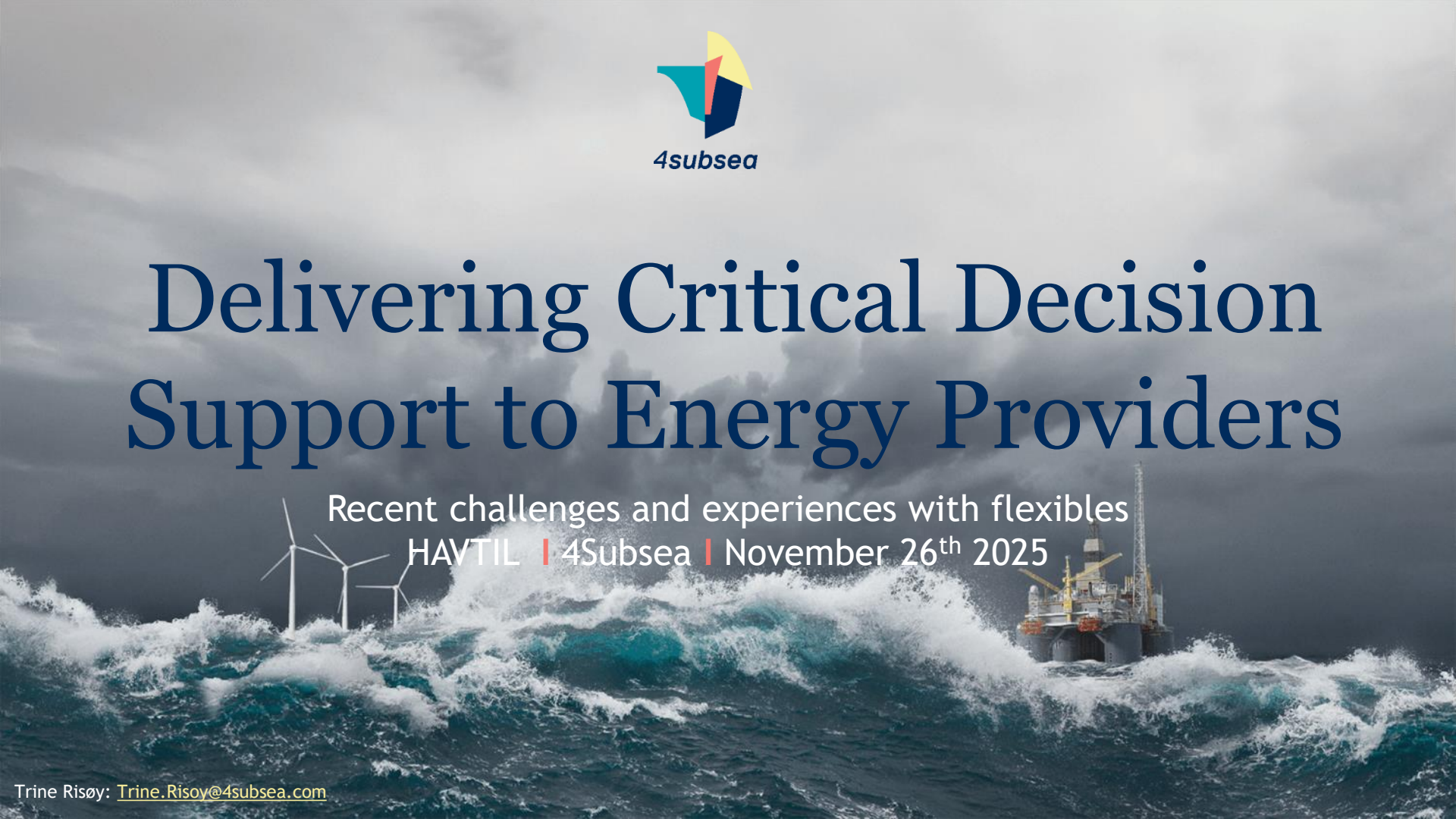


Delivering Critical Decision Support to Energy Providers

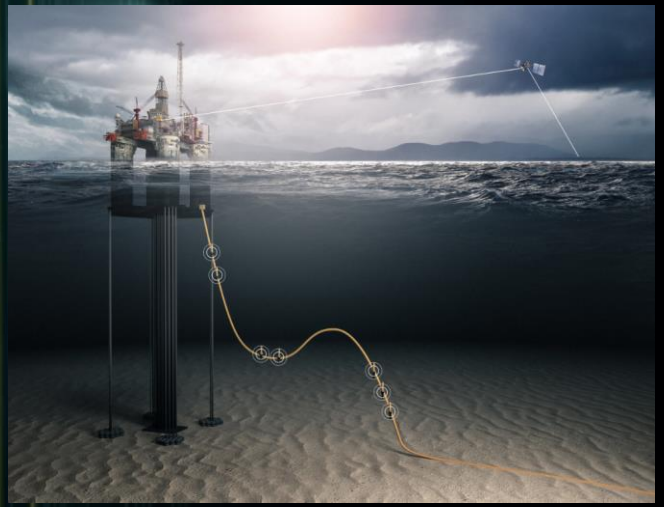
Recent challenges and experiences with flexibles

HAVTIL | 4Subsea | November 26th 2025

Trine Risøy: Trine.Risoy@4subsea.com

Agenda

- Sharing experience
  - Handbook JIP
  - FlexShare
- Corrosion assessment
- Permeation of heavier hydrocarbons
- Hydrate calculations
- Global analysis
- Lifetime extension

