FLOATING OFFSHORE WIND CENTRE OF EXCELLENCE | Delivered by CATAPULT Offshore Renewable Energy

Technology Review of Tension-Leg Platform Floating Wind Turbines

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Credit: Equinor Hywind Floating Offshore Wind Farm

AGENDA

- Introduction & objectives
- Project outline
- TLP viability matrix
- Techno-economic analysis
- Findings & Knowledge gaps

INTRODUCTION & OBJECTIVES

Objectives and Focus

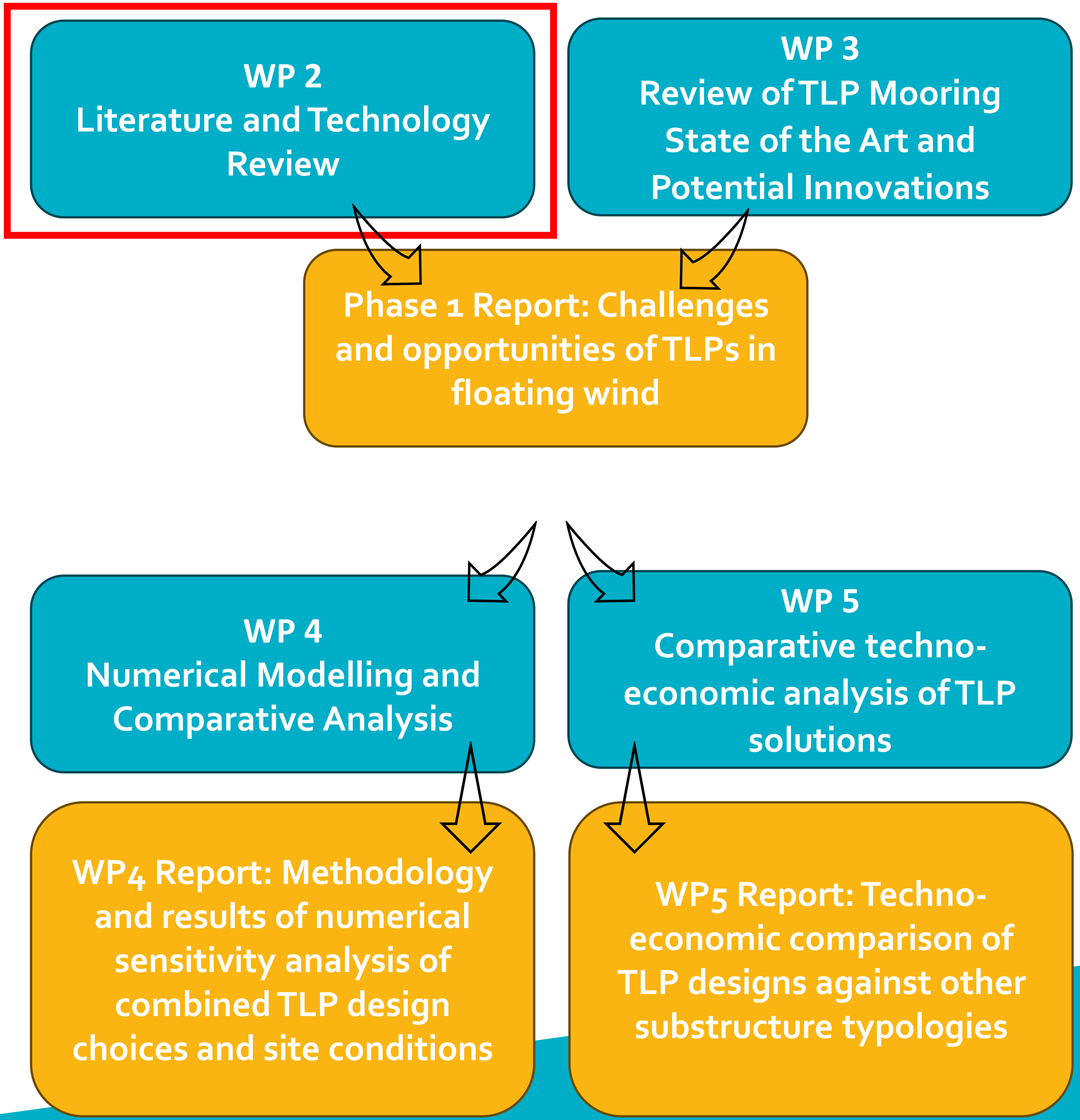
- Explore the offshore wind industry's concerns about TLP Floating Offshore Wind Turbines
- Examine existing literature, designs, and insights from industry partners and stakeholders
- Identify key design drivers, challenges, and favorable conditions for TLP-WTs
- Highlight technologies and developments critical for TLP integration

Key Highlights

- Design Requirements
  - Review existing research and standards
  - Outline stability requirements for towing configurations
- Lifecycle Analysis
  - Insights on consenting, insurance, installation, and decommissioning
  - Opportunities for local supply chains in TLP manufacturing
- Mooring and Anchoring Solutions
  - Evaluation of synthetic cables, inclined tendons, and load reduction devices
  - Representative Bills of Materials for TLP systems
- Innovative Solutions
  - Cutting-edge approaches to substructure, mooring, and anchoring.

