HOW SUBSEA TECHNOLOGY IS ABLE TO PROVIDE A "SECOND" LIFE FOR THE DRAUGEN FIELD

Draugen, Subsea Boosting and Industry Initiatives

Richard Tong
Senior Subsea Processing Engineer
AGENDA

1.0 Introduction to Draugen

2.0 Draugen Infill Project

3.0 Subsea Pumping System
   - Scope of Supply - Testing - Technology Qualification API 17N

4.0 Technology & Industry Initiatives on Subsea Boosting

5.0 Field Screening of Subsea Boosting
1.0

DRAUGEN

History and Introduction to Draugen
HISTORY OF DRAUGEN

- First and only Single-leg GBS platform
- Low number of wells, due to successful production strategy
- Continuous project activity and investments underway to make Draugen a high integrity mature producer
- Robust and sustainable design; fit-for-purpose for potential future 3rd party Tie-ins
HISTORY OF DRAUGEN

Draugen Field Résumé

Field Properties

- Located in Haltenbanken area, 140km North of Kristiansund
- Discovered in 1984 and production start 19.10.1993
- Partners: A/S Norske Shell (Operator, 44.56%), Petoro AS (47.88%), VNG (7.56%)
- Water Depth ~ 250-280 m
- Peak Production 225 000 bbl/day
- High uptime- high recovery
HISTORY OF DRAUGEN

Draugen Field Résumé (continued)

- Geological / Geophysical Properties
  - Main reservoir in sandstone: Rogn and Garn Formations of Late and Middle Jurassic ages respectively
  - “World-Class” Reservoir at 1600m depth
  - Produced by pressure maintenance from water injection and aquifer support; gas lift used
2.0

DRAUGEN INFILL PROJECT

Project Scope
Draugen Infill Drilling Campaign

- 4x New Subsea Production Wells
- Subsea Boosting Pump
- Subsea Tee Manifold @ Rogn South
- 19 km of New Flowlines
- 11 km of New Umbilicals
- 52 tie-ins
- 113 GRP Covers
- 70 Concrete Mattresses
- 245 000 m³ Rock Installation
- 11 000 m³ Rock Removal

10 April 2016
Risk Description:

**Cause** - Lift gas circulated in flowlines

**Potential Event** - At an unexpected long shutdown, a hydrate plug may form

**Consequence** - Loss of flowline, i.e. potential loss of production

Risked Value = Cost x Probability

Assumptions-Information:

- The plug can only be remediated by flowline replacement
- Gas lift will have to be used in the future to maintain the production
Hydrate formation risk was a key factor towards driving concept towards subsea pump.

Experimental and theoretical work indicates hydrate formation is possible with Draugen oil. Risk increases with introduction of lift gas.

![Draugen wells graph](image)
Advantages of Framo Dual-Pump Station (FDS)

- Subsea Boosting Pump Station
  - Reduces back pressure “seen” by wells = increased oil recovery ~70%
  - Accelerated End-of-Field Life production
  - Increased efficiency as water cut increases over time
  - Reduces risk of hydrate formation – no need for continuous gas lift
  - Allow field start-up
  - Offers metering of new wells coming on-stream
  - Future expansion flexibility
3.0
DRAUGEN SUBSEA PUMPING SYSTEM

3.1 SMUBS 1993
3.2 Scope of Supply
3.3 Testing
The Draugen Subsea Well Facilities Contract was the largest subsea EPC contract in Norway at the time. All subsea installations were designed for *diverless* installation, operation and maintenance.

The seabed pumps (i.e. system integration of FRAMO pumps) were the *world’s first commercial multi-phase pump installation*.

The pump was installed in 1993. It ran successfully from 1995 for 12.2 months (1000 operating hours) and was decommissioned and abandoned due to change in water injection strategy.