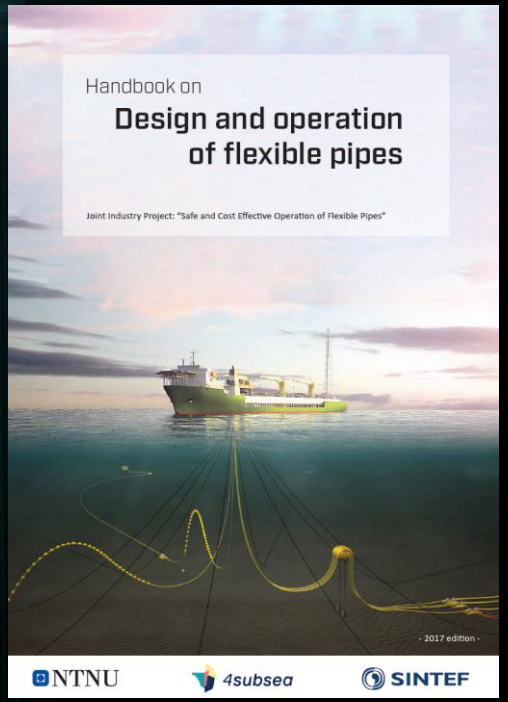


Sharing experience

- Handbook
- FlexShare

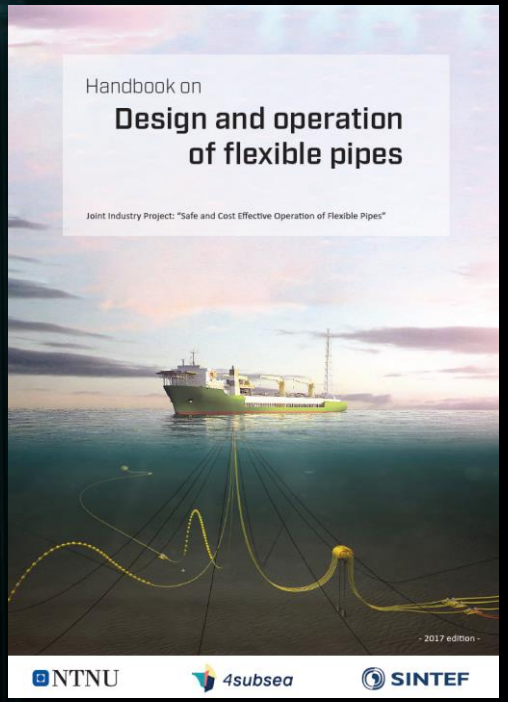
JIP – Update of Flexible Pipe Handbook

- **Objective:** Update of existing handbook on design and operation of flexible pipes
  - latest revision 2014/2017
- **Purpose:** Provide methods and guidance supplementary to API17B/J
  - including 10 years of new knowledge
- **Kick-off:** April 2025
- **Completion:** April 2027



JIP – Update of Flexible Pipe Handbook

- **Status**
  - Table of content updated
  - Writing initiated
- **Selected scope activities**
  - Polymer materials
  - New failure modes - including torsion
  - SN-curves
  - Global analysis – step-by-step guide
  - Local buckling
  - Reliability based decision support and safe long-term operation
- Room for late participants!



FlexShare – A sharing community

- Formed to share industry experiences of flexibles
- Quarterly webinars and yearly in-person workshops to present and share knowledge & discussions
- User-friendly and scalable platform with privacy controls to share relevant incident data
- Interactive dashboards allowing for in-depth analysis and insights to deliver critical decision support
- Bulletins and newsletters with industry trends and news

The FlexShare™ vision:

"To be a trustworthy arena for sharing flexible pipe experiences, so that all stakeholders contribute to risk and cost reduction for design and operation of flexible pipes."

Top 5 failure layers - FlexShare

1) Outer sheath
   - Hole, tear, rupture or crack
   - Ageing, fatigue
   - Ingress of seawater
2) End-fitting
   - Internal pressure sheath pull-out
   - Vent valve blockage / leakage
3) Carcass
   - Collapse / ovalisation
   - Unsupported carcass / full extension of carcass under its own weight
4) Tensile armour layers
   - Corrosion
   - Wire rupture
5) Internal pressure sheath
   - Ageing embrittlement / chemical degradation

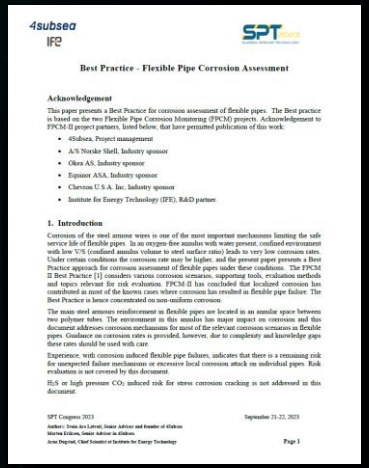
Corrosion assessment

Corrosion assessment

- Outer sheath breaches leading to corrosion issues
- Establish most likely damage location, size and time
- Assess annulus conditions
  - Including current and future operational condition
  - CO_2 fugacity
  - Annulus pressure variations to assess water ingress pulsations
  - AVGM data valuable (when available)
- Establish corrosion rates
  - Cooperation with IFE
  - Based on FPCM and field experience
  - Main concern: Armour wires close to the outer sheath damage
- Assess pipe integrity
  - Structural capacity and fatigue

Tensile armour – 11 yrs operation North Sea – 6 yrs flooded, Ref. Handbook 2017:

FPCM – Best practice:



4subsea IFE SPT

Best Practice - Flexible Pipe Corrosion Assessment

Acknowledgement

This paper presents a Best Practice for corrosion assessment of flexible pipes. The Best practice is based on the two Flexible Pipe Corrosion Monitoring (FPCM) projects. Acknowledgement to FPCM-II project partners, listed below, that have permitted publication of this work:

- 4Subsea, Project management
- A/S Norske Shell, Industry sponsor
- Okea AS, Industry sponsor
- Equinor ASA, Industry sponsor
- Chevron U.S.A. Inc, Industry sponsor
- Institute for Energy Technology (IFE), R&D partner.