PROJECT OUTLINE

- **Literature and Technology Review, Mooring Requirements, Challenges and Opportunities**
  - Design requirements for TLPs at high level
  - Focus on sensitivity to environmental conditions
  - Installation and major component exchange considerations
- **Review of TLP Mooring State of the Art and Potential Innovations**
  - Novel anchor solutions, changes to installation processes, synthetic cables, inclined tendons
  - Representative and novel Bills of Materials for TLP M&A systems
  - Hardware and installation cost assessment of a TLP mooring system will be carried out



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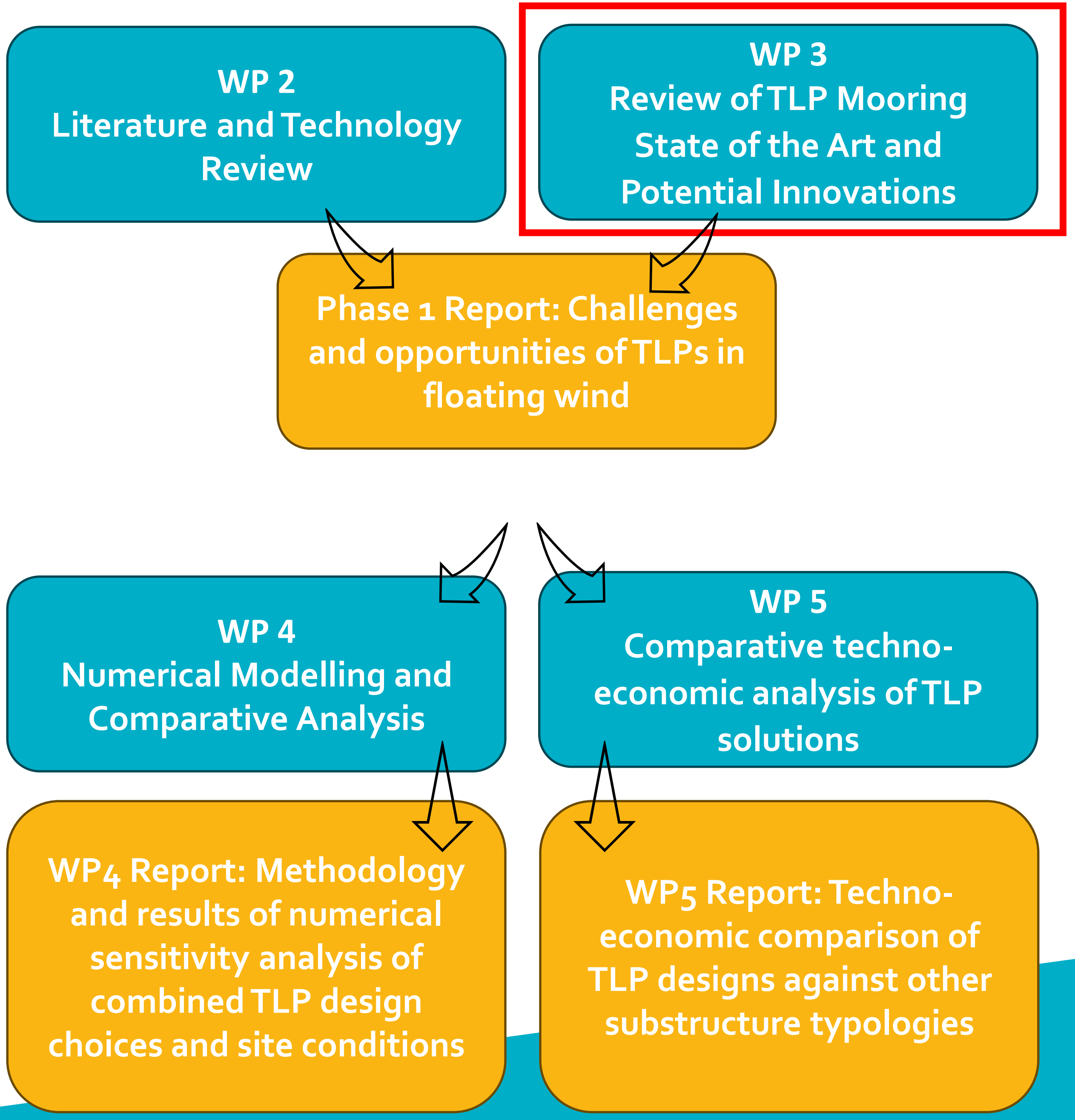
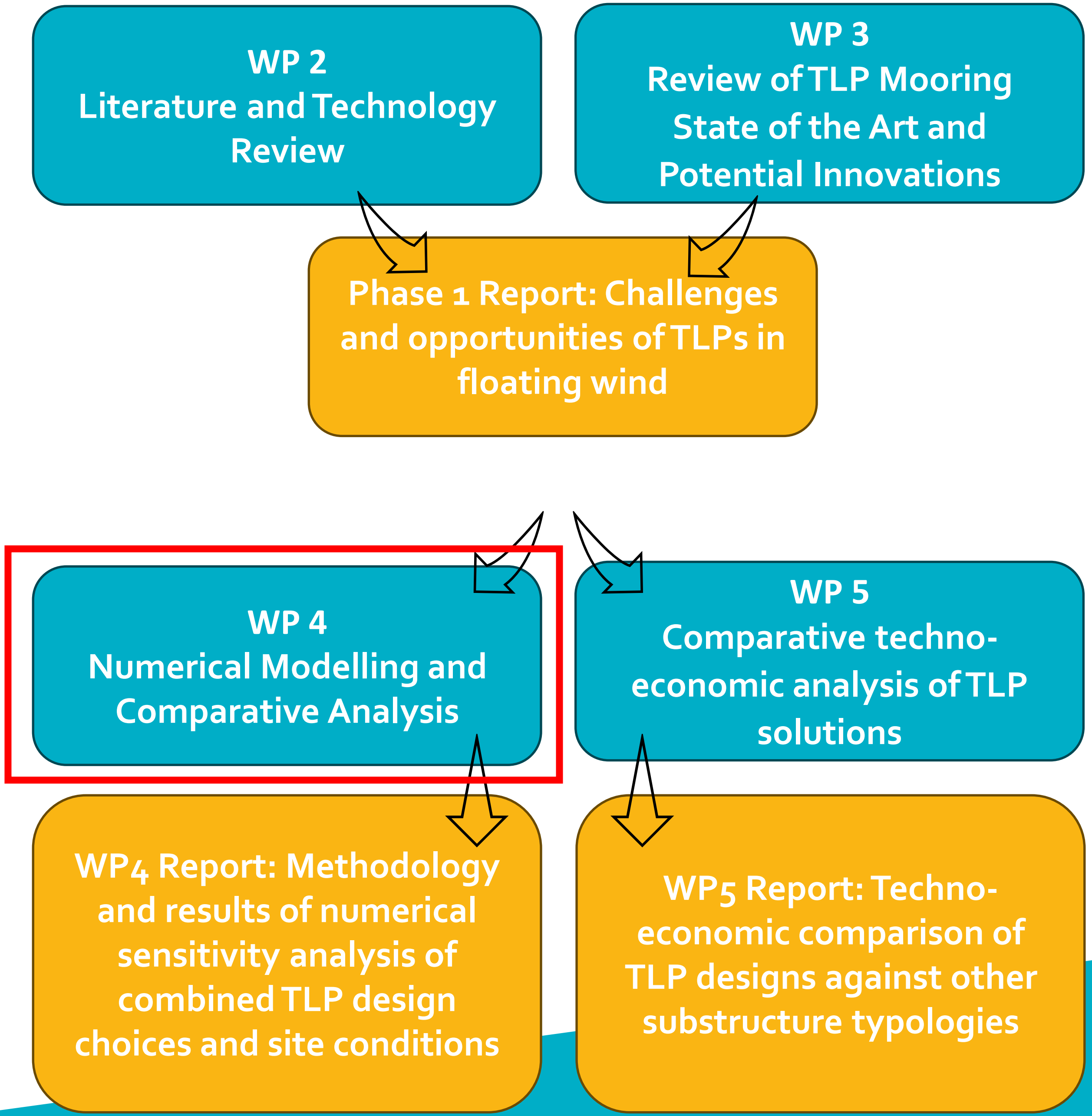


