Eelume
SUBSEA INTERVENTION

A snake robot in offshore wind

Morten Bjerkholt / CEO

KONGSBERG

equinor

EELUME PARTNERS

Eelume SUBSEA INTERVENTION

equinor

LOOP Agreement
Demanding customer

- Demanding customer
- User requirements
- Extensive subsea operation experience
- Access to Equinor's partners
- Pilot customer

Eelume
SUBSEA INTERVENTION

- Development of Eelume vehicles
- Technology IPR, patents
- Research projects
- Dedicated team

Experience,
Marketing & Sales

KONGSBERG

- AUV technology and experience
- Industrialisation and manufacture
- Supply chain
- Marketing and sales
- Investments

Expertise, theory, algorithms

The Research Council of Norway

NTNU AMOS
Centre for Autonomous Marine Operations and Systems

- World class research expertise snake robots
- Theory, algorithms
- MSc, PhD and Post Doc projects and people

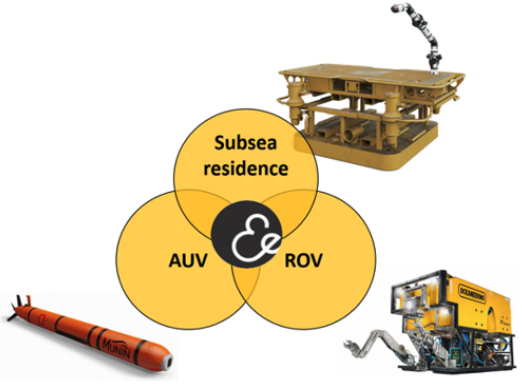
Innovation Norway

Eelume M3

Autonomous, modular, flexible, articulated

- Key edges:
  - **Form factor** : Slender body profile enables access to confined spaces
  - **Modular and scalable** : A selection of modules which can be exchanged.
  - **Flexible** : Sensors and payloads can be adapted to the need.
  - **Manoeuvring** : 6 DOF, the robot can attain any pose in the water.

The Eelume concept

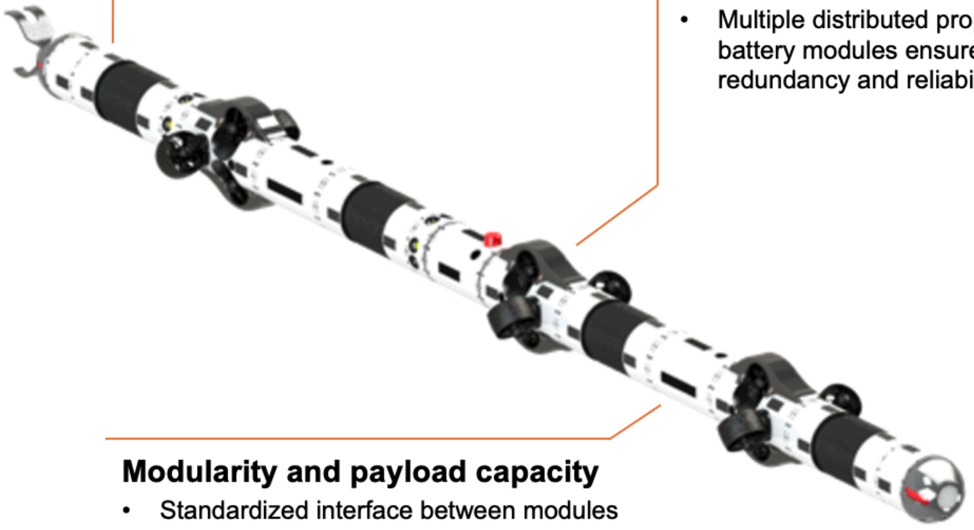


Slender and energy efficient

- Low drag with torpedo shape due to small diameter

Redundancy and reliability

- Multiple distributed propulsion and battery modules ensure inherent redundancy and reliability



Modularity and payload capacity

- Standardized interface between modules
- Length and module quantity can be large
- New modules/functions are plug-and-play
- Many battery modules give long range

