5th Annual Offshore Wind O&M Forum

Case Study

Operations & IMR: The WindFloat Way

Clara de Moura Santos

Commercial & Strategy Manager

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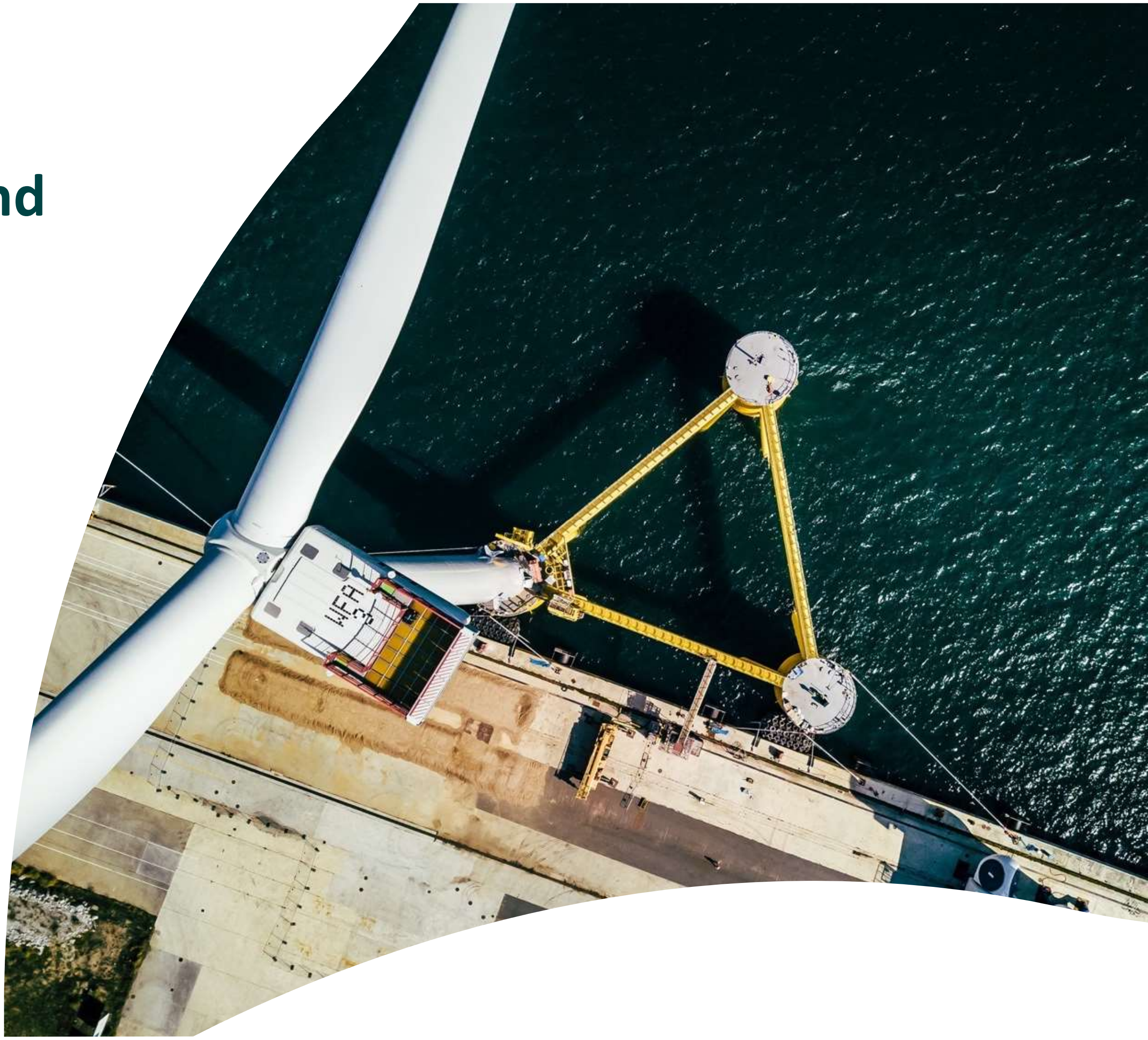
Principle Power | Globalizing floating wind



Agenda

1. Principle Power Company Introduction
2. Drivers for LCOE cost reduction – the OPEX role
3. The WindFloat way: repair offshore, replace onshore
4. The importance of a lifestyle approach to cost and risk management
5. Digital innovation: the next step for a full farm optimization

Principle Power Company introduction

Principle Power: Globalizing floating wind

Founded in 2007, Principle Power has grown to be a global leader in the floating offshore wind industry

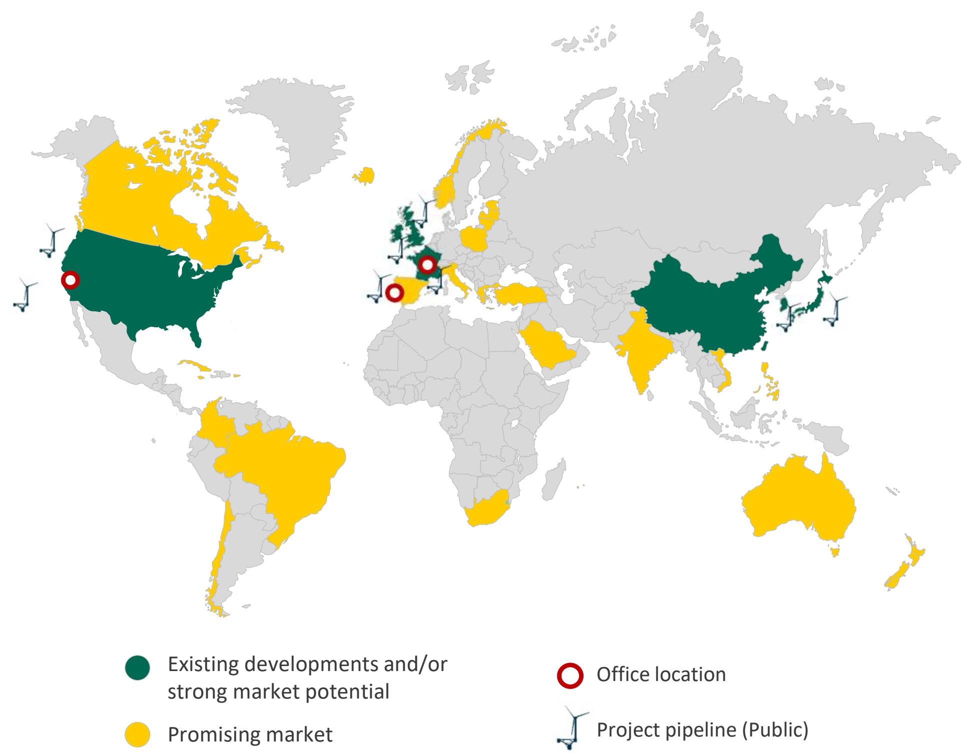
Headquarters in California with offices in Portugal and France and 90 employees with 20 different nationalities