Oil and Gas Journal: “Norske Shell has let a $100-million contract to Framo Engineering for a complete subsea multiphase booster pump system for Draugen oil field offshore Norway, where the world’s first such system was installed in 1994.”
SMUBS – Shell Multiphase Underwater Booster Station
- 1x750 kw subsea multiphase pump, installed in 1993
- Hydraulically driven by WI system

Shell Draugen Field
DRAUGEN SUBSEA PUMP SYSTEM
SCOPE OF SUPPLY
DRAUGEN INFILL PROJECT PUMPING SYSTEM

• Reduces back pressure “seen” by wells = increased oil recovery
• Accelerated end-of-field life production
• Avoid continuous gas lift, reduces hydrate formation risk
• Offers metering of new wells coming on stream & expansion flexibility

• Tie-back distance (To Draugen): ~4 km (12” flexible)
• Ambient Temperature (seawater): 6 – 8 °C
• Design temperature (flowlines): 75 °C
• Design pressure: 220 bar
• Number of Pumps: 2
• Motor Rating: 2300 kW
• Maximum dP: 50 bar
Table 7: Historical operating parameters of subsea helico-axial pumps

<table>
<thead>
<tr>
<th>Project Field</th>
<th>Project Type</th>
<th>Area</th>
<th>Operator</th>
<th>Start (year)</th>
<th>Water Depth (ft)</th>
<th>Tie-back Distance (miles)</th>
<th>Total Flowrate (bpd)</th>
<th>Flowrate per Pump (bpd)</th>
<th>Diff Press (psig)</th>
<th>GVF (%)</th>
<th>Current Status @ February, 2010</th>
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<tbody>
<tr>
<td>Draugen Field</td>
<td>SMUBBS, 1-MPP</td>
<td>Norway North Sea</td>
<td>Norsk Hydro</td>
<td>1995</td>
<td>886</td>
<td>4</td>
<td>29,200</td>
<td>29,200</td>
<td>773</td>
<td>42</td>
<td>Abandoned after 12 months</td>
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<td>Topazio Field</td>
<td>2-MPPs</td>
<td>Equatorial Guinea</td>
<td>ExxonMobil</td>
<td>2000</td>
<td>1641</td>
<td>6</td>
<td>142,000</td>
<td>70,000</td>
<td>50B</td>
<td>75</td>
<td>Operating after 114 months</td>
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<td>Ceba C3 C4</td>
<td>2-MPPs</td>
<td>Equatorial Guinea</td>
<td>Hess</td>
<td>2002</td>
<td>2461</td>
<td>5</td>
<td>90,600</td>
<td>45,300</td>
<td>653</td>
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<td>Ceba Field EFD</td>
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<td>Hess</td>
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<td>337,600</td>
<td>67,520</td>
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<td>Muntaner Exalto</td>
<td>2-MPPs</td>
<td>NWS Australia</td>
<td>Santos</td>
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<td>476</td>
<td>4</td>
<td>181,300</td>
<td>90,650</td>
<td>435</td>
<td>40</td>
<td>Operating after 50 months</td>
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<td>Brenda &amp; Nicole Fields</td>
<td>Multi Manif w/ 1 MPP</td>
<td>UK North Sea</td>
<td>OILEXCO N.S.</td>
<td>2007</td>
<td>476</td>
<td>5</td>
<td>120,800</td>
<td>120,800</td>
<td>276</td>
<td>75</td>
<td>Operating after 34 months</td>
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</tbody>
</table>
Draugen Pump System Parameters

- Design pressure: 220 barg
- Process operating temperature: 4 to 75 ºC
- Max pump differential pressure: 50 bar
- Pump suction pressure: 21 - 29 bara
- Pump suction GVF: 10 - 32% (75%)
- Pump flow rate: 643 - 855 Am³/h
- Pump speed: 1500 – 4200 rpm
- Pump motor shaft power: 2300 kW
- Water Depth: 268 m
TOPSIDE - POWER CONTROL MODULE (PCM)
MPP1
MPFM2
MPFM3
MPFM1
V4, retrievable choke insert
SCM