Stable and versatile

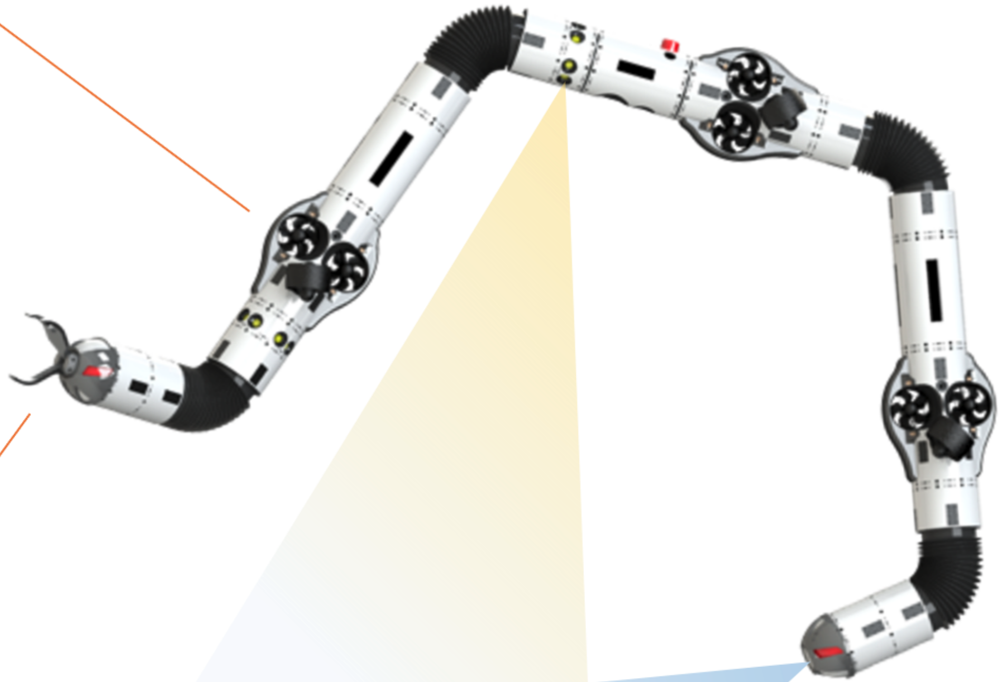
- Stable hovering in U-shape
- Adapt shape to situation
- Full 6-DOF control
- Active roll also when straight

Articulated body

- Enables intervention (dual robotic arm)
- Orient sensors and payloads
- Adapt shape to situation
- Access constrained locations (snake)
- Simplified handling, launch and recovery

Intervention capability

- Each end of the vehicle is the tip of a robotic arm

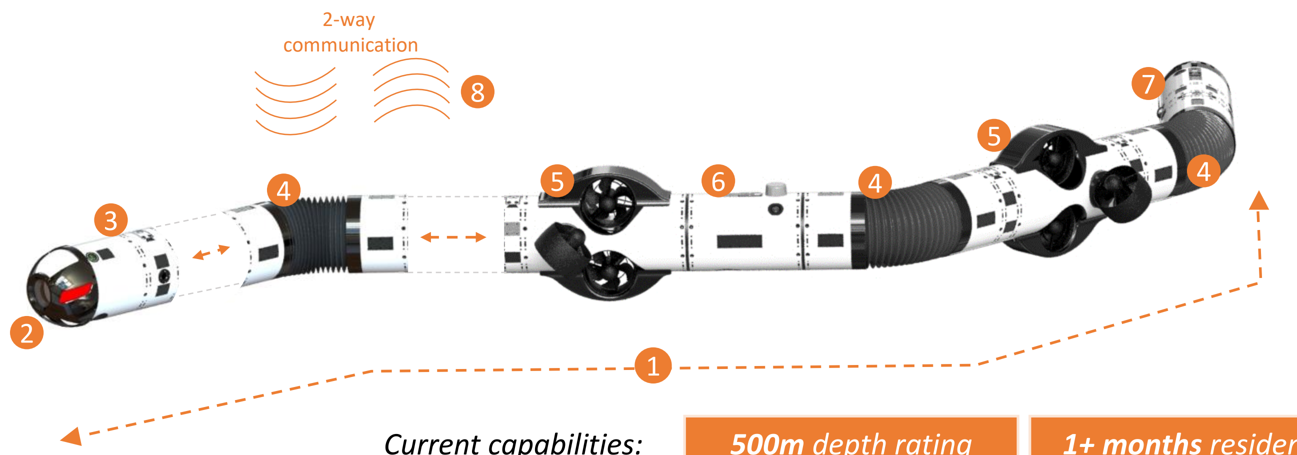


Superior video and stills

- Long body enables large distance between cameras and lights (reduces back scatter)

The Eelume robot is a multipurpose underwater vehicle

The Eelume's concept is all about flexibility: Combine instruments, sensors, modules and joints in a unique way



1. Slender, jointed, and flexible body
2. HD video and stills, LEDs
3. Buoyancy trimming
4. Joint module
5. Thrusters
6. Navigation
7. Docking with inductive charging
8. Acoustic communication, satellite navigation on surface

Current capabilities:	***500m depth rating***	***1+ months residency***
Long-term:	***3000m depth rating***	***6+ months residency***

The Eelume vehicle is an ***autonomous*** underwater ***instrument and sensor carrier***: It can connect to a range of different ***tools and payloads*** to carry out ***inspection, survey*** and ***light intervention*** missions in constrained spaces and open waters

Examples of module categories which can fit on the vehicle:

Joints | Cameras | Sonars & sensors | Batteries | Thrusters | Tool interface | Payloads

Multipurpose vehicle; can be deployed for:

- ~2 days — *Single mission*
- ~2 weeks — *Full campaign*
- ~6 months — *Underwater residence*

Launched from e.g. traditional vessel, platform, or USV[1)] (single mission, full campaign)

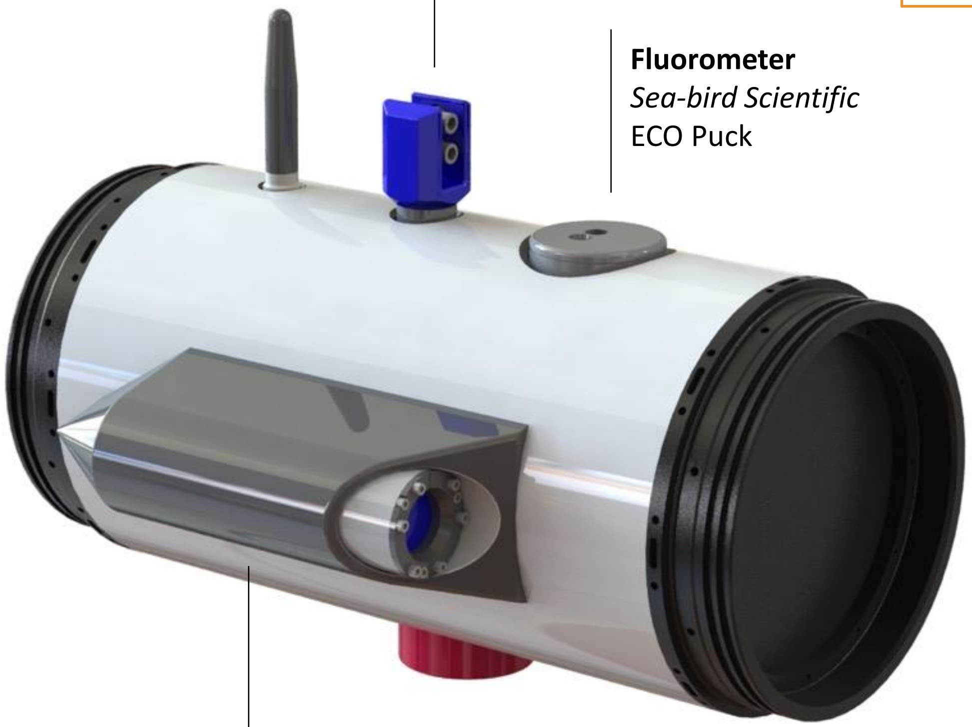
Installed on a dock - no vessel (underwater residence)