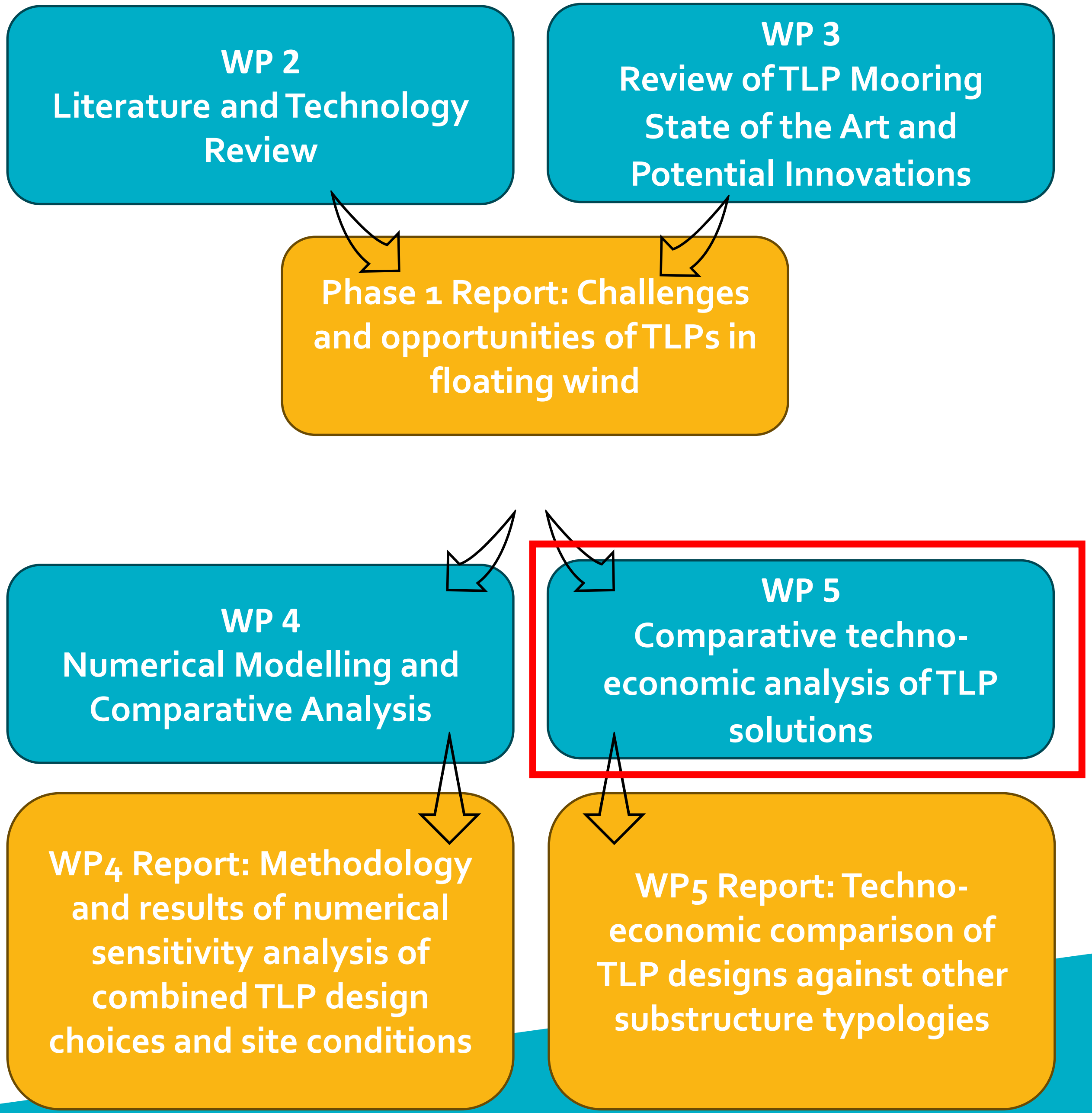
PROJECT OUTLINE

- **Numerical Modelling and Comparative Analysis**
  - Evaluated TLP performance under different load cases and site conditions.
  - Two OEMs with 15+ years of TLP design experience contributed 14 scenario-specific designs, including substructure, tower, and tendon configurations
  - Covered multiple tetrahedral and single-column TLP substructure geometries
  - Varying water depths, tidal ranges, and offshore site energy exposure (benign and severe) to create a comprehensive suitability matrix for TLP wind turbine technology



PROJECT OUTLINE

- **Techno-economic analysis of TLP solutions**
  - Weighing self-stable TLP substructures against additional support options like barges or buoyant elements.
  - Comparing self-stable and hydrostatically unstable platforms to evaluate feasibility.
  - Providing insights to inform decision-making on optimal TLP towing configurations.



TLP VIABILITY

- Delivered by ORE Catapult with support from two OEMs specializing in TLP applications for floating offshore wind
  - Marine Power Systems (MPS) and PelaStar, each with ~15 years of experience in offshore renewable energy systems
  - MPS focuses on tetrahedral TLP platforms
  - PelaStar contributed two single-column TLP designs, featuring three and five tendon legs
