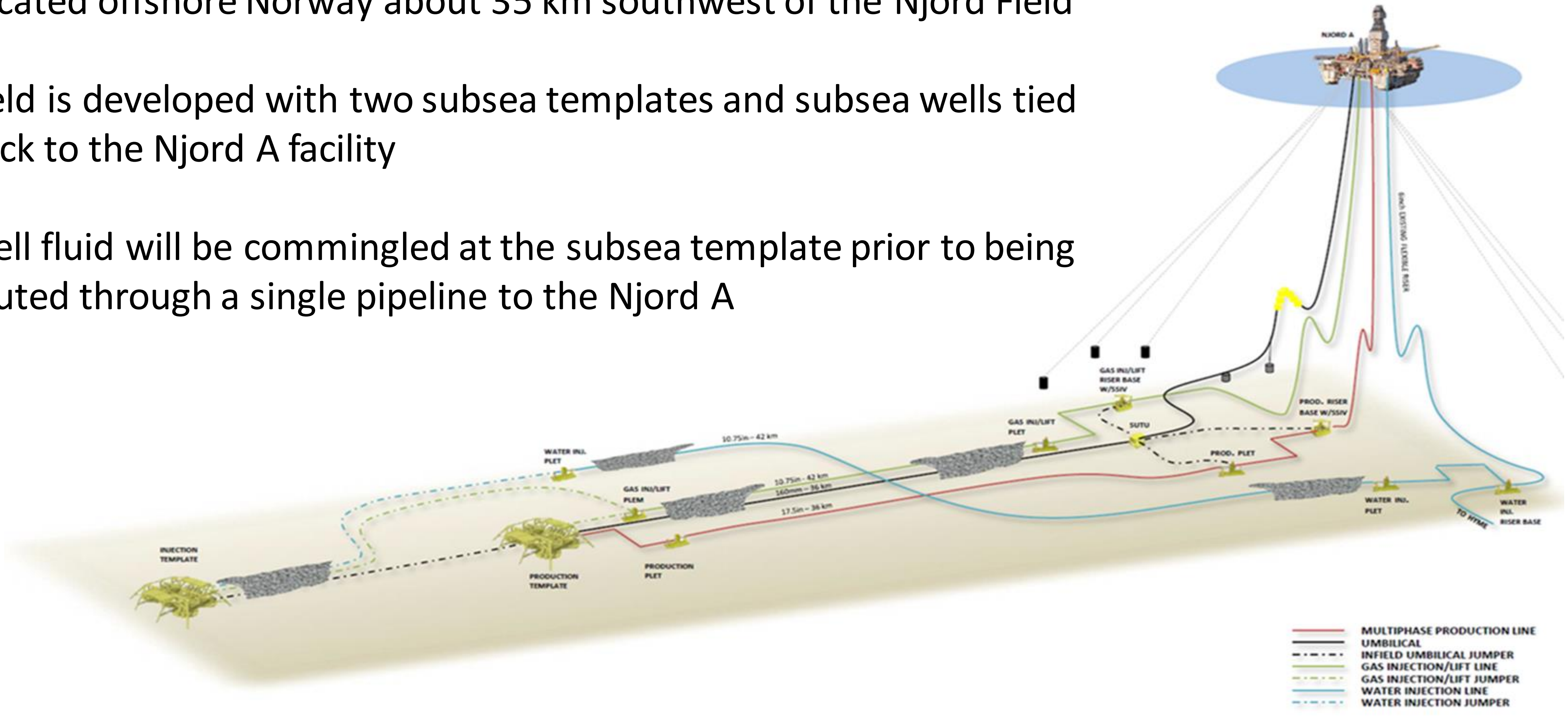
Fenja Development Options

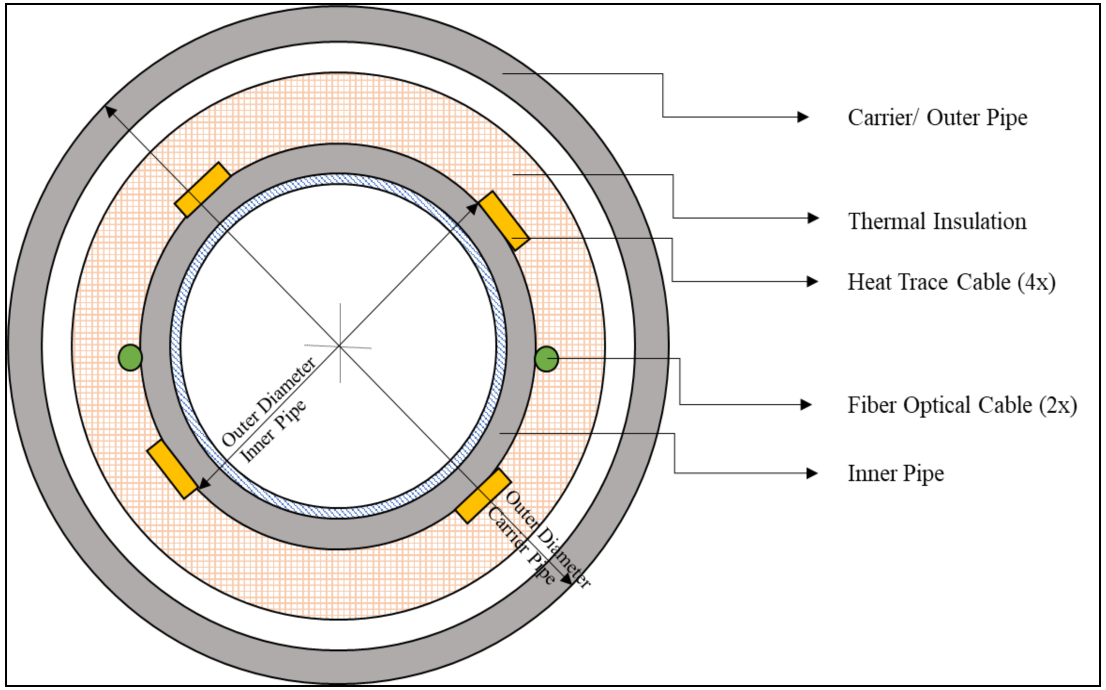
- Fenja was discovered in 2014
- Located offshore Norway about 35 km southwest of the Njord Field
- Field is developed with two subsea templates and subsea wells tied back to the Njord A facility
- Well fluid will be commingled at the subsea template prior to being routed through a single pipeline to the Njord A



Flow Assurance Challenges in Fenja Development

- Multiphase production via a single long tie-back pipeline length **(35 km)** in **cold arctic** environment

- Wax and Gelling Risk
  - High Wax Content,
  - Wax Appearance Temp: 39°C,
  - Pour Point Temp: 27°C
- Hydrate Risk
  - Hydrate Formation Temp: 18°-24°C,
- Liquid Management
  - Host facility constraints



- **World's longest ETH PIP** as the primary layer of protection for Wax & Hydrate