Well G-1
Well G-2
Well G-3
Main inlet
Well A-55

SOUTH
Unrestricted
PUMPING SYSTEM SCOPE OF SUPPLY

- Process Control Module
- Topside Umbilical Termination Unit
  - Hydr. TUTU
  - LY TUTU
  - PO TUTU
  - HV TUTU
- Subsea Umbilical Termination Assembly
MV connector stack-up test

Mock-up ROV access test

Hub cleaning tool stack-up test

Pump module stack-up test

Test of Ocean Install shackle towards the Pump Station

ROV access testing

21 April 2016
STACK UP PUMP STATION INTO PROTECTION STRUCTURE
4.0
TECHNOLOGY & INDUSTRY INITIATIVES ON SUBSEA BOOSTING

API 17N
Industry Initiatives
What is API RP 17N?

Industry collaboration attempting to address a common approach Technology Readiness Level (TRL) and associated Technology Risk Categorization (TRC) for development of new technology

Focus on assessment of modification of existing technologies/equipment to the project specific needs, not just new technologies

Focus on assessment of new technologies already deployed, particularly with respect to reliability

Present assessment in the form of a risk/readiness matrix

References internal/external standards and codes
# Table A.1—Technical Risk Categorization

<table>
<thead>
<tr>
<th>Key</th>
<th>Technical System Scale and Complexity</th>
<th>Operating Environment</th>
<th>Organizational Scale/Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> (very high) Reliability improvements (technology change): A significant reliability improvement requiring change to the technology involved.</td>
<td>Novel technology or new design concepts: Novel design or technology to be qualified during project.</td>
<td>Novel application: Architecture/configuration has not been previously applied by supplier.</td>
<td>New environment: Project is pushing environmental boundaries such as pressure, temperature, new part of world, severe meteorological conditions or hostile on land test location.</td>
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<tr>
<td><strong>B</strong> (High) Reliability improvements (design change): Significant reliability improvement requiring change to the design but no change to the technology.</td>
<td>Major modifications: Known technology with major modifications such as material changes, conceptual modifications, manufacturing changes, or upgrades. Sufficient time remains for qualification. Not mature for extended operating environments.</td>
<td>Orientation and capacity changes: Significant architectural/configuration modifications such as size, orientation and layout; changes fully reviewed and tested where viable. Large scale, high complexity.</td>
<td>Significant environmental changes: Many changes noted; extended and/or aggressive operating environment; risk requires additional review.</td>
</tr>
<tr>
<td><strong>C</strong> (Medium) Minor reliability improvements: Reliability improvements requiring tighter control over quality during manufacture, assembly and fabrication.</td>
<td>Minor modifications: Same supplier providing equipment with minor modifications such as dimensions or design life. Modifications have been fully reviewed and qualification can be completed.</td>
<td>Interface changes: interface changes, either with different equipment or control system changes; where appropriate, configuration has been tested and verified.</td>
<td>Similar environmental conditions: Same as a previous project or no major environmental risks have been identified.</td>
</tr>
<tr>
<td><strong>D</strong> (Low) Unchanged reliability: No reliability improvements required, existing quality assurance (QA) and control is acceptable.</td>
<td>Field proven technology: Same supplier providing equipment of identical specifications, manufactured at same location; provide assurance no changes have occurred through the supply chain.</td>
<td>Unchanged: Architecture/configuration is identical to previous specifications; interfaces remain unchanged, with no orientation or layout modification.</td>
<td>Same environmental conditions: Same as recent project.</td>
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</table>
## TRL Definition