Backed by global energy and utility leaders and involved in partnerships with influential industry players

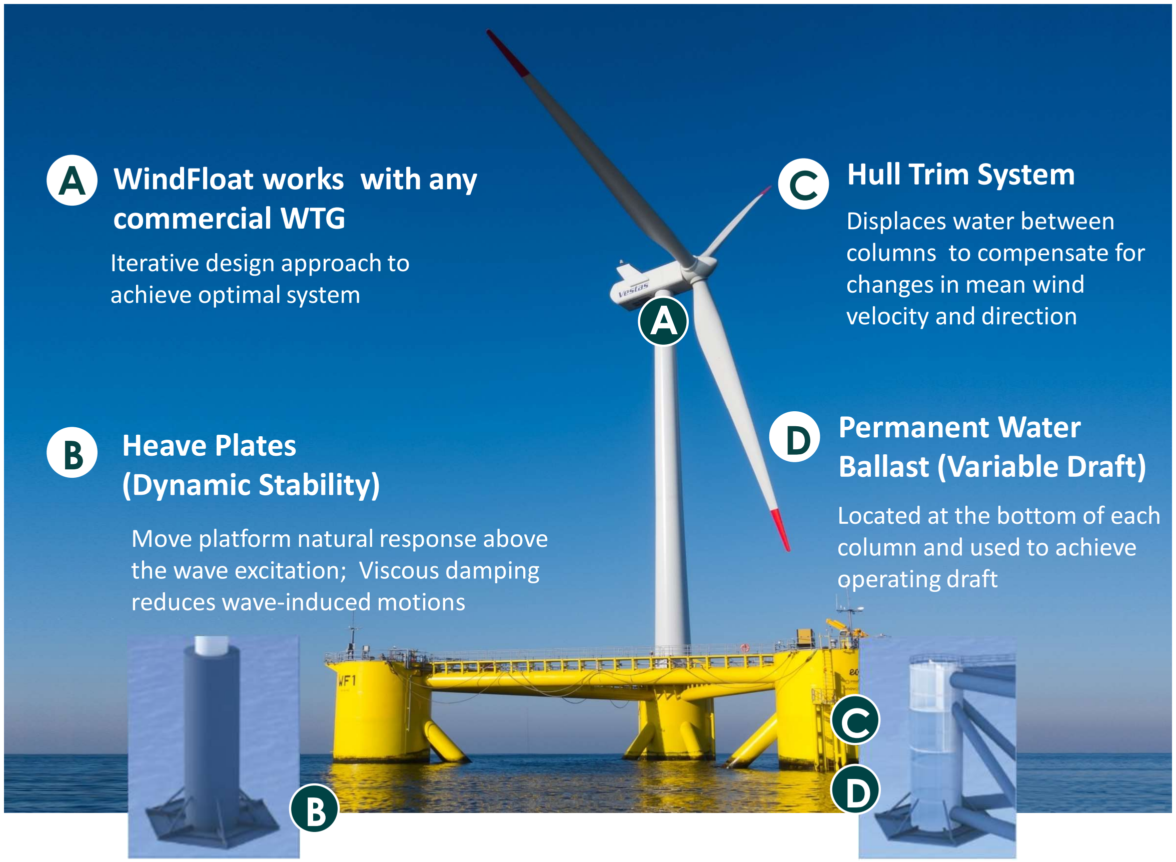
Globally patented and proven floating platform technology that under deployment in precommercial projects totaling 105 MW

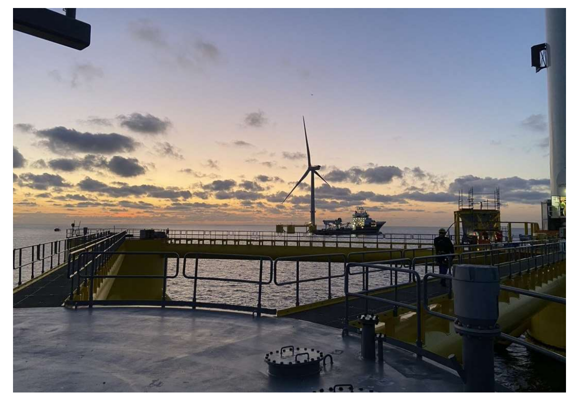
Important global project pipeline secured & serving clients in all key floating offshore wind markets

principlepowerinc.com



Our solution – the WindFloat® floating foundation





Principle Power provides full support to customers to optimally implement the WindFloat Technology across the entire lifecycle

Activity across the entire value chain

Project phase	Project development		Construction	Operations
Service Model	**Project co-origination** Applied expertise to assist developers in structuring early stage opportunities	**Design Engineering Owner's Engineering** Services to adapt WindFloat for client requirements Logistics & O&M simulation	**Technology licensing** License Principle Power IP Portfolio for exploitation within the project	**Operations & maintenance support services** Service and Maintenance Agreement