- Both OEMs supplied versions of their TLP-WT designs for the study
- Designs focussed on extreme loading
  - DLCs 1.6 and 6.1, ad additionally 6.6 and 7.2 for redundancy and robustness

Examples of shallow-draught, tetrahedral TLP design (MPS PelaFlex, left) and deep-draught, single column TLP design (PelaStar, right)

TLP VIABILITY

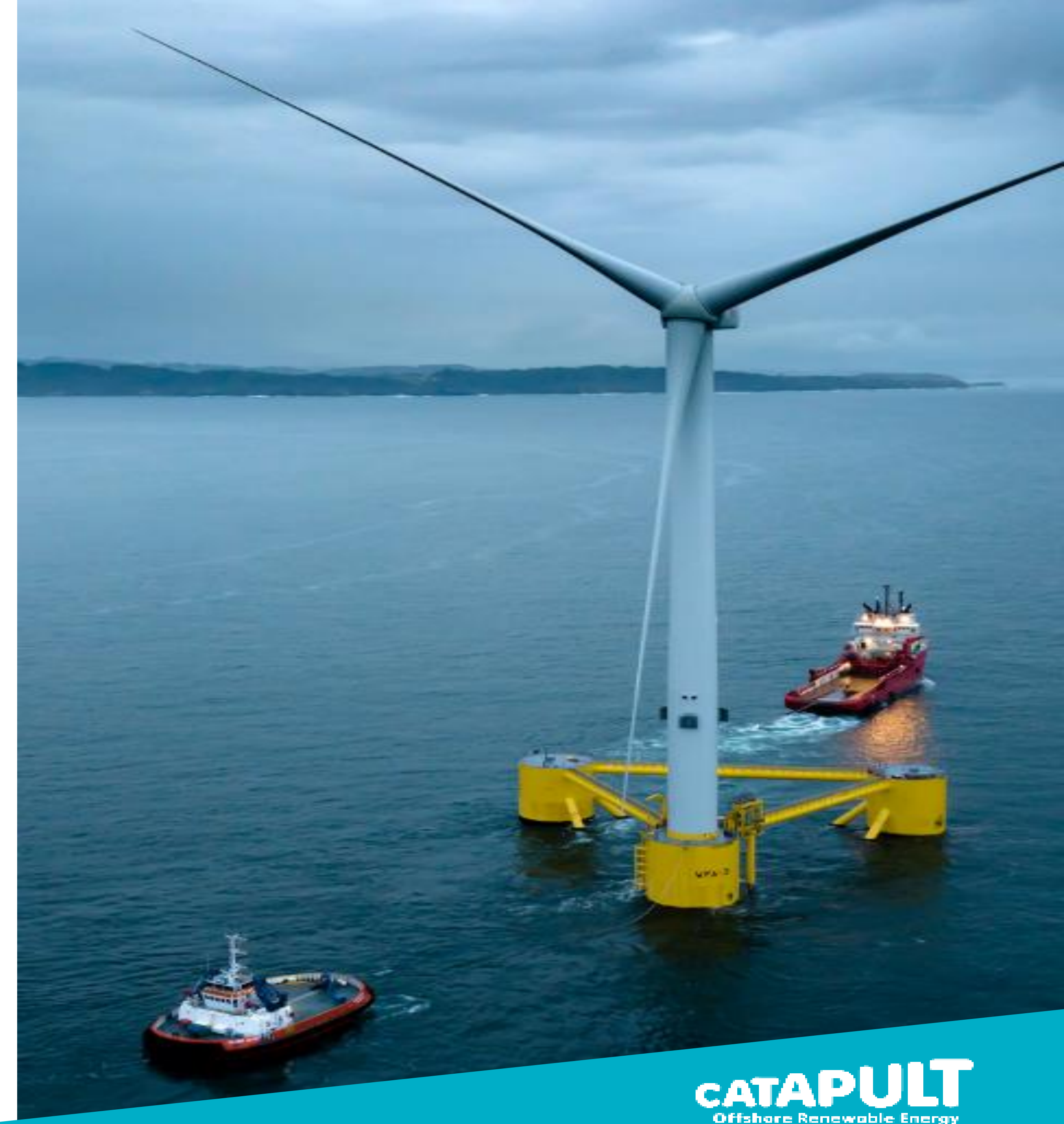
Design	Substructure concept	Design tailored to water depth	Design tailored to site conditions	# Legs & Tendons
1	Tetrahedral (MPS)	Shallow (70m)	Benign	L3
2	Tetrahedral (MPS)	Shallow (70m)	Exposed	L3
3	Tetrahedral (MPS)	Intermediate (150m)	Benign	L3
4	Tetrahedral (MPS)	Intermediate (150m)	Exposed	L3
5	3-Leg Single column (PelaStar)	Shallow (70m)	Benign	L3 & T6
6	3-Leg Single column (PelaStar)	Intermediate (150m)	Benign	L3 & T6
7	3-Leg Single column (PelaStar)	Intermediate (150m)	Exposed	L3 & T6
8	3-Leg Single column (PelaStar)	Ultra-deep (900m)	Benign	L3 & T6
9	3-Leg Single column (PelaStar)	Ultra-deep (900m)	Exposed	L3 & T6
10	5-Leg Single column (PelaStar)	Shallow (70m)	Benign	L5 & T5
11	5-Leg Single column (PelaStar)	Intermediate (150m)	Benign	L5 & T5
12	5-Leg Single column (PelaStar)	Intermediate (150m)	Exposed	L5 & T5
13	5-Leg Single column (PelaStar)	Ultra-deep (900m)	Benign	L5 & T5
14	5-Leg Single column (PelaStar)	Ultra-deep (900m)	Exposed	L5 & T5