### Table B.19—Definition of Technology Readiness Levels (TRLs)

<table>
<thead>
<tr>
<th>TRL</th>
<th>Development Stage Completed</th>
<th>Definition of Development Stage</th>
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<tbody>
<tr>
<td>0</td>
<td>Unproven Concept (Basic R&amp;D, paper concept)</td>
<td>Basic scientific/engineering principles observed and reported; paper concept; no analysis or testing completed; no design history</td>
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</tbody>
</table>
| 1   | Proven Concept (Proof of concept as a paper study or R&D experiments) | a) Technology concept and/or application formulated  
b) Concept and functionality proven by analysis or reference to features common with/to existing technology  
No design history; essentially a paper study not involving physical models but may include R&D experimentation |
| 2   | Validated Concept Experimental proof of concept using physical model tests | Concept design or novel features of design is validated by a physical model, a system mock up or dummy and functionally tested in a laboratory environment; no design history; no environmental tests; materials testing and reliability testing is performed on key parts or components in a testing laboratory prior to prototype construction |
| 3   | Prototype Tested (System function, performance and reliability tested) | a) Item prototype is built and put through (generic) functional and performance tests; reliability tests are performed including; reliability growth tests, accelerated life tests and robust design development test program in relevant laboratory testing environments; tests are carried out without integration into a broader system  
b) The extent to which application requirements are met are assessed and potential benefits and risks are demonstrated |
<p>| 4   | Environment Tested (Pre-production system environment tested) | Meets all requirements of TRL 3; designed and built as production unit (or full scale prototype) and put through its qualification program in simulated environment (e.g. hyperbaric chamber to simulate pressure) or actual intended environment (e.g. subsea environment) but not installed or operating; reliability testing limited to demonstrating that prototype function and performance criteria can be met in the intended operating condition and external environment |
| 5   | System Tested (Production system interface tested) | Meets all the requirements of TRL 4; designed and built as production unit (or full scale prototype) and integrated into intended operating system with full interface and functional test but outside the intended field environment |
| 6   | System Installed (Production system installed and tested) | Meets all the requirements of TRL 5; production unit (or full scale prototype) built and integrated into the intended operating system; full interface and function test program performed in the intended (or closely simulated) environment and operated for less than 3 years; at TRL 6 new technology equipment might require additional support for the first 12 to 18 months |
| 7   | Field Proven (Production system field proven) | Production unit integrated into intended operating system, installed and operating for more than three years with acceptable reliability, demonstrating low risk of early life failures in the field |</p>
<table>
<thead>
<tr>
<th>Technical Risk Categorization</th>
<th>Very High Technical Risk / Unacceptable Reliability</th>
<th>A</th>
<th>N/A</th>
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<td></td>
<td>High Technical Risk / Low Reliability</td>
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<td>N/A</td>
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<td>Medium Technical Risk / Moderate Reliability</td>
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<td>Low Technical Risk / Acceptable Reliability</td>
<td>D</td>
<td>25</td>
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<tr>
<th>Field Proven</th>
<th>System Installed</th>
<th>System Tested</th>
<th>Environment Tested</th>
<th>Prototype Tested</th>
<th>Validated Concept</th>
<th>Proven Concept</th>
<th>Unproven Concept</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(less than 3 years) or immature with respect to reliability</td>
<td>New Technology, or Some Reconfiguration of Existing Technology</td>
<td>New Technology or significant reconfiguration of existing technology</td>
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</tbody>
</table>

**Technology Readiness Level**

- **Note:** Numbers above are examples. Not a reference to Draugan system.
INDUSTRY INITIATIVES

Longstep tie-back developments (>20 km)
- Electrically heated lines
- Long step out power supplies (<120 km)
- Simplifying control system – onshore based system

Standardisation
-API 17X Recommended Practice on Subsea Pumping Systems
-Subsea Processing JIP – Standardization of Subsea Pumping.

Building market competitiveness
- Pumping, higher pressures
- Compression – Wet tolerance
- Wet Compression – increasing the product range
- Subsea water injection – Seabox (NOV)
LONGSTEP OUTS

- Electrically heated lines:
  - Electrical heat tracing (Lowest power usage, highest CapEx)
  - Wet insulation direct electrical heating
  - Pipe in pipe direct electrical heating
- Long step out power supplies
  - Onshore VSDs – 120 km & 12.5 MW vs.
  - Subsea VSD and switch gear (cable cost vs. subsea cost)
- Simplifying control system – onshore based system
  - Communication protocols for safe shore based control of subsea systems
BUILDING MARKET COMPETITIVENESS