Why Active Heating is Required for Wax Management?

- The active heating system constitutes the only layer of protection against gel blockage in the pipeline after shutdown.
- The length of gelled section is dictated by the oil content in the pipeline after shutdown and depressurization

Flowline Condition	Total length of Blocked Sections (m)	Number of Sections	Length of Longest Individual Sections (km)	Gel Strength at 4°C (Pa)	Differential Pressure to Break the Gel (bar)
Shutdown	16000	12	5	180	223
Shutdown	16000	12	5	350	434
Depressurized	8000	12	4	180	133
Depressurized	8000	12	4	350	259

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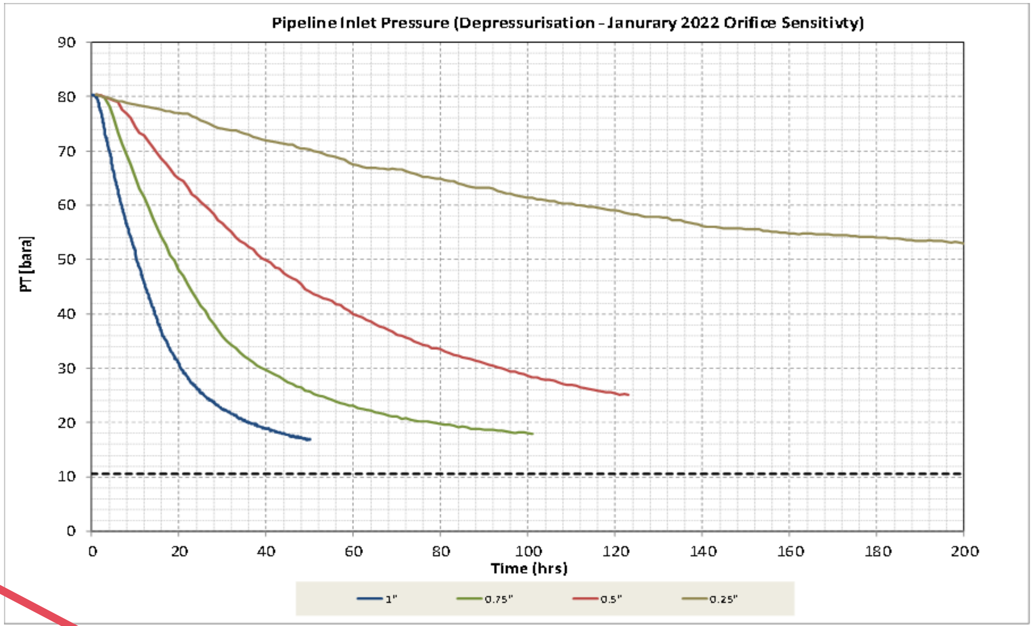
Why Active Heating is Required for Hydrate Management

- Hydrate Management Challenges
  - Depressurization is identified as a challenge during early field life production
  - Low Pressure start-up is technically infeasible