Environmental survey module

Hydrophone
Ocean Sonics
icListen RB9-ETH

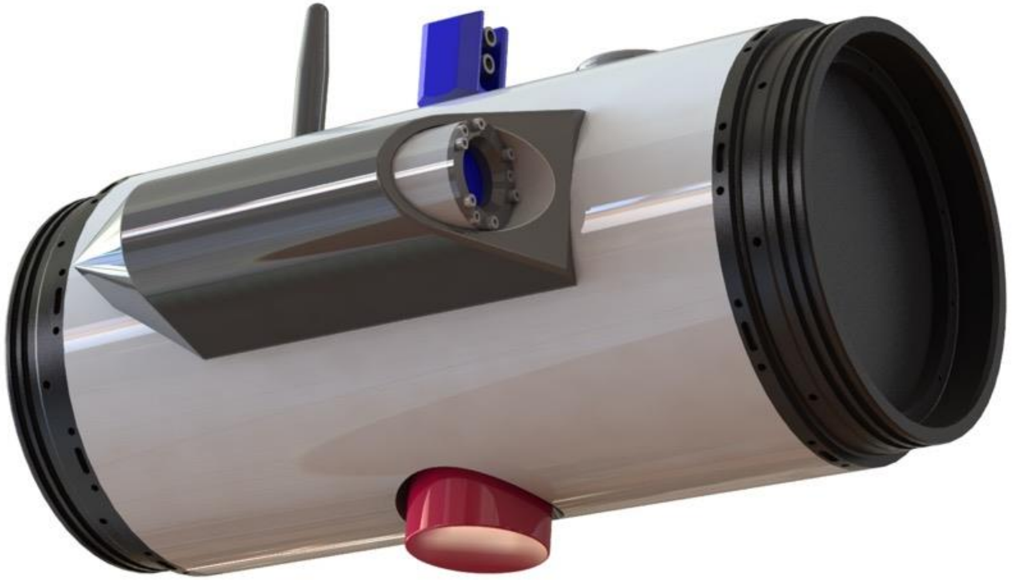
CTD
AML
CT-Xchange

Fluorometer
Sea-bird Scientific
ECO Puck