TLP VIABILITY

	Units	Based on DLC 1.6 (operational turbine)		Based on DLC 6.1 (idling turbine)	
		Benign	Exposed	Benign	Exposed
Hs	m	7.5	9.9	7.6	13.3
Peak Wave Period (Tp)	s	9.7	11.1	9.8	12.9
Gamma	./.	5.0	5.0	5.0	5.0
Wave directions	°	120 & 180	120 & 180	120 & 180	120 & 180
Max surface level (from MWL)	m	+0.50	+3.40	+0.50	+3.40
Min surface level (from MWL)	m	-0.50	-3.50	-0.50	-3.50
Reference Current Speed	m/s	0.15	0.14	1.0	1.0
$U_0(3600, 10)$ **Wind Speed (1hr @ 10m above MWL)**	m/s	7.93	8.02	21.3	36.39
Turbulence intensity value	./.	0.077	0.079	0.116	0.145

TECHNO-ECONOMIC ANALYSIS

- Stakeholders engagement, including the supply chain, industry and project partners, to inform the cost model's assumptions:
  - Bottom-up cost modelling: stakeholder engagement with supply chain and industry
  - Top-down cost modelling: stakeholder engagement with project developers
- Identify and assess the cost drivers and their impact on LCOE
- Employ a cash flow model to output LCOE in 2012 and 2024 prices along with other financial metrics.



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Credit: Principle Power

TECHNO-ECONOMIC ANALYSIS

Platform designs considered:

i. Tetrahedral TLP Non self-stable

ii. Single Column TLP Self-stable in towing

iii. Single Column TLP Non self-stable

iv. Semi-submersible

Each platform is considered in a severe site in the UK utilising, 7 x 15 MW turbines