Liquid volume > available topside liquid surge handling volume



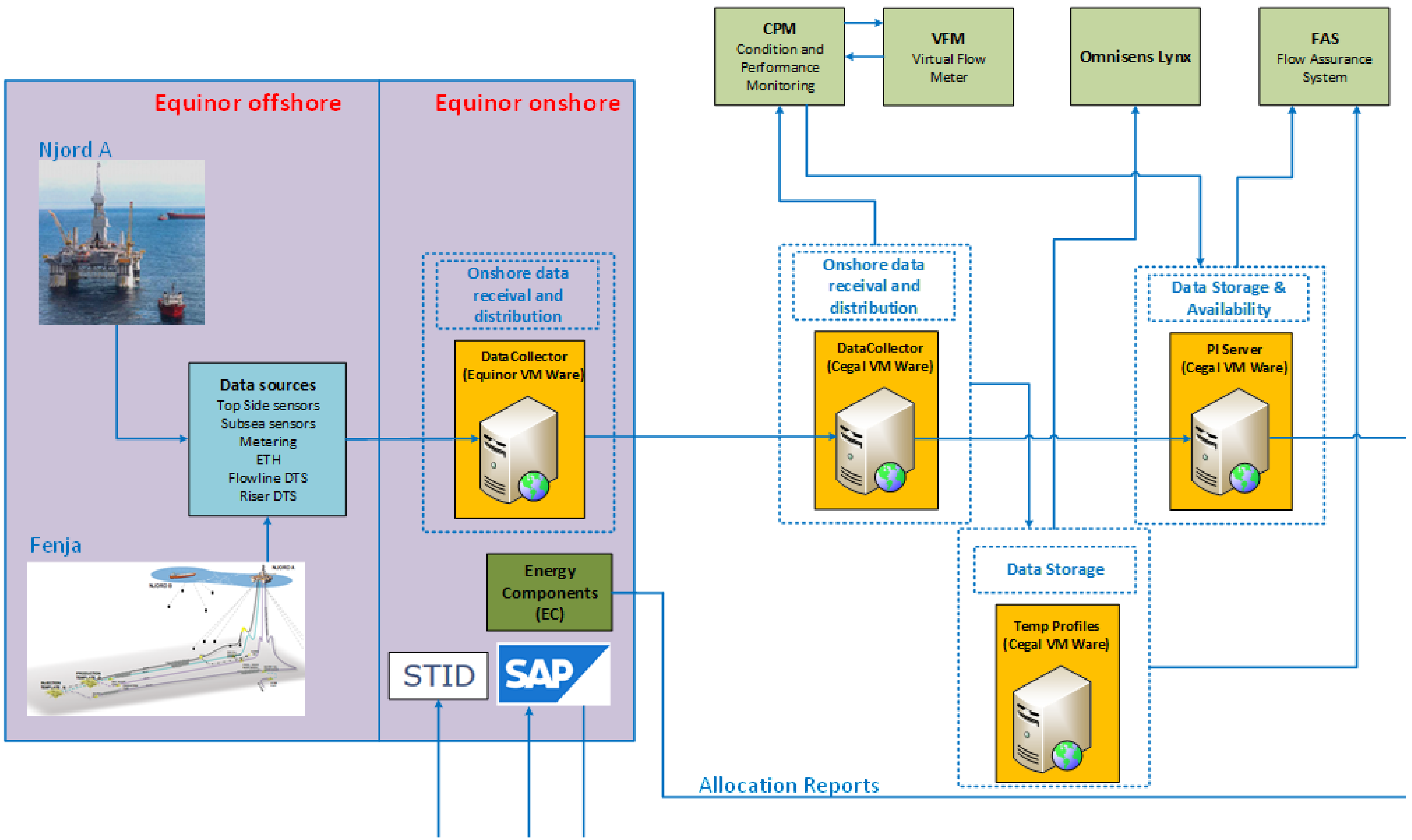
Pipeline does not reach hydrate safe pressure