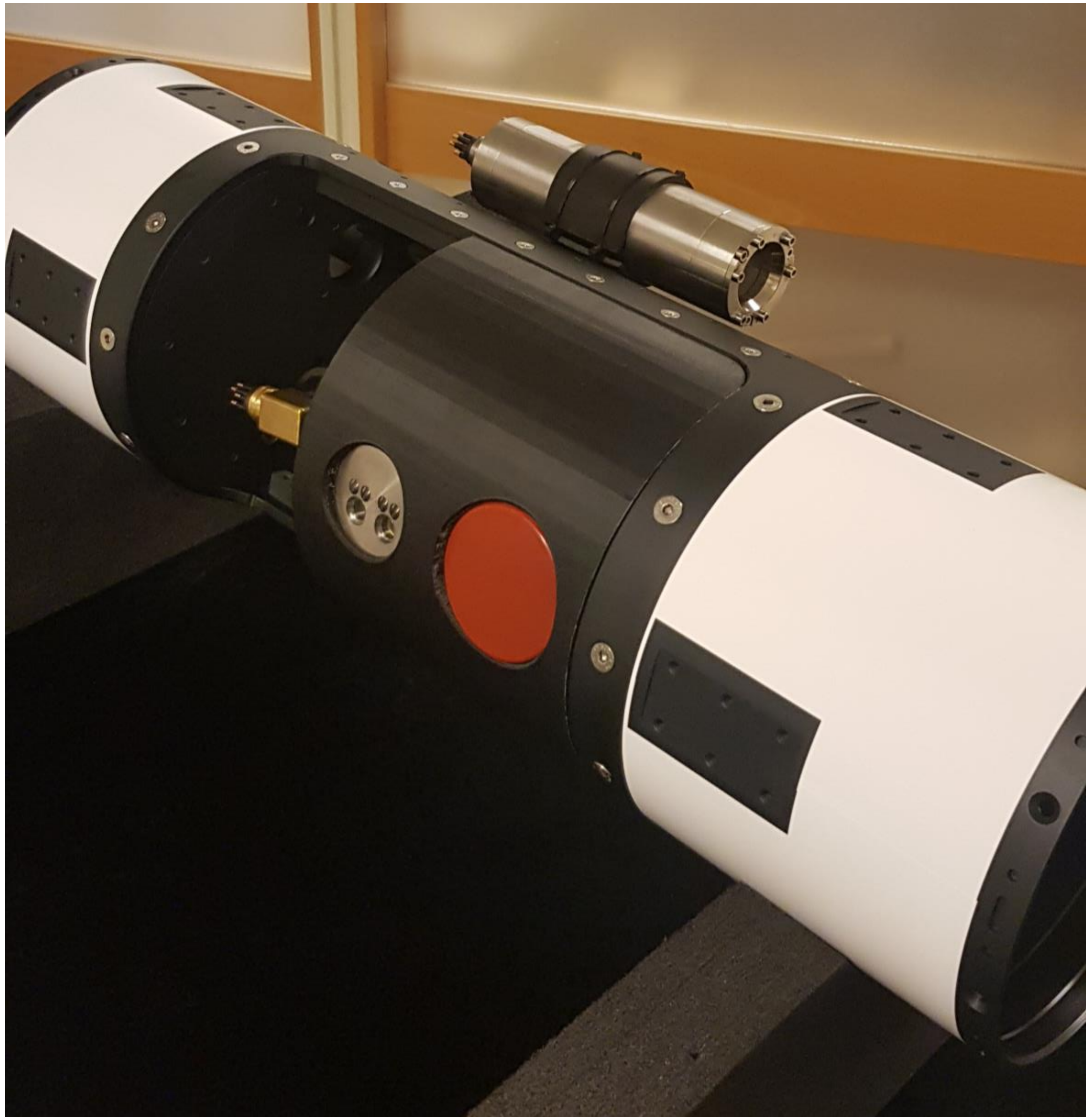
CH4
Franatech
Mets methane sensor

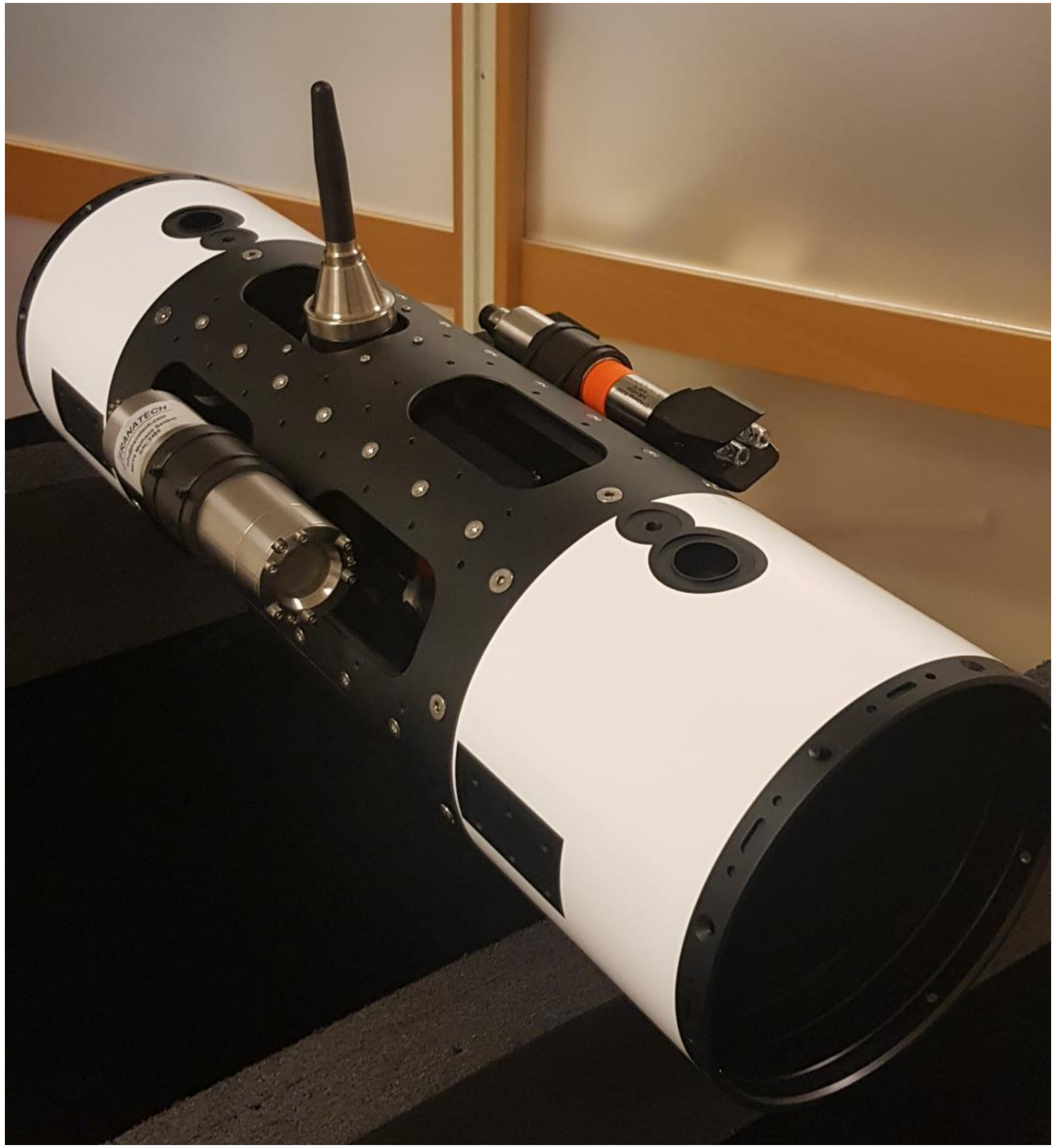
Sensors are exchangeable and a range of different sensors can be fitted to suit the need.