Pumping

- OneSubsea one major vendor, lack of competition
- Qualifying FMC/Sulzer for the BC-10 project Brazil

Compression – Wet tolerance

- Man and GE furthering technologies to be tolerant to 95% GVF, 30% liquid w/w. Testing completed
- Wet Compression One Subsea dual drive axis axial compressor
  - WGC 4000 deployed for Statoil on Gulfaks
  - Developing WGC 6000, Testing. Chevon Gorgon project
5.0
FIELD SCREENING OF SUBSEA BOOSTING

Technology Maturity, Field Screening Process
## Proven Technology – 2 Million Running Hours

### TABLE 1 – 2015 WORLDWIDE SURVEY OF SUBSEA GAS COMPRESSION, BOOSTING, WATER INJECTION, AND SEPARATION (1/2) – As of Feb. 2016

<table>
<thead>
<tr>
<th>PROGRAMS DIVERGED</th>
<th>FIELD OR PROJECT (Ordered by Start Date)</th>
<th>COMMENTS</th>
<th>ON-HIGH FIELD OPERATOR</th>
<th>REGION OR BASINS</th>
<th>WATER</th>
<th>DEPTH</th>
<th>TIEBACK DISTANCE</th>
<th>SYSTEM FLOW RATE (LINE CONDITIONS)</th>
<th>DIFFERENTIAL</th>
<th>INLET</th>
<th>EXIT</th>
<th>TOTAL EOR</th>
<th>TOTAL FLOW</th>
<th>TOTAL POWER</th>
<th>TOTAL INVESTMENT</th>
<th>SYSTEM PACKAGER</th>
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<td>Destiny Field</td>
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<td>Offshore Norway, Norway</td>
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**2015 WORLDWIDE SURVEY OF SUBSEA PROCESSING: SEPARATION, COMPRESSION, AND PUMPING SYSTEMS**

**STATUS OF THE TECHNOLOGY**

**MARCH 2015**

Lori Hermon, Chicago Metropul News, As Editor, Richard Wight, Jordan Honduras, Peter Allen, Wayne Grove, and others from INTECSEA.

E. Kurt Edmond and Daniel T. Pasha, and Field Films of Offshore Magazine.

Editorial Worked by Chris Jones of ESS Madagascar.

Contact: Power Source by INTECSEA of Cahay, Windows.

E-Mail: Chris.Carleo@intecsea.com

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**INTECSEA OFFSHORE**

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**21 April 2016**
OneSubsea Design Pressure Milestones

- 1997, Lufeng
- 2003, Ceiba
- 2006, Columba E
- 2013, JSM
- 2014
OneSubsea Motor Shaft Power Milestones

- 1997, Lufeng
- 1998, Troll
- 2000, Columba E
- 2007, Tordis
- 2010, Gullfaks WGC
- 2013, JSM
- 2009, Pazflor
- Q4-2013

Shaft Power (kW)
OneSubsea Water Depth Milestones

- SMUBS
- LufengTroll
- Topacio
- Ceiba
- Azurite
- JSM
- Julia

Design depth (m):
- 0 m
- 500 m
- 1000 m
- 1500 m
- 2000 m
- 2500 m
- 3000 m

Year:
- 1990
- 1995
- 2000
- 2005
- 2010
- 2015
Reservoir Development Concept

- Reservoir
  - Pressure Maintenance
  - Fluid Displacement
    - CO₂/Chemical/WAG
  - Production system sizing
  - Back Pressure Reduction
    - Gas Lift
    - ESP
    - Multiphase boosting