Customers

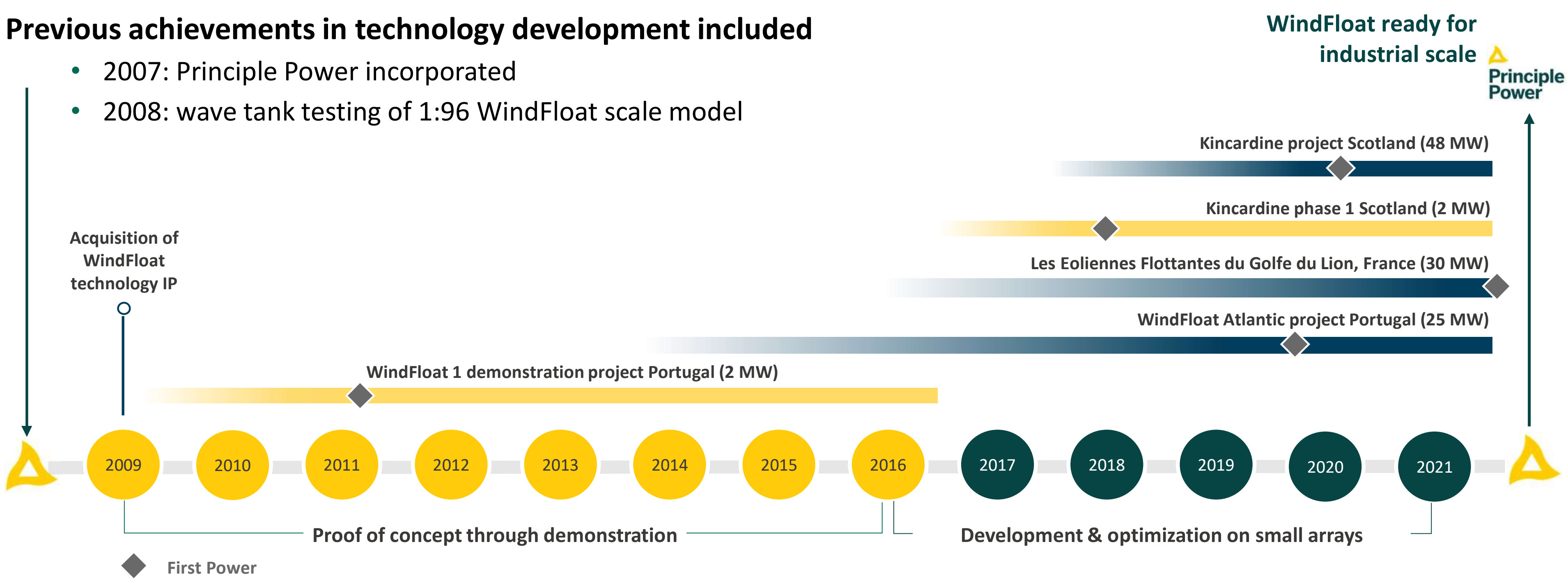
- **Project developers:** progression energy, Aker Offshore Wind, Simply Blue Energy
- **Utilities & Majors:** OW Ocean Winds, Shell, Total
- **Contractors:** Aker Solutions, Eiffage, cobra
- **Offshore wind owners:** Repsol, ACS

Principle Power has already contracted across the entire value chain from co-development to operations

Successful company history taking a step-by-step approach to commercialization

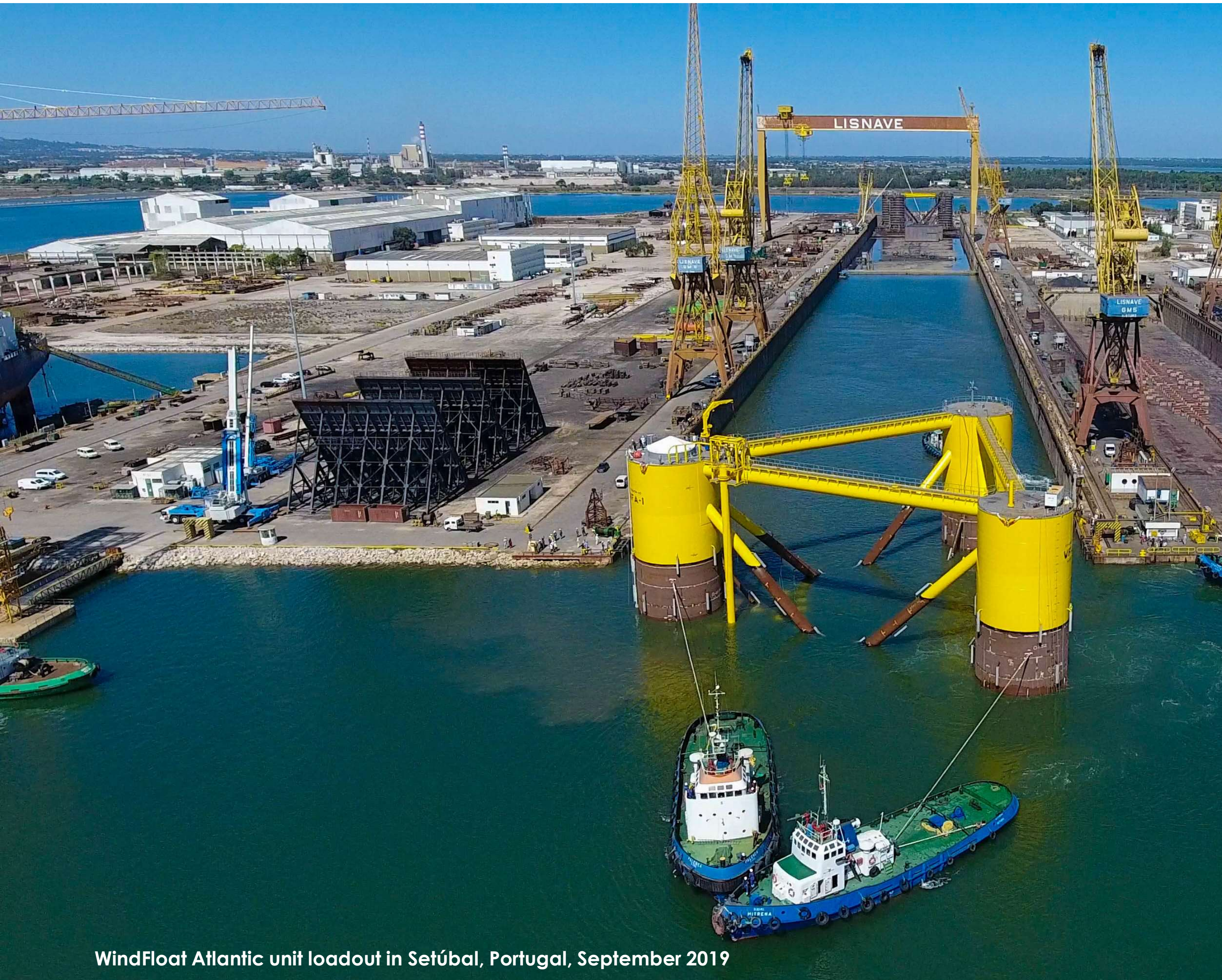
Previous achievements in technology development included