Echosounder
Kongsberg
EK80

Eelume ESM module





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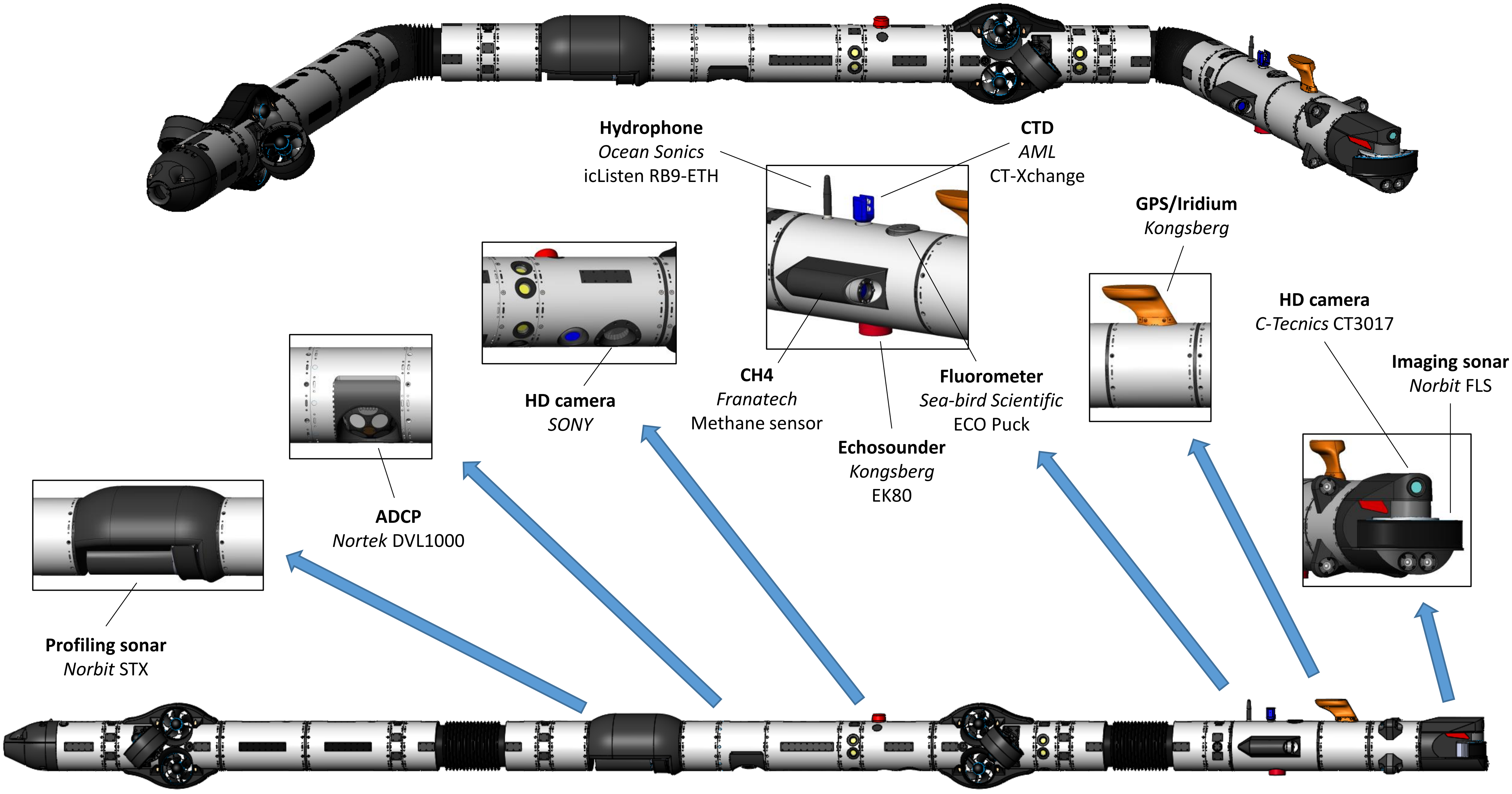