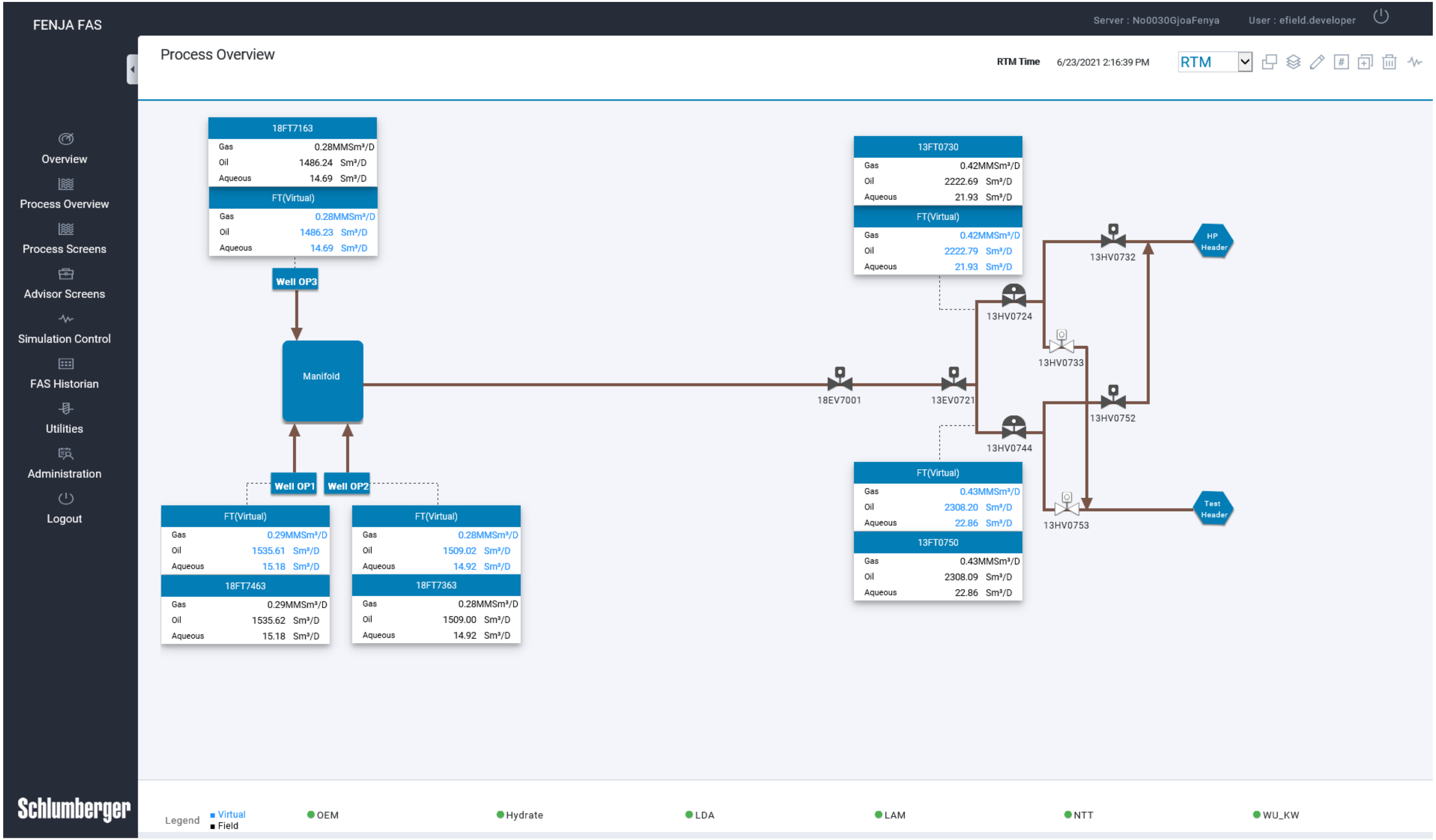
Case	Restart Time (to nearest 1 hr before CDT)	Final Pressure [bara]		Max DTHYD [oC]		Pipeline Inlet Final Temperature [oC]	Hydrate Safe Pressure (@ 4oC) [bara]	Time to Hydrate Safe Pressure [h] @ Pipeline Inlet	Accumulated Liquids [m3]			Accumulated Gas Mass Volume [Te]	Minimum Temp D/S 'LEAK' [oC]
		PIPINLET	Riserbase Spool	PIPINLET	Pipeline Outlet				Oil	Water	Liquid		
Jan-21	50	18.06	6.9	1.12	-1.72	6.7	10.5	NOT POSSIBLE	257	0.36	258	126.5	-23.2
Jan-22	44	16.40	5.7	-0.38	-2.46	7.5	10.5	NOT POSSIBLE	348	0.38	348	149.9	-22.5
Apr-23	50	14.59	4.5	0.23	-1.31	6.5	10.0	NOT POSSIBLE	211	0.28	212	162.8	-35.3
Jun-25	49	11.22	4.6	-8.75	0.86	14.5	9.0	NOT POSSIBLE	16	1.25	17	169.2	-61.4
Aug-27	44	7.84	3.8	-11.83	-0.43	14.9	8.8	41	3	0.01	3	142.9	-54.5
Oct-29	38	7.57	3.9	-12.16	-2.19	15.2	8.8	32	2	0.04	2	134.4	-52.2
Dec-31	36	7.03	3.1	-14.53	-4.05	16.9	8.7	40	2	0.04	2	135.0	-53.4
Feb-34	38	7.25	3.1	-15.20	-3.93	17.8	8.7	38	3	0.15	3	134.4	-53.9
Apr-36	38	7.99	3.5	-16.46	-5.12	19.8	8.7	45	2	0.13	2	130.6	-51.3