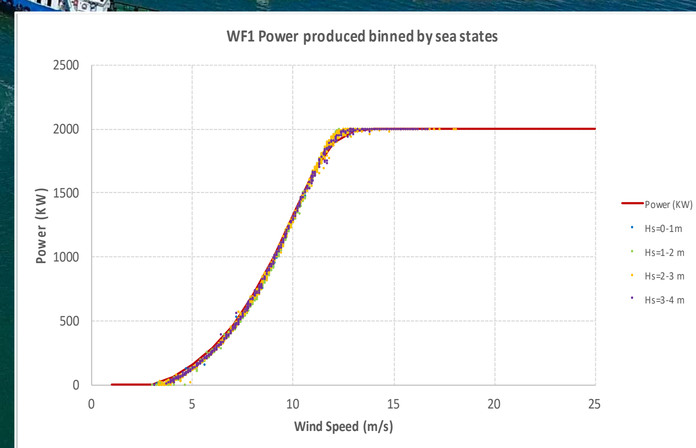
- 2007: Principle Power incorporated
- 2008: wave tank testing of 1:96 WindFloat scale model



The route to commercial floating wind:

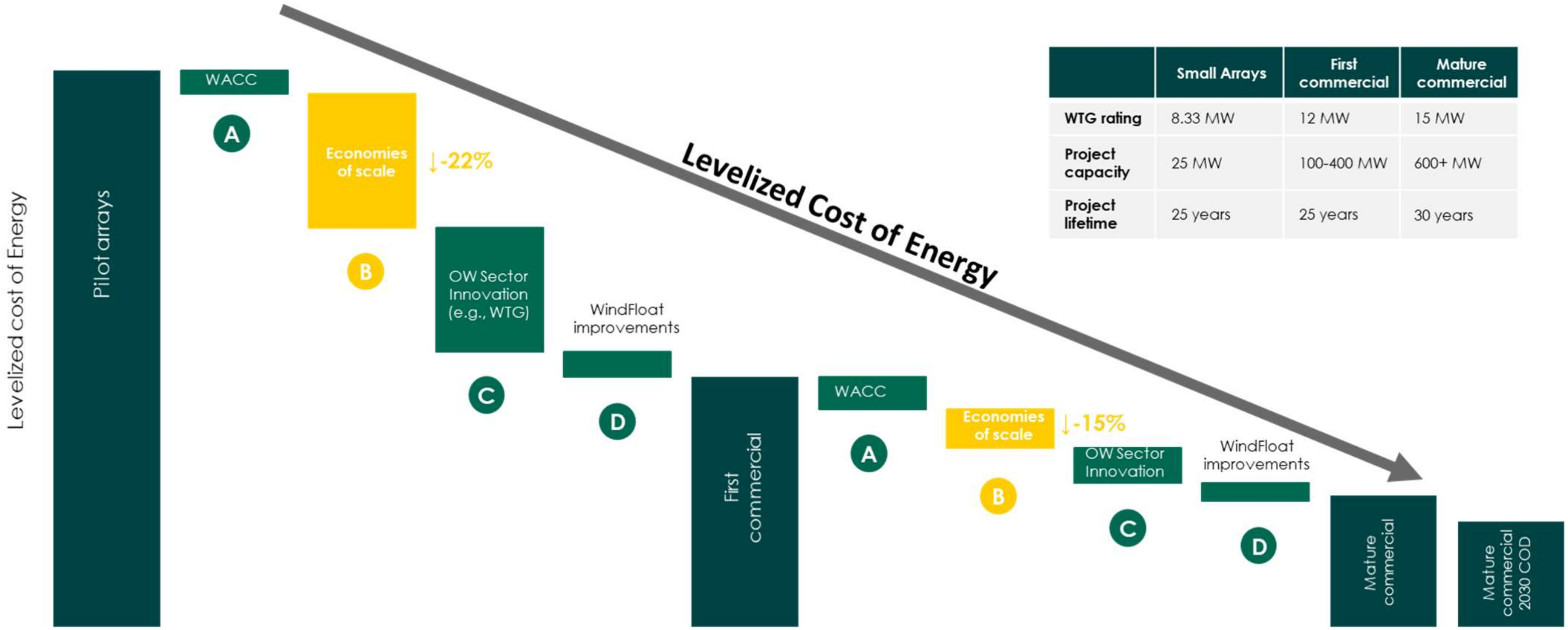
- Survivability
- Bankability
- Industrialisation





WindFloat Atlantic unit loadout in Setúbal, Portugal, September 2019

OPEX has an important role to play in reducing Floating Offshore Wind LCOE with main drivers economies of scale, increasing WTG size, and innovation



	Small Arrays	First commercial	Mature commercial
WTG rating	8.33 MW	12 MW	15 MW
Project capacity	25 MW	100-400 MW	600+ MW
Project lifetime	25 years	25 years	30 years

Timing depends on political and regulatory conditions enabling such projects (e.g., site control, permitting, and offtake support)

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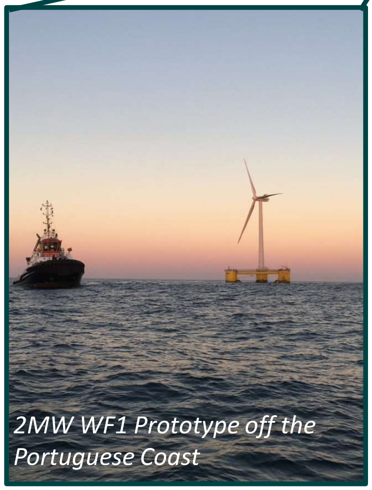
3 Phases of Floating Offshore Wind Industry Maturity



2MW WF1 Prototype off the Portuguese Coast

DOES IT WORK?