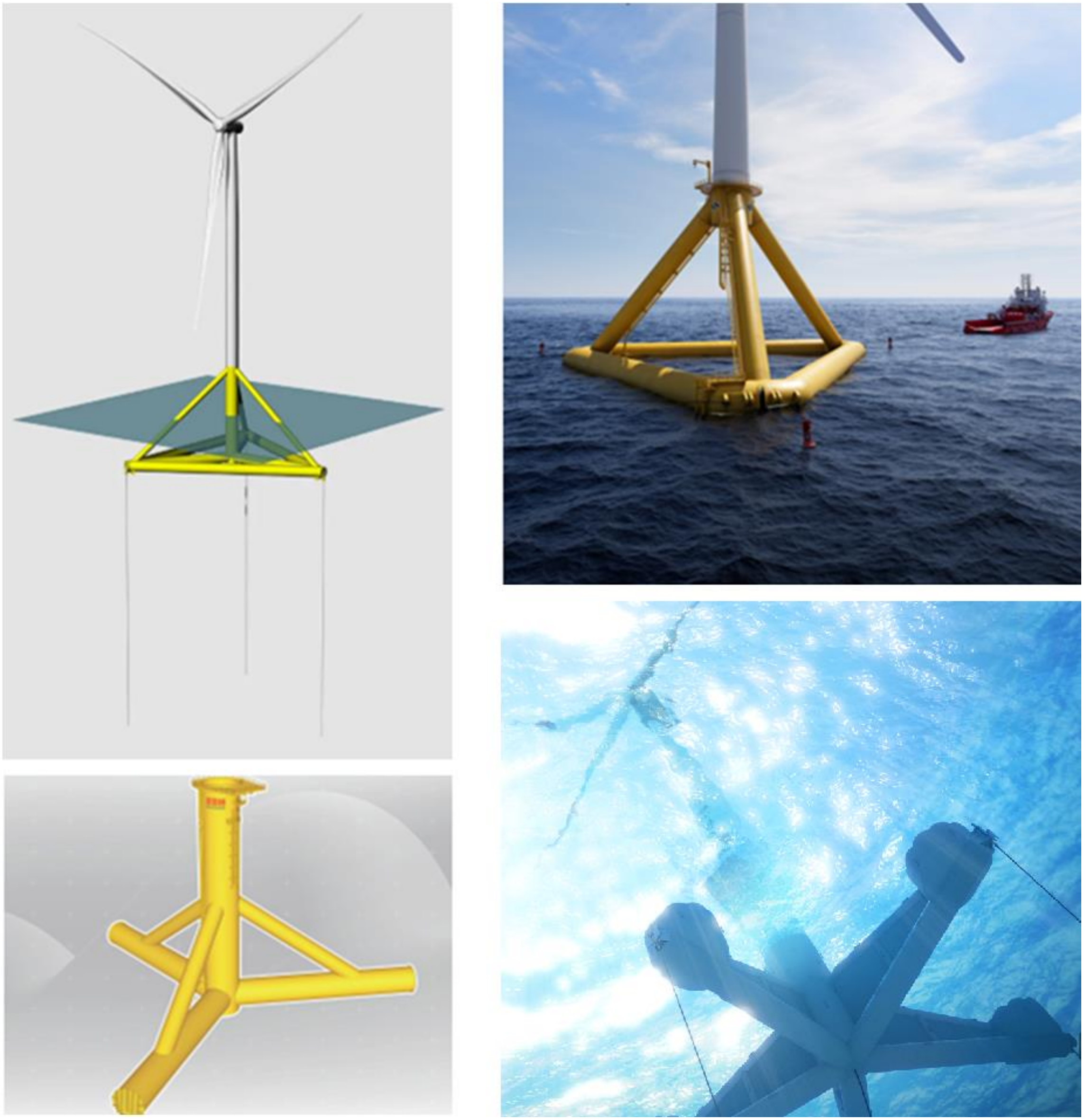
Sensitivity studies

- Water depth, shallow, intermediate and deep
- Varying distance to shore
- Varying failure rates

- Cable cost savings
- Lower mass lower platform cost
- Better power production
- Installation savings
- Intermediate water depths looks like the best option

FINDINGS

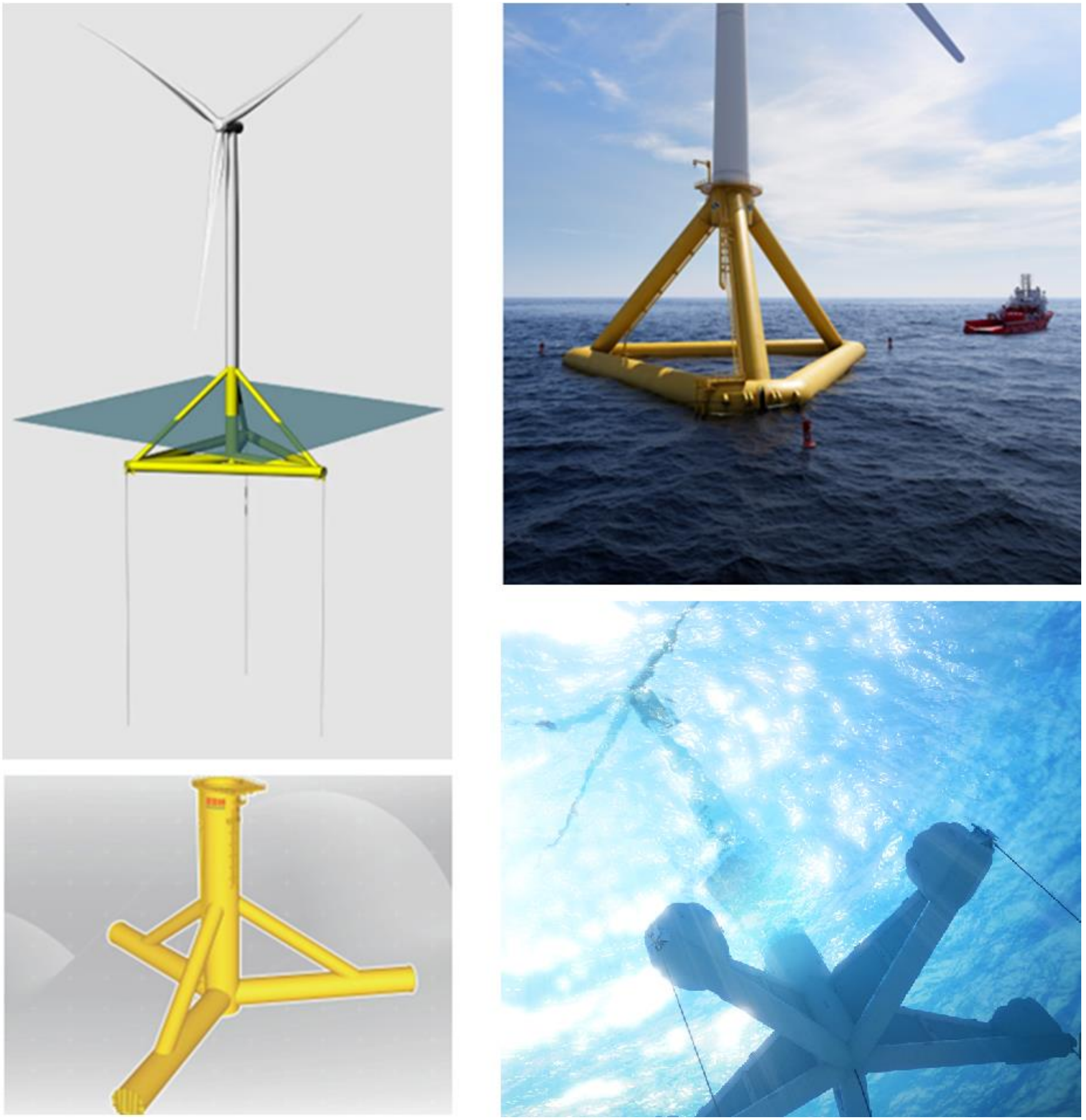
- Strengths and Benefits of TLP Technology
  - Limited motion responses
  - Dynamic behavior control through mooring design
  - Constant power control
  - Reduced substructure size
  - Lighter mooring lines & reduced footprint
- Development Challenges
  - Lower towing stability (solutions available)
  - Complexities in mooring and anchoring
- Development Priorities
  - Modular substructure design
  - Advancements in mooring geometry and materials
  - Clear operational processes
  - Hook-up process identified as an area of uncertainty