1. Introduction

Corrosion of the steel armour wires is one of the most important mechanisms limiting the safe service life of flexible pipes. In an oxygen-free annulus with water present, confined environment with low V/S (confined annulus volume to steel surface ratio) leads to very low corrosion rates. Under certain conditions the corrosion rate may be higher, and the present paper presents a Best Practice approach for corrosion assessment of flexible pipes under these conditions. The FPCM II Best Practice [1] considers various corrosion scenarios, supporting tools, evaluation methods and topics relevant for risk evaluation. FPCM-II has concluded that localized corrosion has contributed in most of the known cases where corrosion has resulted in flexible pipe failure. The Best Practice is hence concentrated on non-uniform corrosion.

The main steel armours reinforcement in flexible pipes are located in an annular space between two polymer tubes. The environment in this annulus has major impact on corrosion and this document addresses corrosion mechanisms for most of the relevant corrosion scenarios in flexible pipes. Guidance on corrosion rates is provided, however, due to complexity and knowledge gaps these rates should be used with care.

Experience, with corrosion induced flexible pipe failures, indicates that there is a remaining risk for unexpected failure mechanisms or excessive local corrosion attack on individual pipes. Risk evaluation is not covered by this document.

H_2S or high pressure CO_2 induced risk for stress corrosion cracking is not addressed in this document.

SPT Congress 2023 September 21-22, 2023

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Morten Eriksen, Senior Advisor in 4Subsea
Jesse Dugstad, Chief Scientist at Institute for Energy Technology

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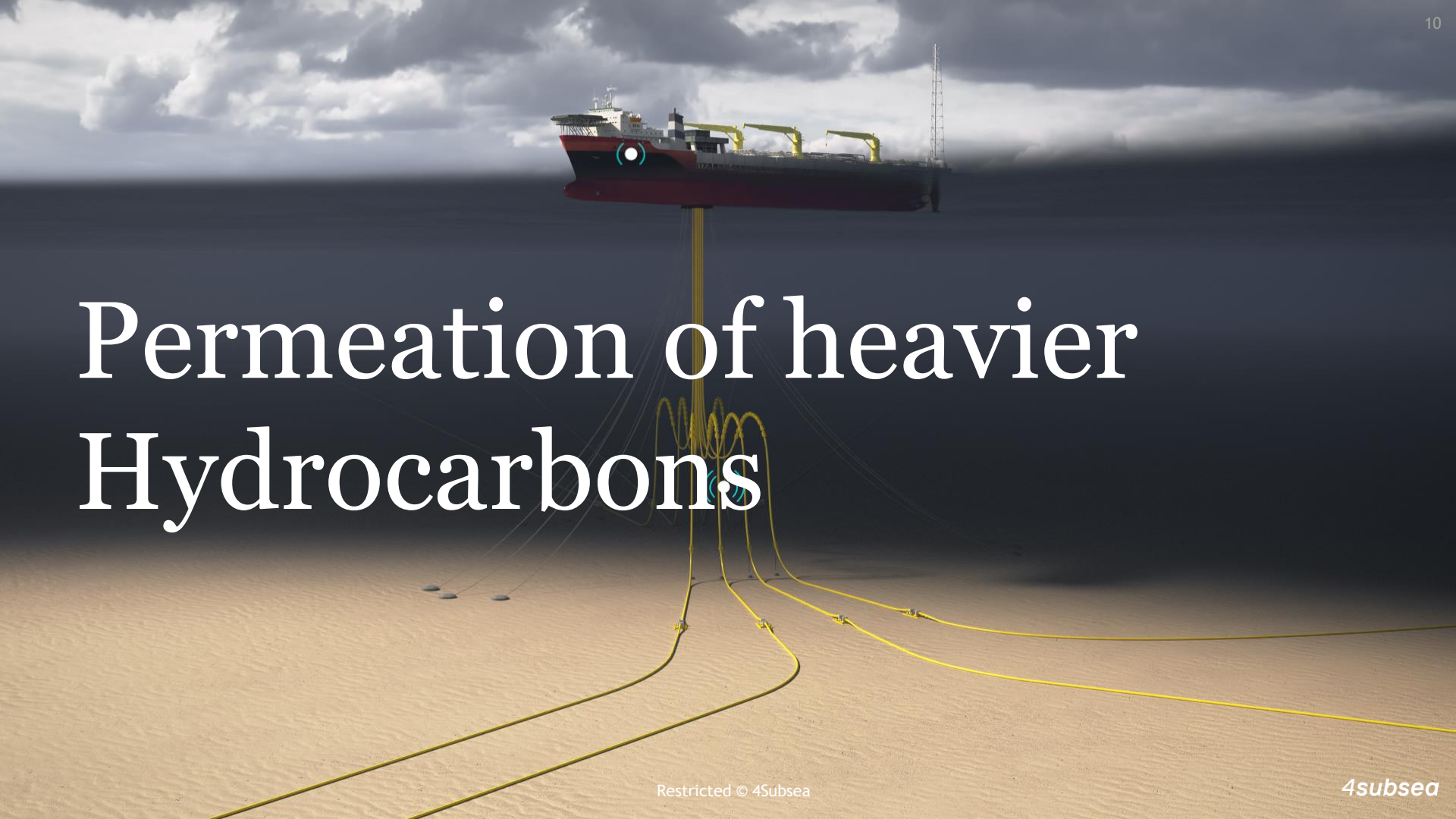
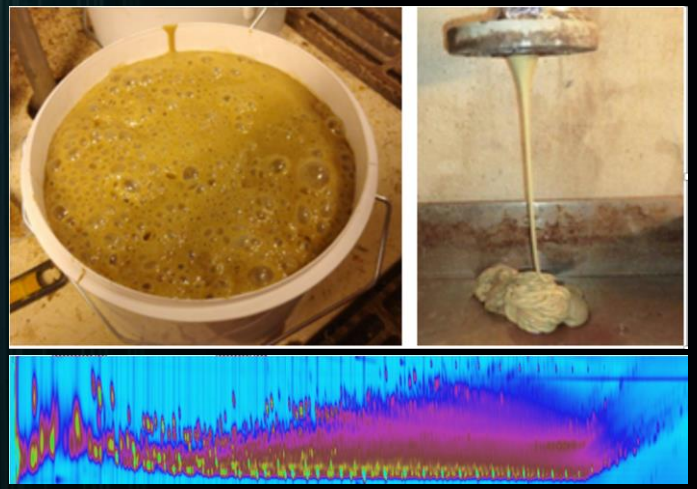