CAN WE BUILD IT?

25MW WFA Project off the Coast of Viana do Castelo, Portugal

CAN WE MAINTAIN IT?

WTG being installed with Saipem Norway.
Courtesy: Siemens Gamesa

Or

Quay Assembly of WFA WTG with Onshore Crane, Spain
Courtesy: Principle Power

The WindFloat way

Repair offshore, replace onshore

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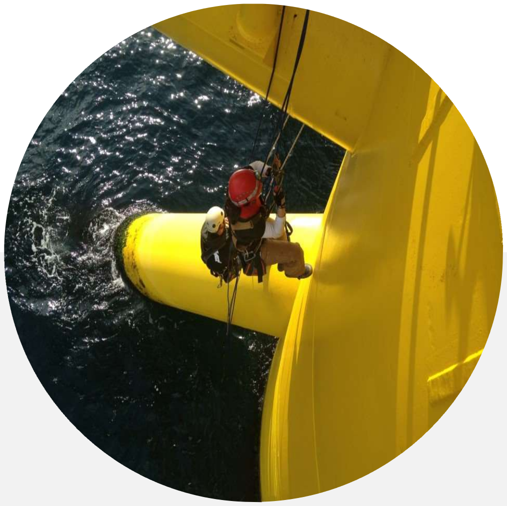
Principle Power Ops. & IMR Principles



Safety

Skills

Performance

Scheduled inspections & maintenance carried out at the offshore site, in a similar manner as for fixed-bottom offshore wind farms

WindFloat increases Production while Minimizing OPEX

Enhanced Performance

- Excellent motion performance
- Enhanced design using hull trim system to boost performance and improve throughout lifetime

Optimal accessibility

- Standard vessels (CTV and/or SOV)
- High platform stability means no change in access criteria relative to fixed-bottom wind

Flexible access methods

- Boat landing(s) to be fitted on one or more columns for maximum shelter
- Walk-to-work system compatible (SOV)
- Helicopter access for emergencies

Easy access with CTVs

Helicopter access

Deck space for equipment & shelter

Large Correctives carried out at O&M Port or Sheltered area

WindFloat enables Tow-to-Shore Maintenance

Plug-n-play connection system

- Principle Power patented plug-n-play solution allows (dis)connection operations to be performed in 1 day
- Principle Power patented floating I-Tube ensures uninterrupted production through the array during while affected unit in transit and repair

Heavy O&M in the harbor

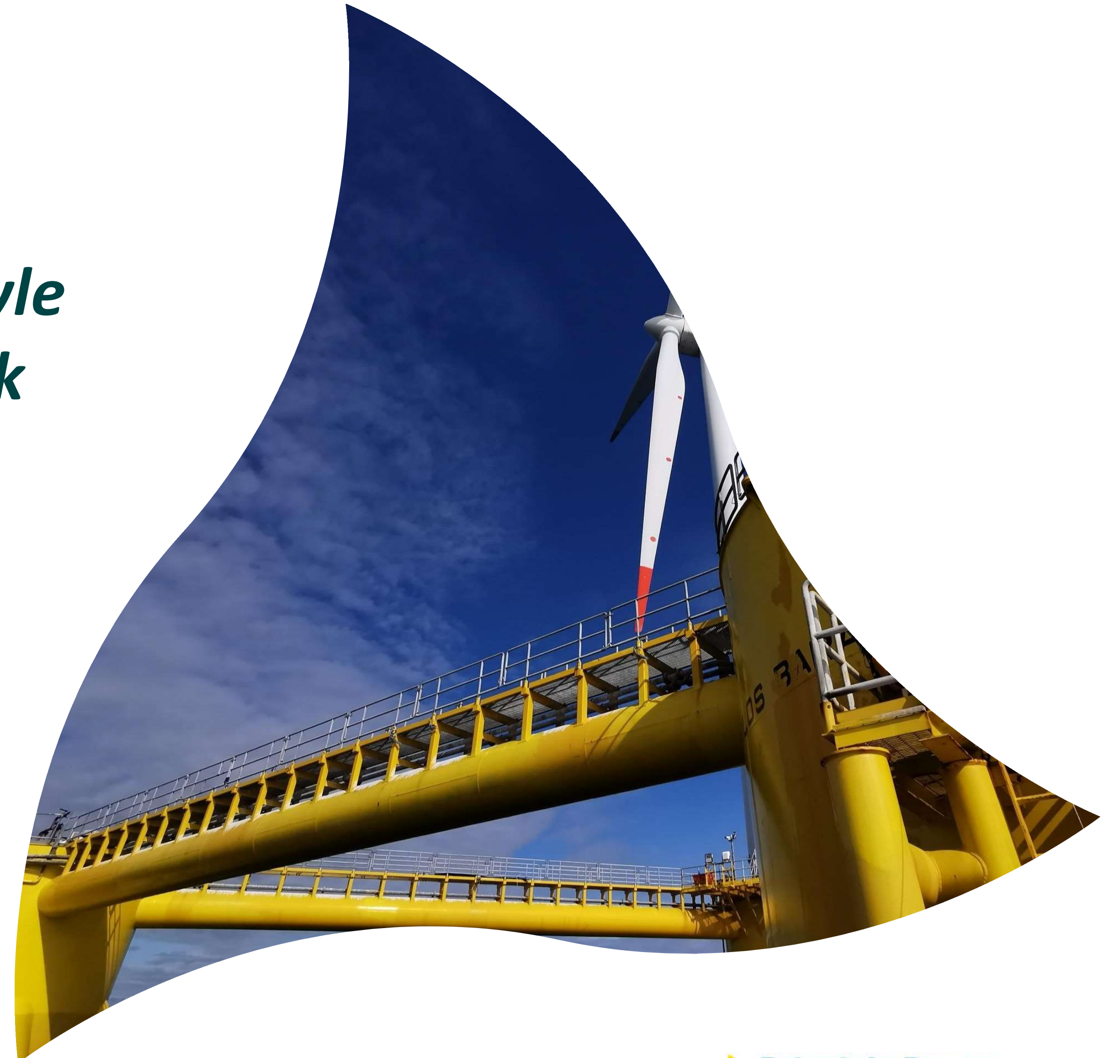
- WindFloat's shallow draft (adjustable ballast) allows up-tower repairs to be performed quayside in most harbors
- Standard onshore cranes have suitable reach/capacity due to location of WTG on outer column