Examples of commercial TLP design solutions. From top left, clockwise: Stiesdal TetraTLP, MPS PelaFlex, PelaStar, SBM Float4Wind

FINDINGS

- Innovations in Mooring Tendons
  - Recommended leveraging advanced materials with enhanced strength profiles and fatigue resistance
  - Integration with quick-connection components ensures efficient compatibility with anchors and substructures
- Advancements in Anchor Technology
  - Choice of anchors benefits from quick-connection interfaces, streamlining the installation process
  - Innovative anchors expected to offer significant reductions in material and installation costs



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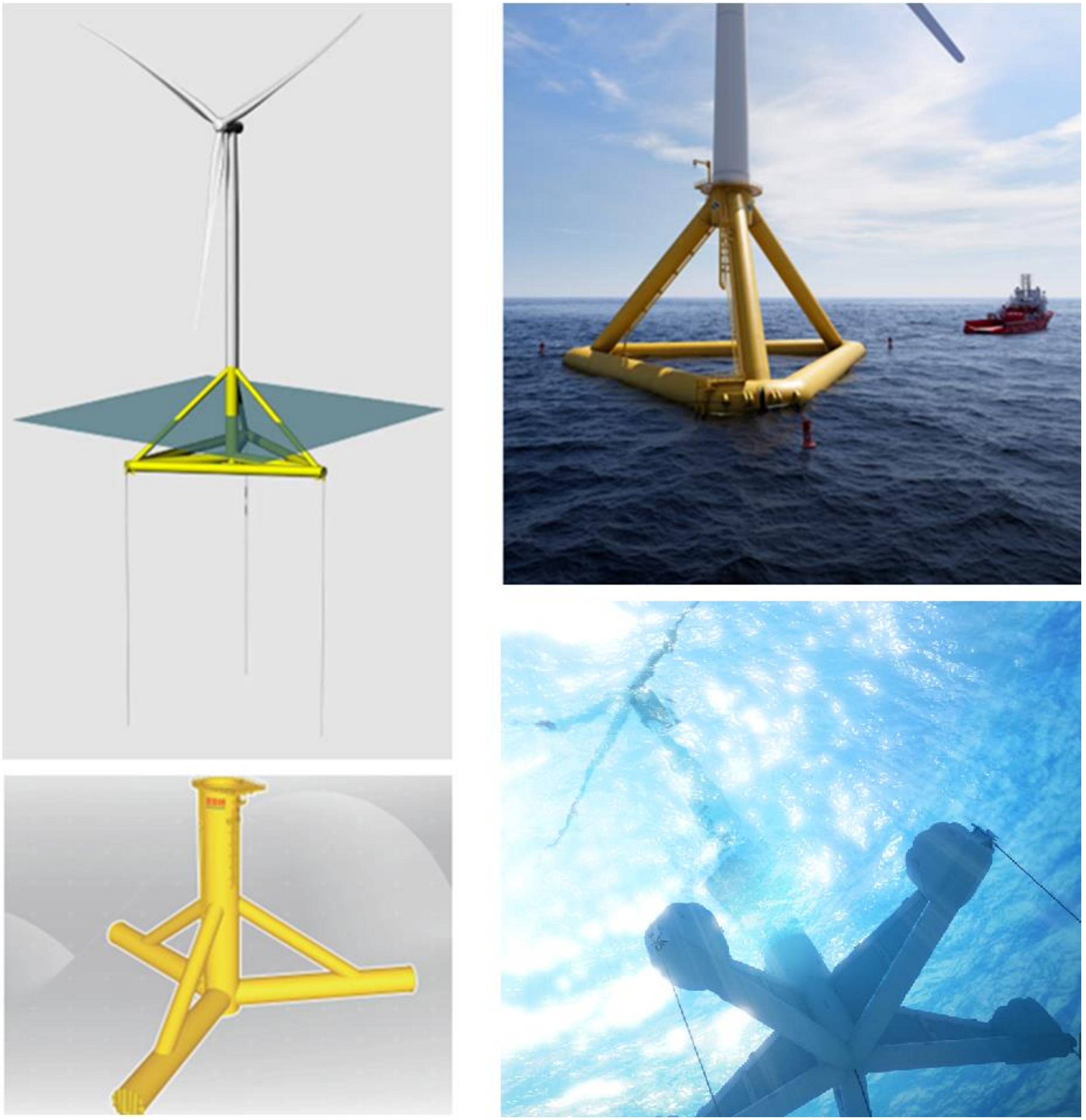
KNOWLEDGE GAPS