Permeation of heavier Hydrocarbons

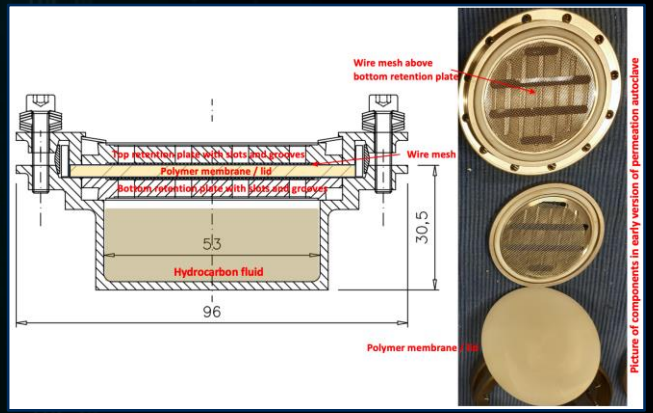
Fluid hydrocarbons (HC) in annulus
– Leakage or permeation?

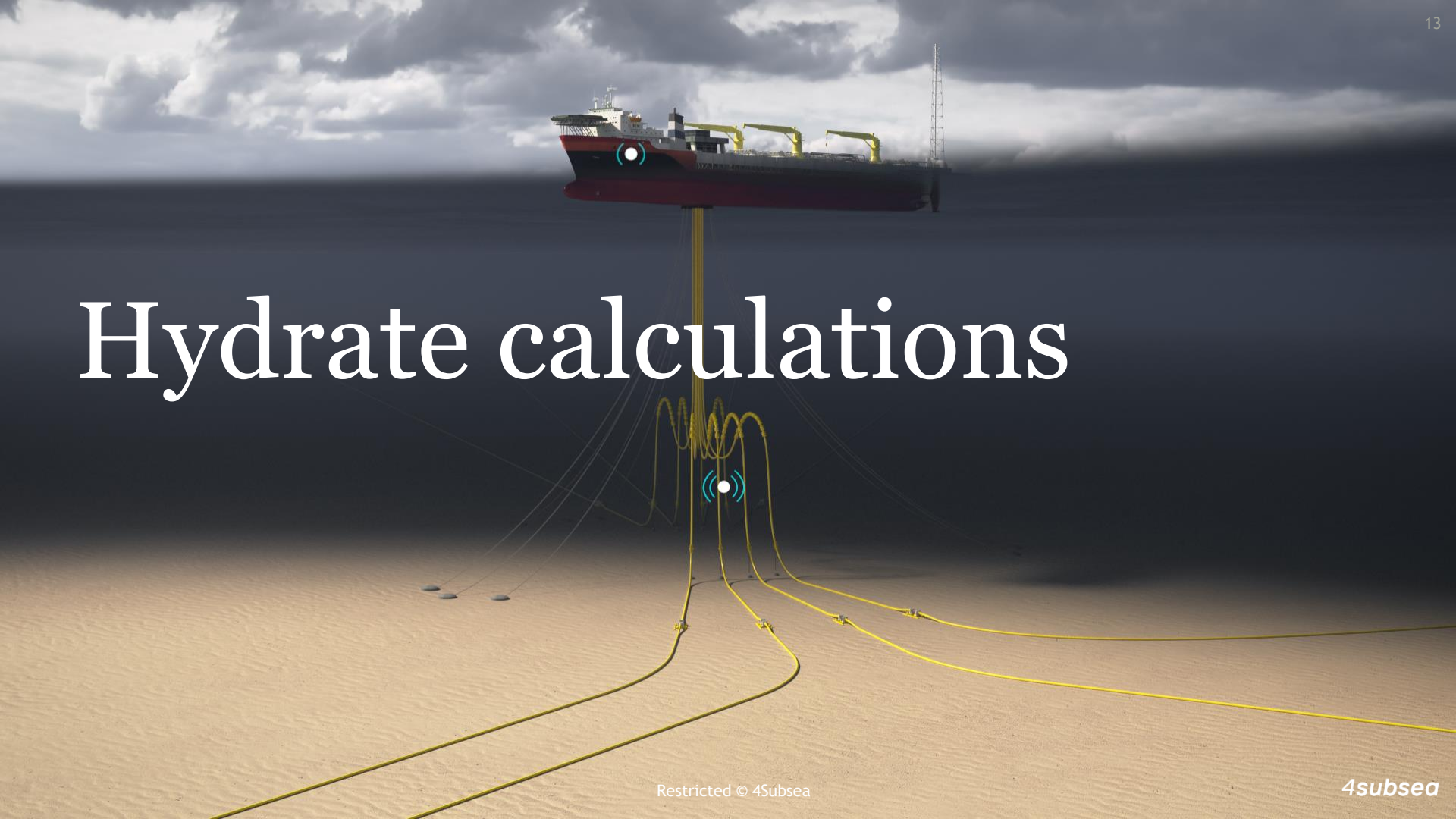
- Observations of oil or wax-like substances discharging from annulus of production risers
- Fluid composition resembles bore crude oil
- Questions raised: Can annulus oil come from permeation of Hydrocarbons from bore?