Easy installation via towing

- Low system pretension means simple offshore tugs can be used for towing operations, even for next-gen WTGs
- No vessel availability risk; short mobilization times
- Lower weather risk and interface risk with offshore contractor

WFA unit at quayside, Spain

The importance of a ***lifestyle approach to cost and risk management***



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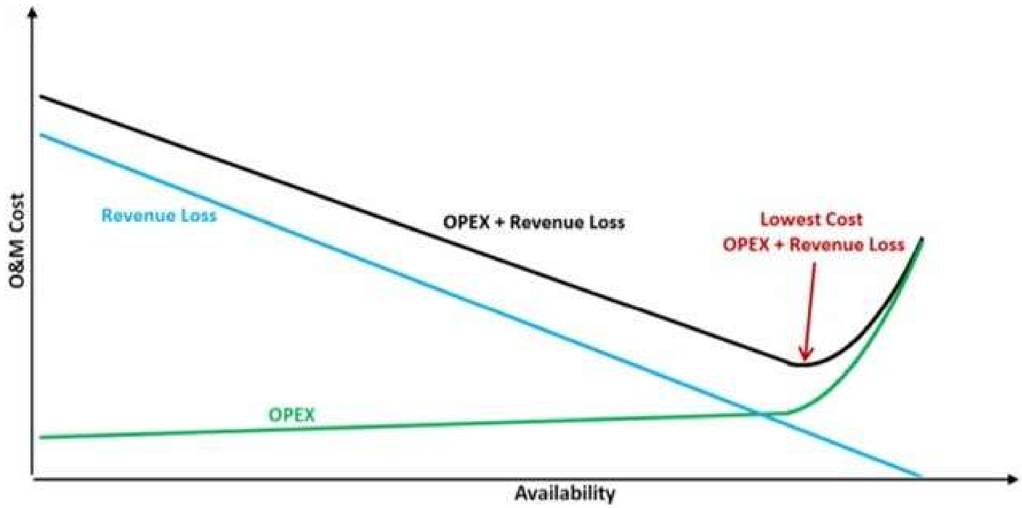
The importance of a lifestyle approach to cost and risk management

Case Study Results– Costs

- The economics of offshore wind O&M require a balance between the money spent on maintaining the project and the revenue lost when the electricity output is limited by technical problems.
- The balance between O&M cost and the lost revenue incurred by non-availability will be different for every project.
- The Cost Vs Loss of revenue curve on the right shows indicative trends for the cost of O&M as a function of turbine/platform availability.
- Although the cost of lost revenue declines towards zero as the turbines approach 100% availability, the cost of achieving it approaches exponential growth if 100% availability is required.

Cost Vs Loss of Revenue curve



Depiction of O&M optimization criteria; Source: *https://reoltec.net/wpcontent/uploads/2018/09/LCOE_OFFSHORE.pdf*

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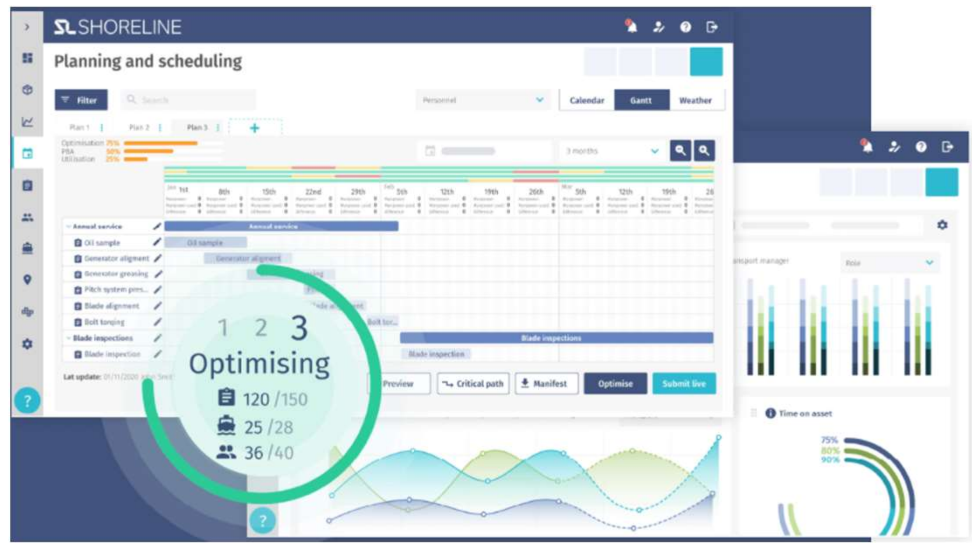
As no commercial scale floating projects exist, simulation during design phase is critical to test hypotheses and support decision making

- Principle Power has partnered with Shoreline to develop capabilities to simulate the full operational lifecycle for floating wind farms using WindFloats
- Agent-based simulations consider:
  - Infrastructure (O&M and Large Corrective Ports)
  - Equipment characteristics and failure rates
  - Metocean conditions (wind, wave, current)
  - Different logistical spreads
- High-resolution modeling capabilities enables Principle Power to support clients with tradeoff analysis and help identify solutions that offer the best balance of cost and performance, at minimum risk



Example of Shoreline Interface

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After defining the optimal strategy given the inputs of the model, different performance and cost metrics are provided as outputs

INPUTS
Wind farm and ports location
Logistics Strategy
Schedule and Corrective Maintenance Data
Weather data

RUN *n* SIMULATIONS

SHORELINE
Superior Simulation Solutions

OUTPUTS
Availability (%)
Lost production (MWh)
O&M Costs (€)
Utilization Rates (%)
Logistics Scheduling

Case Study Base Line

Name	Value	Unit
Wind turbine rated power	12	[MW]
Wind farm size	600	[MW]
Number of turbines	50	[#]
Number of years	10	[yrs]
Electricity price	75	[€/MWh]
Distance to O&M Port	60	[km]
Distance to Large Correctives Port	180	[km]