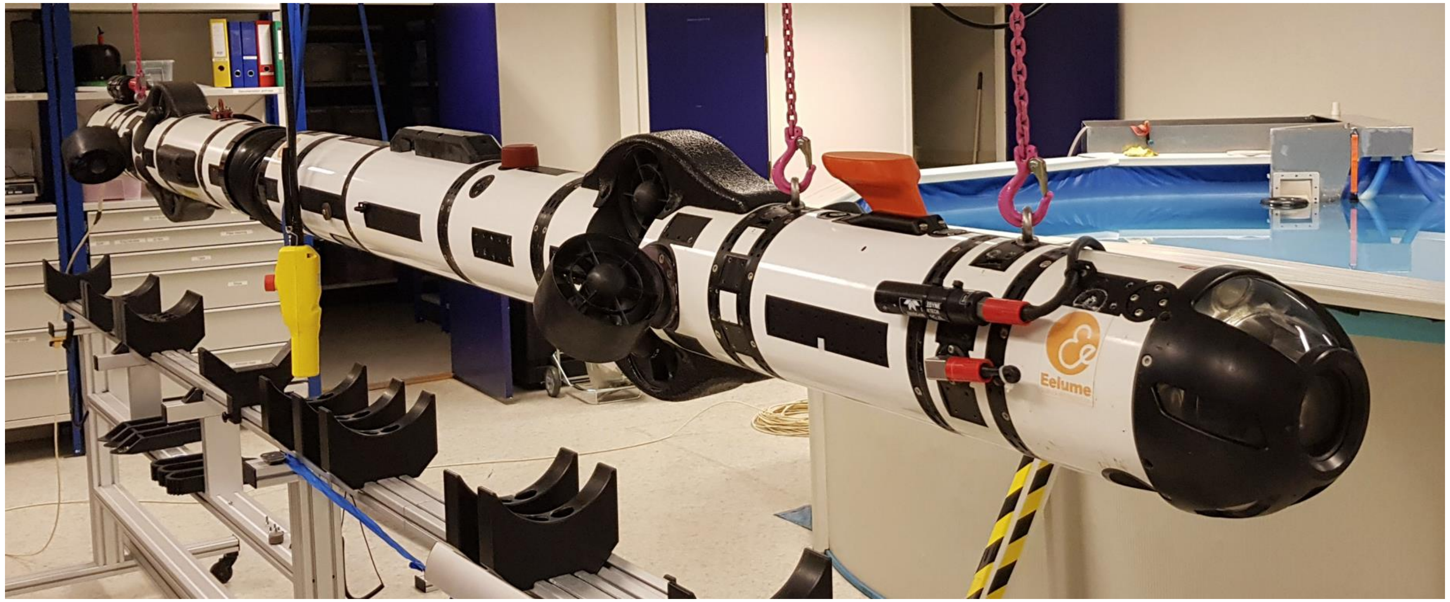
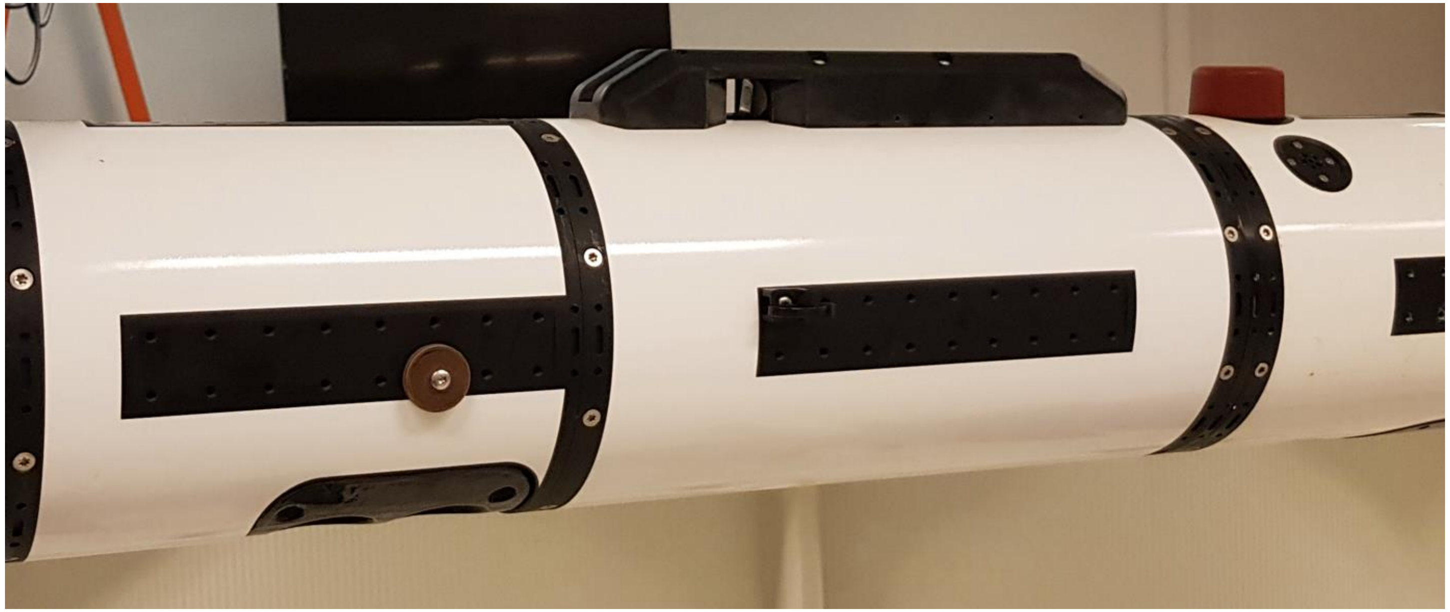
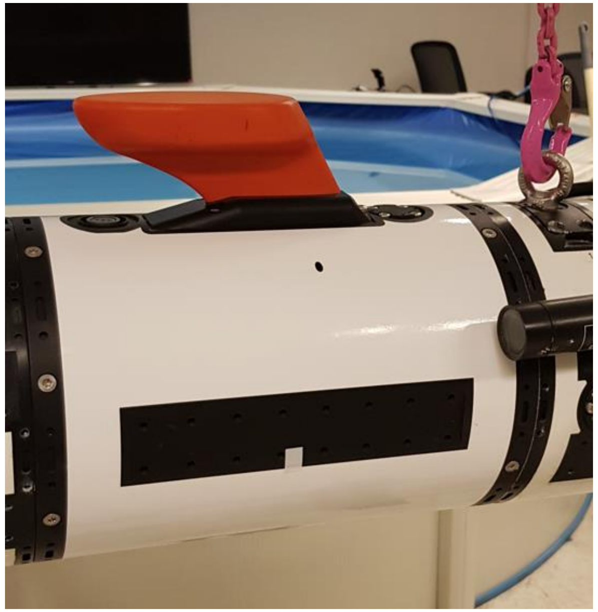
Example of integration of sensor suite in the robot