- Production System

Unrestricted
## High level Comparison of typical Subsea Fields EOR methods

<table>
<thead>
<tr>
<th></th>
<th><strong>Gas/Water/WAG Injection</strong></th>
<th><strong>Boosting</strong></th>
<th><strong>Gas Lift</strong></th>
<th><strong>ESP</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td>• Could reduce alternative investments (Prod. Wells, Flow lines, risers and topside equipment)</td>
<td>• Very high volume capability</td>
<td>• Excellent flexibility in injection/production rate</td>
<td>• High volume/rate capability</td>
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<td>• High flexibility when injecting into multiple reservoirs</td>
<td>• Effective on long tiebacks, requires smaller pipeline sizes</td>
<td>• Excellent gas handling</td>
<td>• Wide production rate range between applications.</td>
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<td>• Disposal produced water / reduce topside cleaning requirements</td>
<td>• Positive effect on flow assurance</td>
<td>• Excellent sand and solids handling</td>
<td>• Effective on long tiebacks</td>
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<td>• Combine with artificial lifts</td>
<td>• Can be shared by multiple wells/manifolds</td>
<td>• No advanced subsea rotating equipment is required.</td>
<td>• Positive effect on flow assurance</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td>• Large topside investments Topside Water Injection System including pump with filter, de-aerator, piping, valves, etc.</td>
<td>• High cost per unit</td>
<td>• Compression cost is high and compressor must be reliable</td>
<td>• Narrow production rate range for a specific application</td>
</tr>
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<td>• Platform modifications/extensions, installation, hook-up and commissioning work.</td>
<td>• Not economical for very small fields</td>
<td>• Gas delivery line can be expensive</td>
<td>• Reliability is a major issue</td>
</tr>
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<td>• Weight and space constraints</td>
<td>• Fewer applications compared with Gas Lift/ESP</td>
<td>• Fair operating efficiency, but poor for intermittent gas lift.</td>
<td>• Poor solids handling</td>
</tr>
<tr>
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<td>• High pressure injection pipelines</td>
<td>• Limited GVF range</td>
<td>• Tend to cause or increase flow assurance issues</td>
<td>• Poor gas handling (without inlet gas separators).</td>
</tr>
<tr>
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<td>• Extra Wells cost</td>
<td></td>
<td>• Limited increase of production rates</td>
<td>• High intervention frequency and cost</td>
</tr>
</tbody>
</table>

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21 April 2016
Pore to Process Evaluation Involving Artificial Lift

- Sensitivity
  - Well: drainage, well location, number of wells
  - SURF: line sizing, insulation
  - Artificial lift: GL, ESP, Boosting

- Recommendations
  - Optimum SURF
  - AL requirement
  - Well location

- Data
  - Fluid
  - Reservoir
  - Well
  - Production system

- Pore to process simulation for life of Field

- Production

- Risks

- CAPEX

- OPEX

- Revenue

- $$$$ Others factors
  - Company preference
  - Operational challenges etc.
Evaluation of Subsea Boosting

Marketing/Profiling
- Total subsea projects
- Projects with understanding of boosting
- Projects that consider boosting

Time + Audience
- Exploration
- Feasibility
- Concept
- Definition
- Execution
- Processing
- Production
- Facilities
- Reservoir
- G&G
- PM/Asset
- Subsurface
- Drilling

Industry perception
- Increased production
- Accelerated production
- Saving on SURF
- Cost

How can we convey the boosting message to the decision makers in time?

We need to evaluate the technology and the bottom line in a quantitative way.
SCREENING OPPORTUNITIES

- Project economics requires: CapEx, OpEx and Production profiles
- Generally Reservoir Engineers are given surface PQ curves from which predict the impact of different surface options on reservoir production, from which to produce a profile from
- This is a limited approach:
  - Poor accuracy
  - Limited functionality, insensitive to compositional changes
  - Requires fixed water cuts & GORs
  - Difficult to model constraints e.g. compressor curves etc.
  - Etc…
Integrated Production System Modelling
Shell uses PTEX’s Resolve software that links together and optimises:
- GAP – surface network
- Prosper - well
- MoRes – subsurface
Coupled with:
- Equipment Design
- Availability modelling
- Routing Logic
OUTCOME

- No endless iteration with Reservoir Engineering
- Quality of information has been significantly approved, able to assess between different options
- Perform sensitivity analysis: equipment sizing, uncertainties, availability, routing, project timing etc.
- System analysis, understanding what are the governing constraints and what impact of changing them
Q & A
Have a Safe Day