Permeation of large HC molecules in relevant PE materials

- Postulation: Even large Hydrocarbon molecules exhibit high solubility in Polyethylene materials due to similarity in structure
- Studies include
  - Absorption and desorption properties in different HC fluids
  - Permeation through polymer membranes
  - Condensation of HC molecules permeating from crude oil
  - GC analyses to study composition

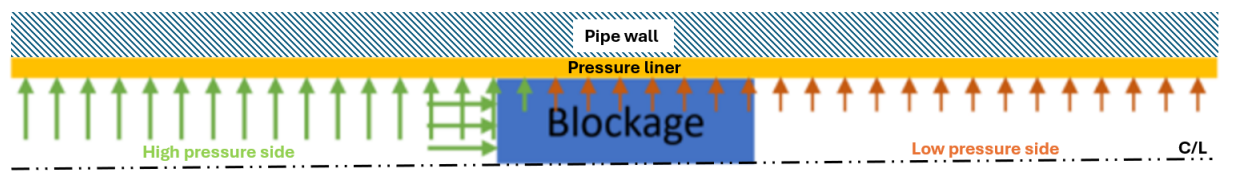




Hydrate calculations

Hydrate related issues

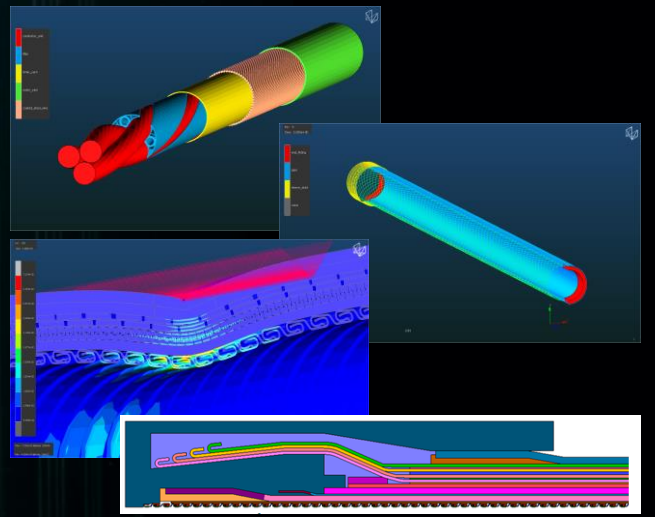
- Hydrates can in worst case create pipe blockage
- Blockage creation – might lead to high Δp which can cause pipe failure
- Blockage removal – common to apply Δp over hydrate to push it out