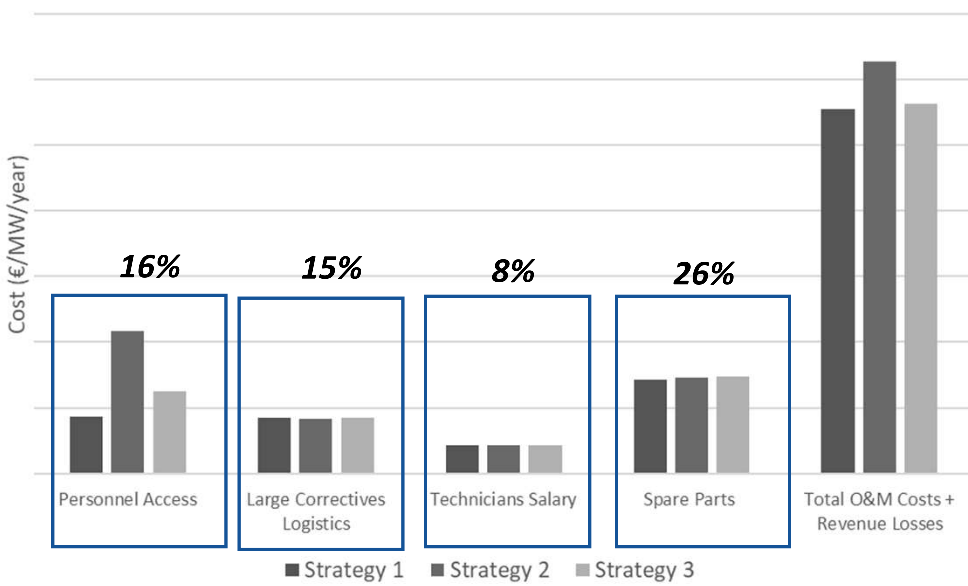
Fig 3. Offshore wind farm site and ports location

In order to evaluate the potential impact of different logistics strategies three alternative scenarios relative to the type of vessel being were modeled

	Type of Access Vessel	Number of vessels	Base	Period of Operation
Strategy 1	CTV	1	O&M Port	Full year
		2	O&M Port	May to September
Strategy 2	CTV	1	O&M Port	May to September
	SOV (w/ daughter craft)	1	Large Corrective Port	Full year
Strategy 3	CTV	1	O&M Port	Full year
	SOV (w/ daughter craft)	1	Large Corrective Port	May to September

Case Study results demonstrate that Strategy 1 enables the lowest overall costs

Strategy 1 found to be cost-effective strategy resulting in lower *'Total O&M Costs + Revenue Losses'*



Breakdown on O&M costs for the Baseline Case

Increased costs due to high SOV daily rates

Strategy	Strategy 2 (percent deviation from Strategy 1)	Strategy 3 (percent deviation from Strategy 1)
O&M Costs [€/MW/year]	+37%	+12%
Revenue Losses [€/MW/year]	-30%	-17%
O&M Costs + Revenue Losses [€/MW/year]	+13%	+1.5%

Increased availability as a result of less restrictive access limits and quicker response time

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Case Study results show that increase in the Wind farm size leads to lower costs as a result of a better optimization of the resources.

WIND FARM SIZE

Larger wind farms have lower OPEX

WTG RATED POWER

	8 MW WTG	16 MW WTG
PERSONNEL ACCESS (percent deviation from the Baseline Case, 12 MW WTG)	+5%	-9%
LARGE CORRECTIVE LOGISTICS (percent deviation from the Baseline Case, 12 MW WTG)	+24%	-25%

Larger WTGs reduce OPEX

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Digital innovation:
The next step for a full farm optimization

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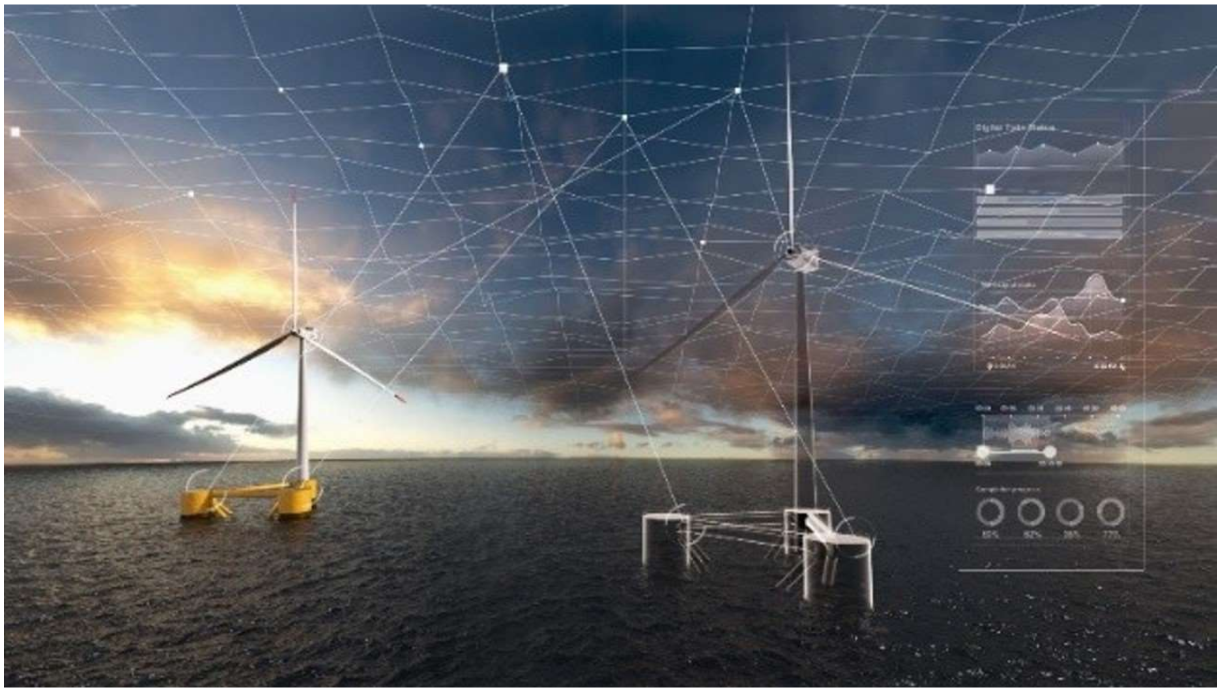
Currently leading a $4 million ARPA-E project that aims to develop and install the first-ever digital twin technology for a large-scale FOWT