Fenja FAS & Automated Advisory Modules

- Fenja Digital Twin is designed not only to enable continuous monitoring, but also to provide advisories and operational guidelines for key operations:
- **Fenja FAS Modes of Operation**
  - Real-Time Mode
  - Look-Ahead Mode
  - What-if-Mode
  - Replay Mode
- **Fenja Advisory Modules**
  - No-touch time (NTT)
  - Warm up and keep warm operations
  - Leak detection
  - Sand Transportation & Risk of erosion
  - Slugging and surge handling
  - Emulsions

Fenja Digital Twin Data Flow Diagram

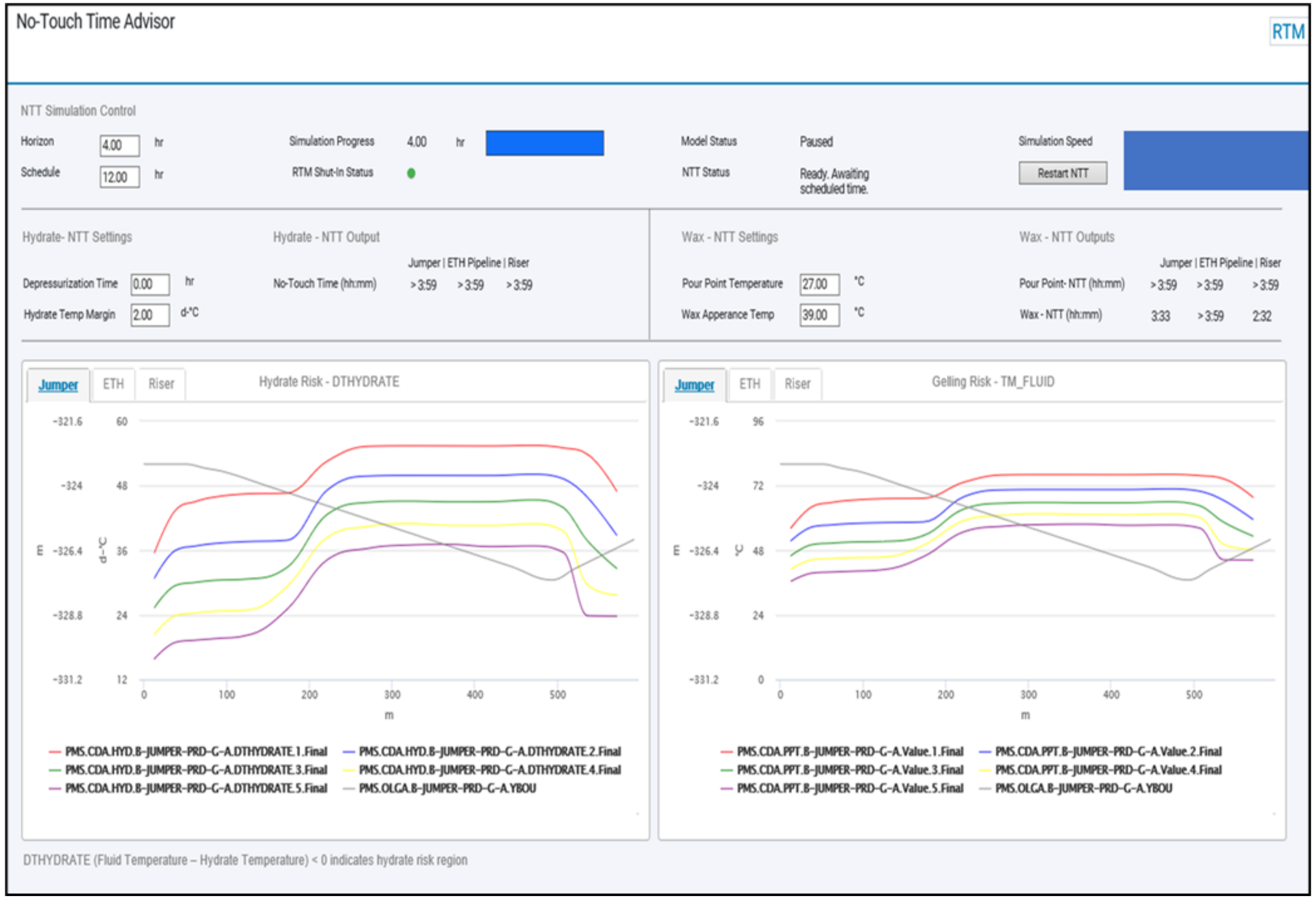




FENJA FAS
Server : No0030GjoaFenya
User : efield.developer
Process Overview
RTM Time
6/23/2021 2:16:39 PM
RTM
Overview
Process Overview
Process Screens
Advisor Screens
Simulation Control
FAS Historian
Utilities
Administration
Logout
Schlumberger
18FT7163
Gas 0.28MMSm³/D
Oil 1486.24 Sm³/D
Aqueous 14.69 Sm³/D
FT(Virtual)
Gas 0.28MMSm³/D
Oil 1486.23 Sm³/D
Aqueous 14.69 Sm³/D
Well OP3
Manifold
Well OP1
Well OP2
FT(Virtual)
Gas 0.29MMSm³/D
Oil 1535.61 Sm³/D
Aqueous 15.18 Sm³/D