- Uncertainty in TLP-WT Substructures
  - Uncertainty in expected size and mass of TLP-WT substructures
  - Conflicting opinions within the industry, reliance on academic research, and challenges aligning theoretical models with practical requirements
- Economic Considerations for TLPs
  - TLPs face cost challenges in the demonstration phase
  - Show potential for economies of scale due to inherent performance and weight advantages
- Gaps in Standards for Floating Offshore Wind
  - Geotechnical anchor design, concrete design requirements, commissioning and decom phases
  - Procedures for applying global performance analysis to local structural checks



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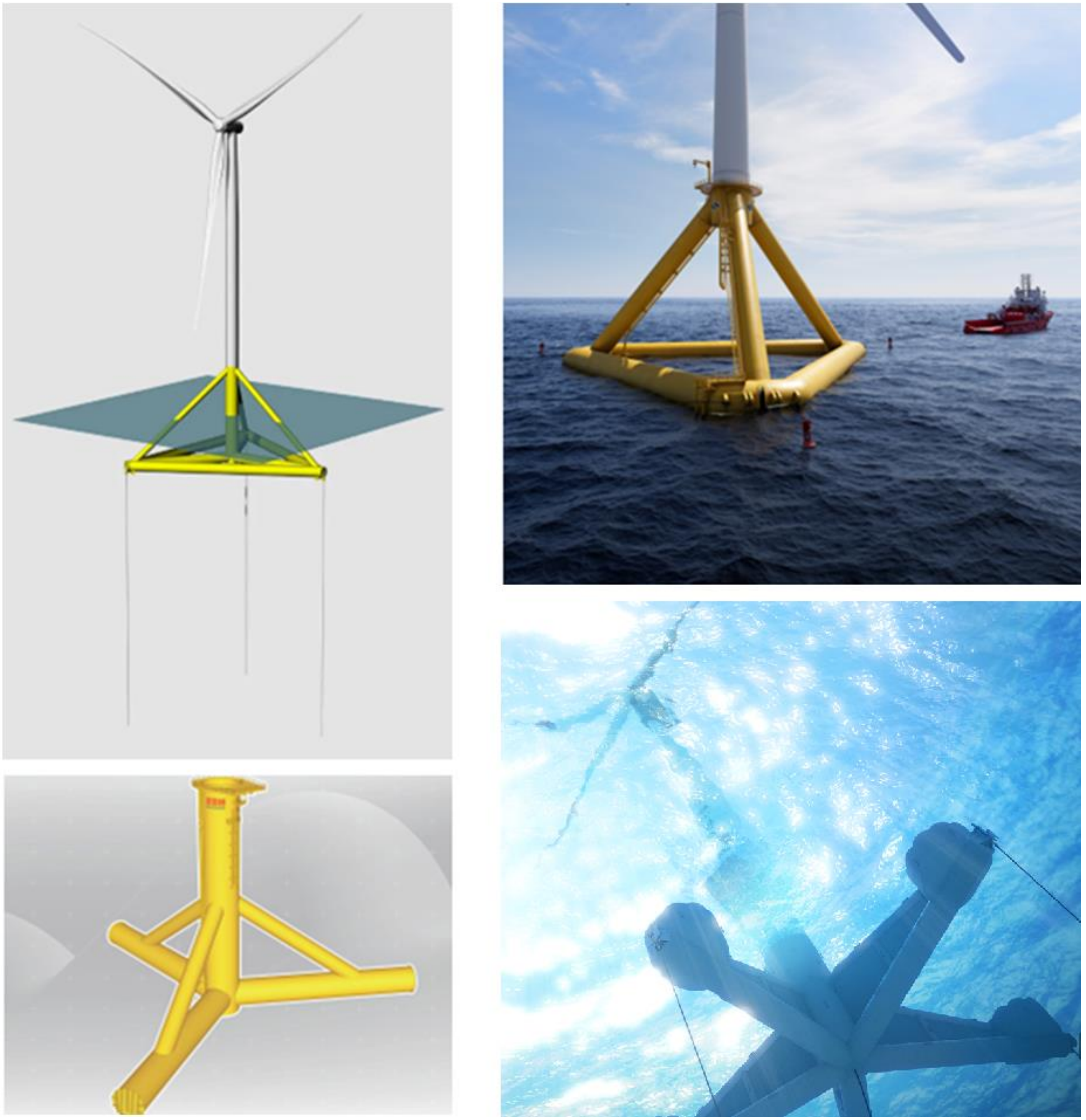
KNOWLEDGE GAPS

- Vessel Selection for Deep Water Maintenance
  - Vessel selection for in-situ maintenance in deep water sites remains relatively unexplored
  - Approaches for deep water scenarios have been considered, but detailed methodologies for different design types and water depths need clarification
  - Alternative technologies being developed for installations and in-situ maintenance
- TLP-WT Loading Patterns and Station-Keeping
  - Gap in expected loading patterns for next-gen TLP-WTs, including pre-tension and maximum loading
  - Stiffness properties of tendons, installation methodologies for innovative anchors, and research into Load Reduction Devices for TLPs are also lacking



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