ARPA-E: DIGIFLOAT – Digital Twin Development



Project Objectives:

- Create FOWT-specific digital twin model at WindFloat Atlantic in Portugal
- Software tool validated using large-scale tank tests, with a turbine emulation technique and adaptive, hybrid testing
- Metocean buoys deployed to collect real-time wind, wave, and current field for comparison to measured data from onboard sensors
- Predictive analytics from onsite measurements used to optimize performance and maintenance scheduling.
- Lessons learned fed into next-gen designs

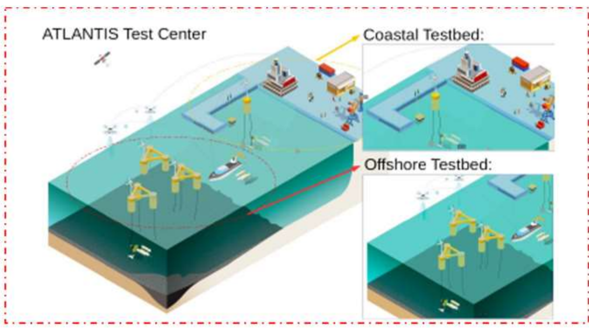
Ops & IMR - The role of digital innovation

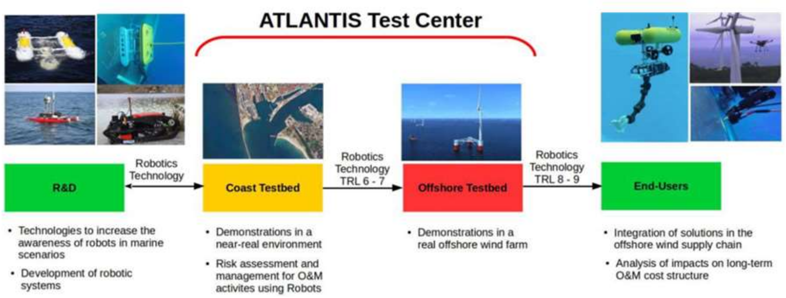
Digital Twin Development promises relevant results with direct impact on O&M of Floating Offshore Wind Farms

- Improved guidelines from Class Societies around risk based inspection as opposed to the interval based inspections that we are doing now (E.g. hull inspection every N years regardless of risk increase)
- Asset Monitoring – Real time structural health monitoring
- Predictive Maintenance – risk based Inspection Plan
- Cloud based data Streaming - Live dashboard of WindFloat SCADA System
- Environmental Monitoring – Real Time site conditions

Ops & IMR - The role of robotics

The Atlantic testing platform for maritime robotics





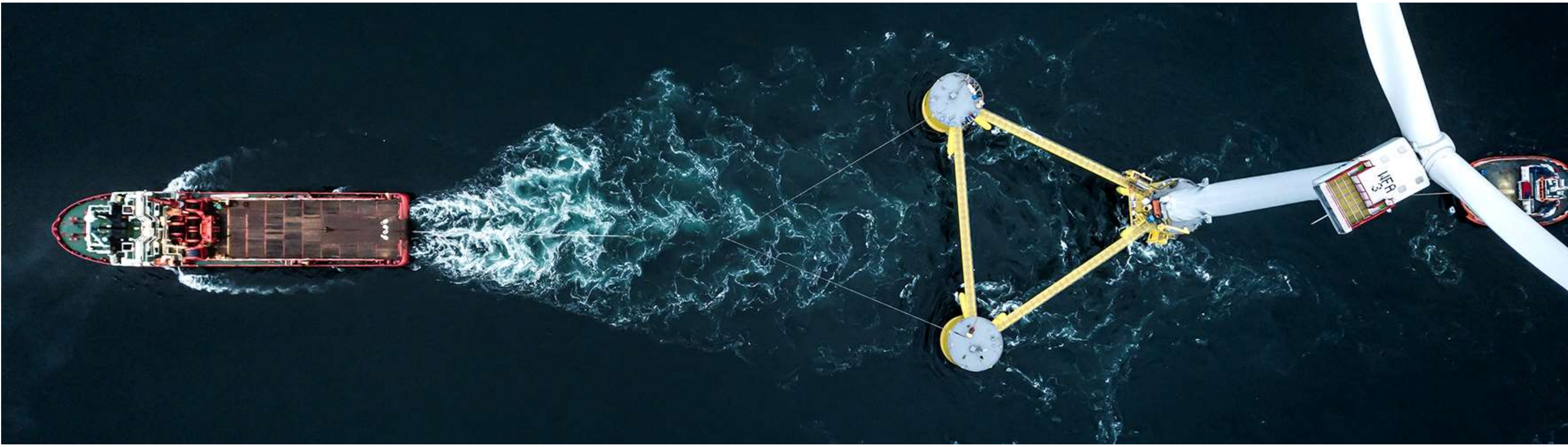
Project Objectives

- Development of robotic solutions to suit the Offshore Industry IMR needs.
- Demonstrate the potential for robotics to impact at scale, LCOE decrease.
- Demonstrate operation risk reduction through deployment of services based on robotic actors within the selected application area.

European Commission

Conclusions

- The nearly 50 GW of floating projects under development globally are driving the sector towards industrialization in both delivery and operations
- Not all floating technologies are created equal – it is crucial to ensure that maintenance solutions are available, especially for large correctives, to achieve 25-30+ year lifetimes
- It is essential to take a lifestyle approach to cost and risk management, starting from the early stages of Project development when critical decisions will be made.
- Operations phase require a balance between OPEX and Performance; numerical simulation is important during the design phase for good decision-making.
- There is high potential for innovation in the Floating Offshore Wind space, and progress will be fundamental for the competitiveness of the sector



Contact Details

Clara de Moura Santos

Commercial & Strategy Manager
csantos@principlepowerinc.com
+351 913 071 879