18FT7463
Gas 0.29MMSm³/D
Oil 1535.62 Sm³/D
Aqueous 15.18 Sm³/D
FT(Virtual)
Gas 0.28MMSm³/D
Oil 1509.02 Sm³/D
Aqueous 14.92 Sm³/D
18FT7363
Gas 0.28MMSm³/D
Oil 1509.00 Sm³/D
Aqueous 14.92 Sm³/D
13FT0730
Gas 0.42MMSm³/D
Oil 2222.69 Sm³/D
Aqueous 21.93 Sm³/D
FT(Virtual)
Gas 0.42MMSm³/D
Oil 2222.79 Sm³/D
Aqueous 21.93 Sm³/D
FT(Virtual)
Gas 0.43MMSm³/D
Oil 2308.20 Sm³/D
Aqueous 22.86 Sm³/D
13FT0750
Gas 0.43MMSm³/D
Oil 2308.09 Sm³/D
Aqueous 22.86 Sm³/D
18EV7001
13EV0721
13HV0724
13HV0733
13HV0732
13HV0752
13HV0744
13HV0753
HP Header
Test Header
Legend
Virtual
Field
OEM
Hydrate
LDA
LAM
NTT
WU_KW

No Touch Time Advisor

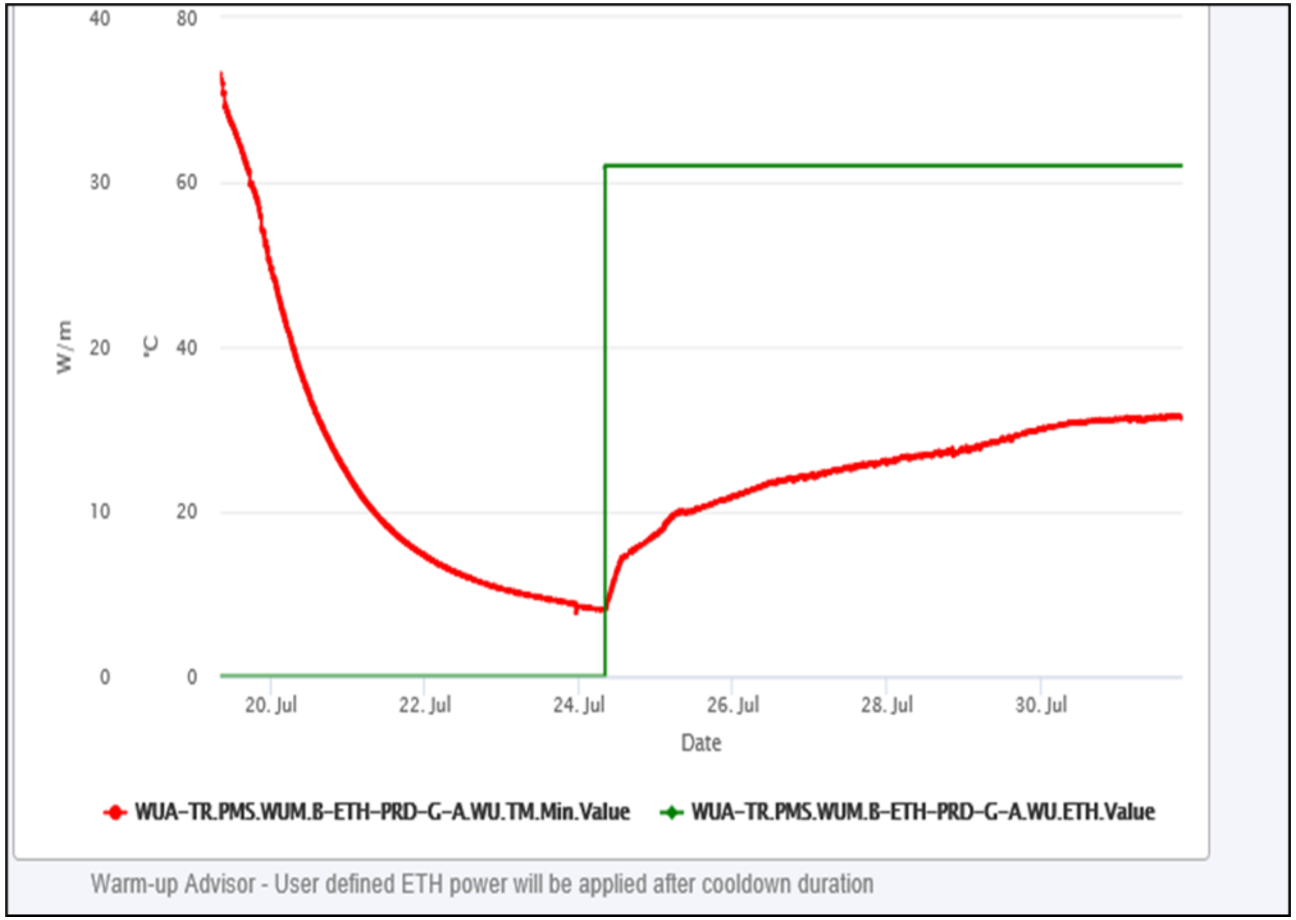
- Predictive simulation using online look-ahead mode
- Performs a predefined shut-in sequence using real-time field conditions
- Simulates into future to predict NTT for key locations
- Alarm/warning raised if temperature drops below hydrate and pour point temperatures alarm/warning threshold
- It runs automatically without any human intervention and provides updated information in real-time