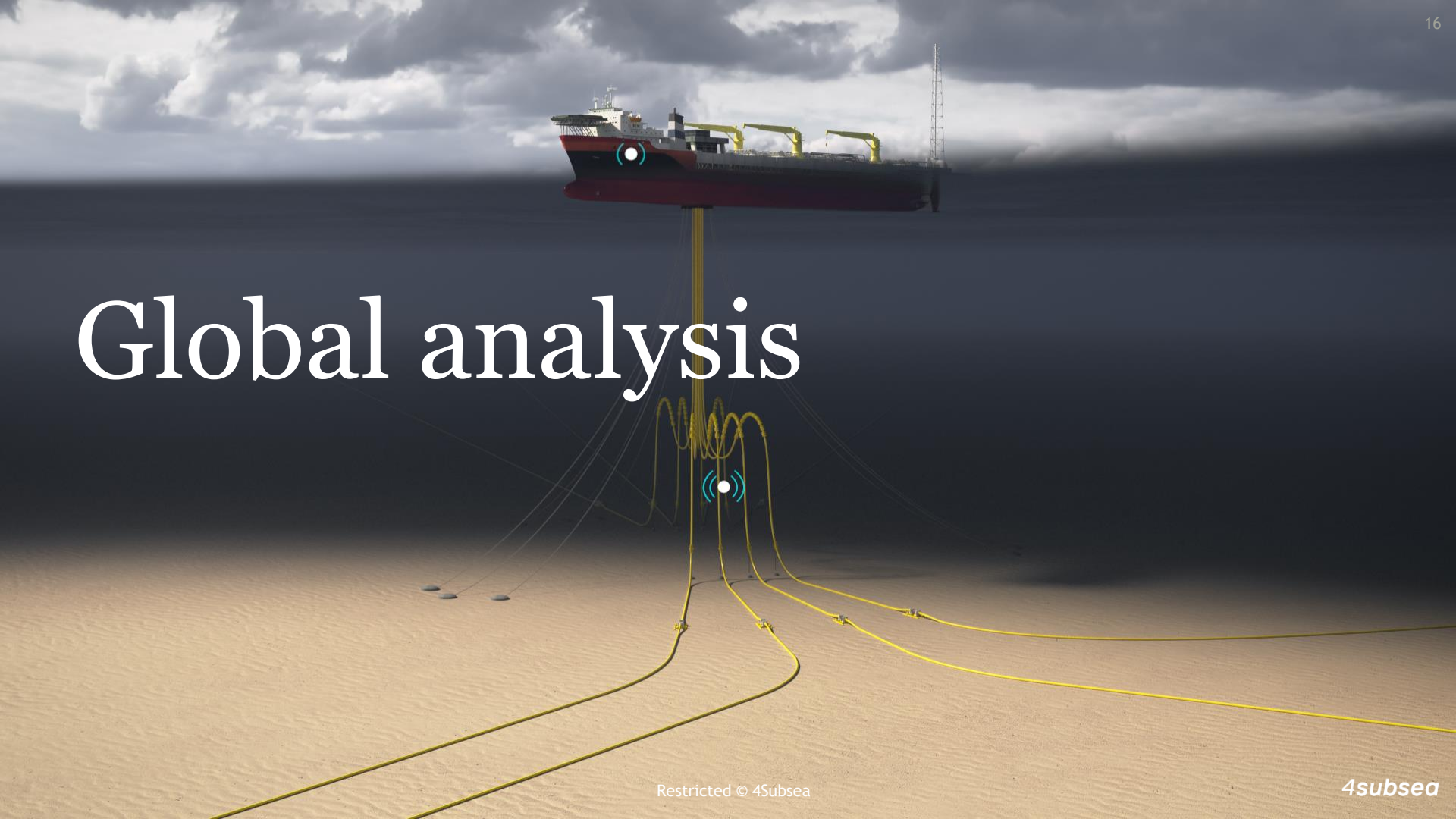
What is the safe differential pressure?

Hydrate calculations

- Simplified method (IOGP)
  - Calculation of axial hydrate capacity
- Advanced method (FEA)
  - More accurate calculation of carcass axial capacity
  - Axial forces acting in carcass and pressure liner due to Δp can be transferred to tensile wire layer by friction between riser layers
  - Local strain effects in pressure liner
  - Carcass locking can occur at large hydrate movement
  - Nub jumping between carcass and pressure liner
  - Polymer material testing / good material property input important

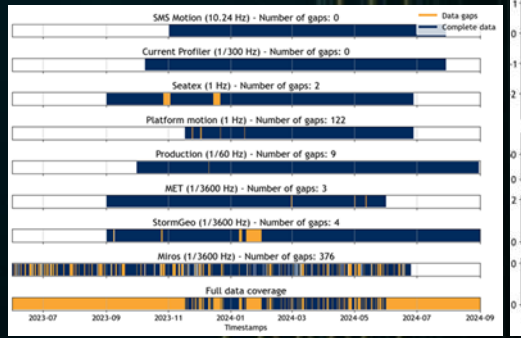


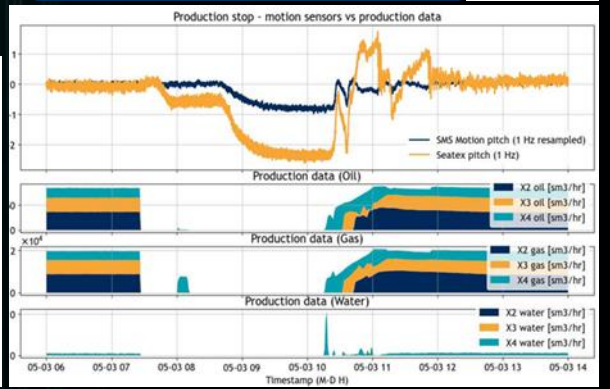
Global analysis



Traditional – Turning unique

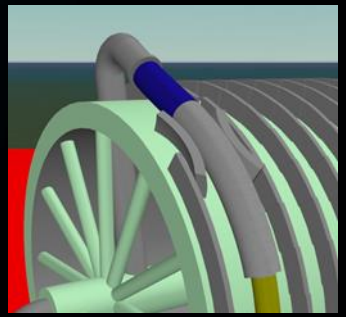
- Design verification / quality assurance
- Need for motion verification – SMS motion sensor
- Need to understand external forces – Current profiler
- 10 months of monitored data, MRU & weather hindcast
- Calibrated OrcaFlex model with accurate responses
- Complex data handling