Warm-up and Keep Warm Advisors

- It provides guidance for ETH pipeline operations. It has two distinct features:
  1) Keep warm: simulate minimum power requirement to stay outside hydrate risk

  2) Warm up: simulate time required to warm up the pipeline for restart
- Using real-time field conditions, simulates into future to predict time and power required for ETH operation
- It runs automatically without any human intervention and provides updated information in real-time



Power (green), Min Temperature in Pipeline (Red)

Leak Detection Advisor Working Principles

- Digital Twin simulates the system behavior without any leaks
- Field measurements that deviate from the real-time model in case of a leak
- **Leak Signatures** that generate a warning and subsequently an alarm when the signatures indicate a change in the operating point outside the **Expected Operating Region** (EOR)

Leak Signatures – Consider field data, simulated data and ambient condition

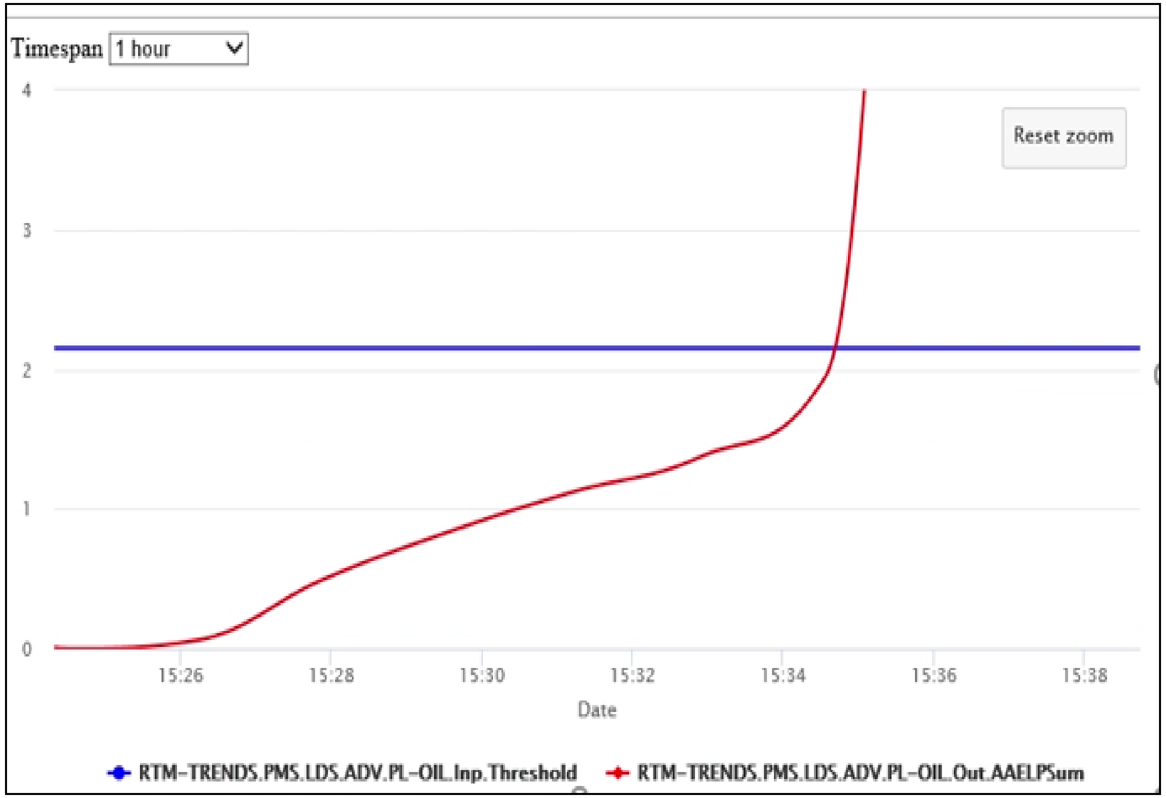
Label	Status	Active	Threshold	Signature
Well OP1				
18-FT-7463-QGST	●	Enabled	0.25	0.07
18-FT-7463-QOST	●	Enabled	0.25	0.07
18-FT-7463-QWST	●	Enabled	0.25	0.07
18-PZT-7441	●	Enabled	0.25	-0.02
18-TT-7441	●	Enabled	0.25	0.00
18-PT-7463	●	Enabled	0.25	-0.02
18-TT-7463	●	Enabled	0.25	0.00
18-PZT-7443	●	Enabled	0.25	-0.10
18-TT-7443	●	Enabled	0.25	0.00

Example of leak signatures at OP1 wellhead

Leak Detection Test Setup and Results

- Testing Setup:
  - To replicate a leak scenario, a FIELD model was made
  - Two models (FIELD and Digital Twin RTM) run in parallel and independently

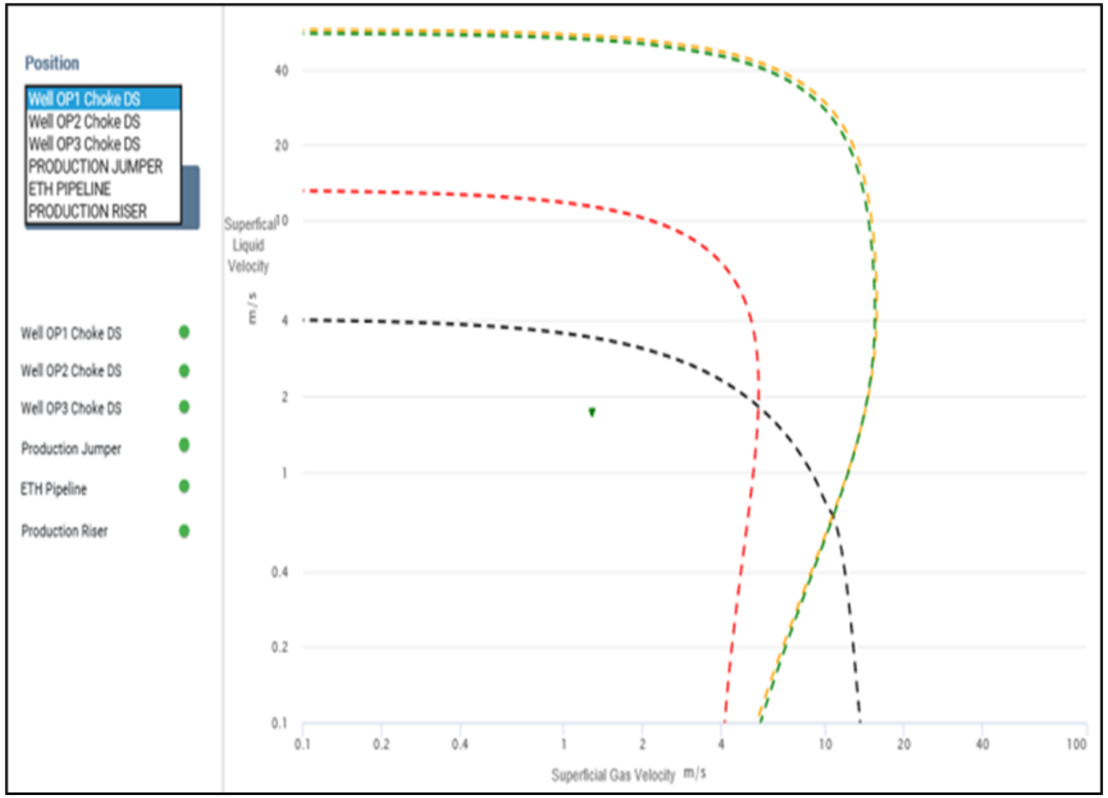
- Testing Outcomes:
  - Reliable operation with high uptime
  - False alarms are rare
  - Small Leak (1% of pipe dia.): 1 hour
  - Moderate Leak (>3% pipe dia.): 15 mins
  - Time to detect a leak depends on various factors, such as operating conditions in the field, leak size, leak location, etc.



Sum of leak signature value (red)
Threshold value (blue)

Sand Deposition and Erosion Risk Advisor

- Instant warning if any of the network sections are experiencing erosional issues
- Advisor monitors the erosion risk at key locations:
  - Production choke downstream piping
  - Production jumper outlet
  - Pipeline outlet
  - Production riser outlet
- Erosion risk static curves can be updated automatically based on field sand production data:
  - Average sand density and particle diameter
  - Average sand production rate (either manual or from sand detector measurements)



Different erosion risk boundaries based on different correlations
Green color dot shows current operating data

Conclusions

- Fenja Digital Twin is deployed to optimize operations and improve surveillance.

- By integrating the automated advisors with the real-time surveillance, this solution will achieve an increased level of accuracy, consistency and avoiding human errors.

- These automated advisors help identifying operational risks (wax, gelling and hydrate formation) in advance.

- Keep Warm & Warm-up advisor provide guidance to optimize the power consumption during various operations.

- A novel leak detection solution incorporating signature and regions definitions ensures "Top-of-the-range" leak detection for long multiphase tie-back pipeline.

- This solution promotes interaction among the various disciplines involved in operations into a single platform.

Acknowledgement

- I would like to express my deep appreciations to Neptune Energy and Schlumberger management for permitting this presentation in Digital Forum 2022.