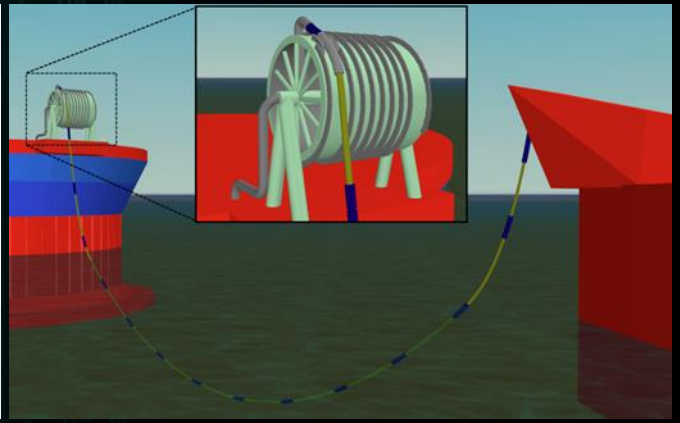




Offloading – hose design & verification

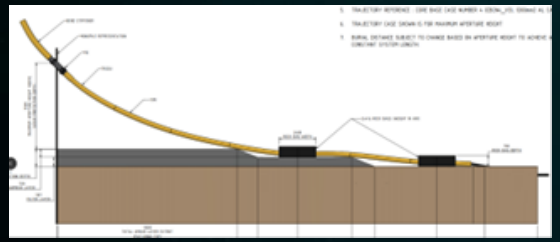
- Struggles related to hose design vs. operational procedure
- Need help understanding & defining actual limitations
- Very detailed OrcaFlex model (reel geometry, hose design)
- Dashboard

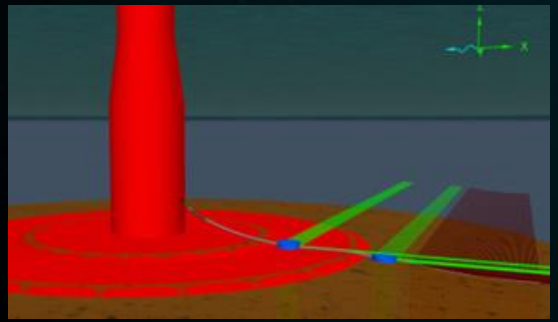




OrcaFlex – Pushing the limits

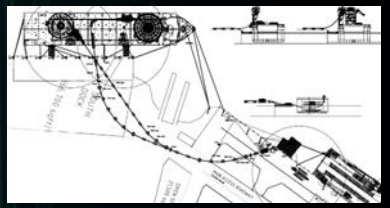
Windfarm cables

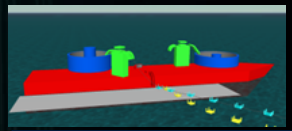


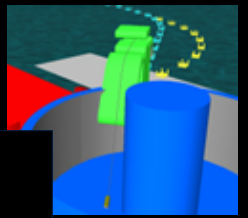


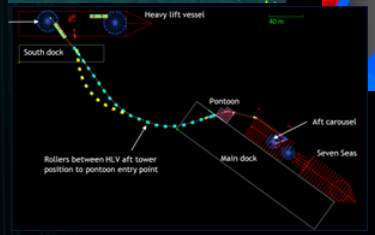
Free span

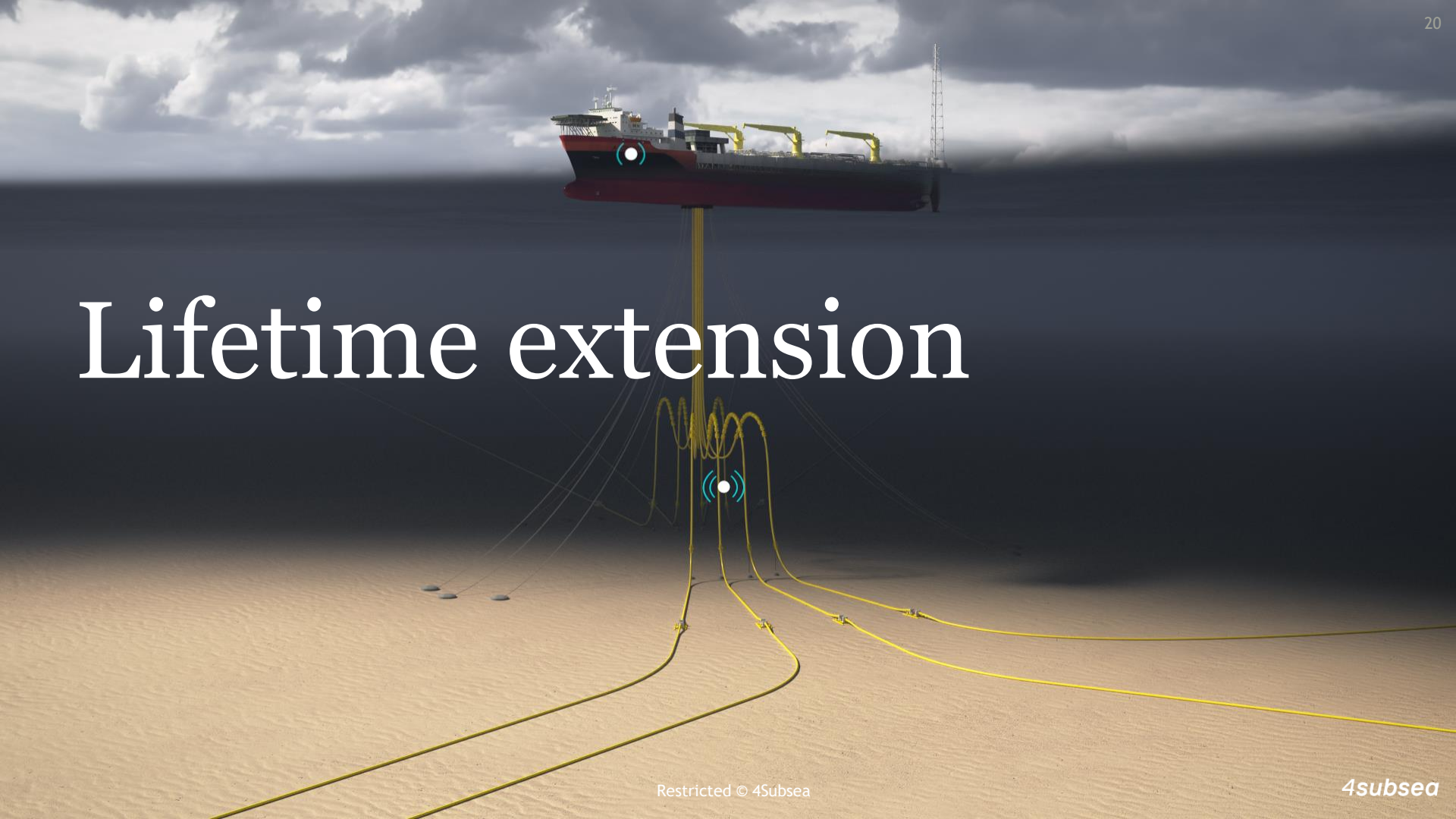
Spooling







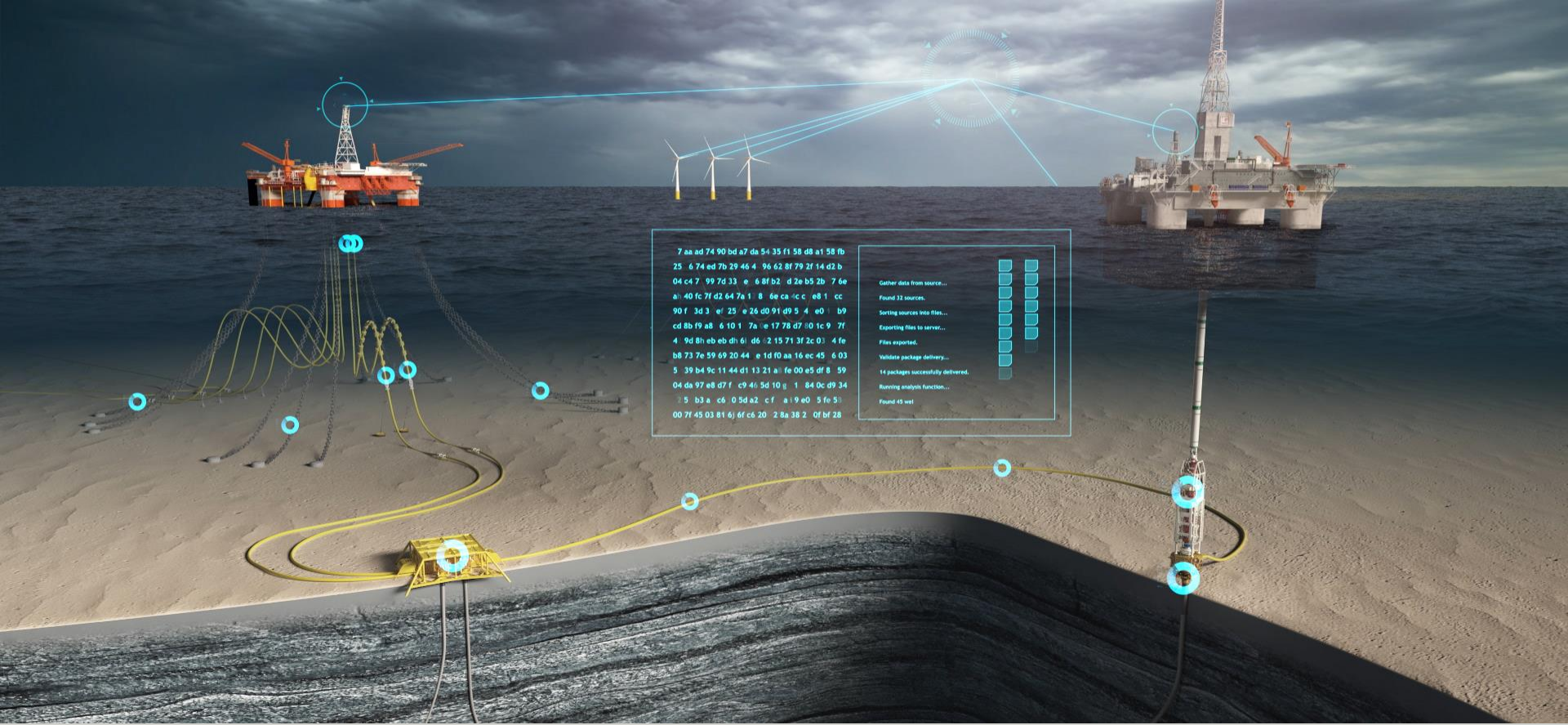




Lifetime extension

Key Takeaways for Operators

1. Life extension (LE) is essential
   - Seen as optional by some
   - Duty of care applies – safety, integrity and risk management
   - Start 2–3 years early – time to plan mitigation
2. Gap analysis: Beyond LE
   - Proactive - uncover hidden risks
   - Periodic (~5 yearly) - improves risk awareness
3. OEM not required for LE
   - Independent specialists assess
   - Flexible and cost-effective
   - Tailored to operator needs



Thank you.

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