Robot w/navigation and GPS/Iridium/WiFi module







Eelume SUBSEA INTERVENTION

Value proposition:
- Subsea missions 24x7x365 independent of weather and surface vessels
- Reduction of OPEX by a factor of 5x – 10x.

Subsea resident and autonomous capabilities

Reduce the vessel need

"Reducing the need for a vessel would significantly reduce our costs"
Senior Specialist pipeline technology, Gassco

Significant OPEX reduction	*~80-90% cost saving[1)]*
Improved HSE performance	*~90% decrease of risk days[1)]*
Reduced carbon footprint	*~90% decrease of carbon emission[1)]*

24/7 availability

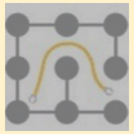
"On-site robots will provide major flexibility to subsea operations"
Technology expert from an Energy operator

Efficient planning & execution	*No delay, smoother operations, weather independent*
Allows for condition based maintenance	*Inspection mission pre-defined*
Emergency capability response	*Emergency response to handle severe incidents*

Eelume's edge

Perform complex tasks in the most efficient way

"The set of tools available will be a major contributor in establishing which competing solution is best"
Technology expert from an Energy operator

Modular, scalable, flexible body		*Can be reconfigured for optimal performance*
Ability to access confined spaces		*Only fully articulated solution; slender and can change shape*
Lower CAPEX for future fields/farms		*Less complex design approaches*

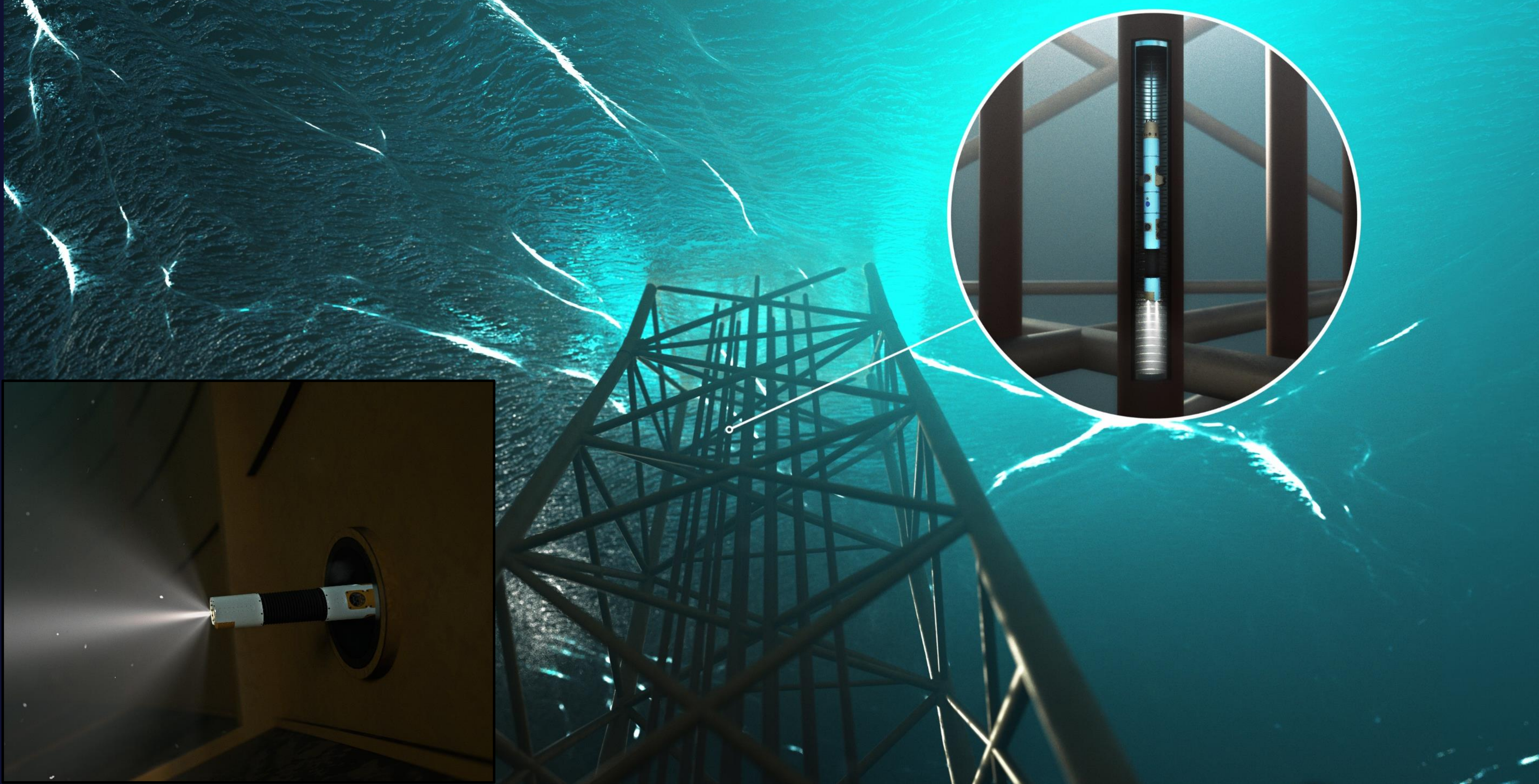
Eelume is significantly more cost effective and environmental-friendly than the current industry standard for offshore energy subsea operations

1) Estimates - Calculated for a 21-day IMR campaign; Number of risk days assuming 50 people vessel crew; Vessel included both for Eelume and conventional (2 days for Eelume: 1 day launch and 1 day recovery).

Source: Management, Rystad, Arkwright research

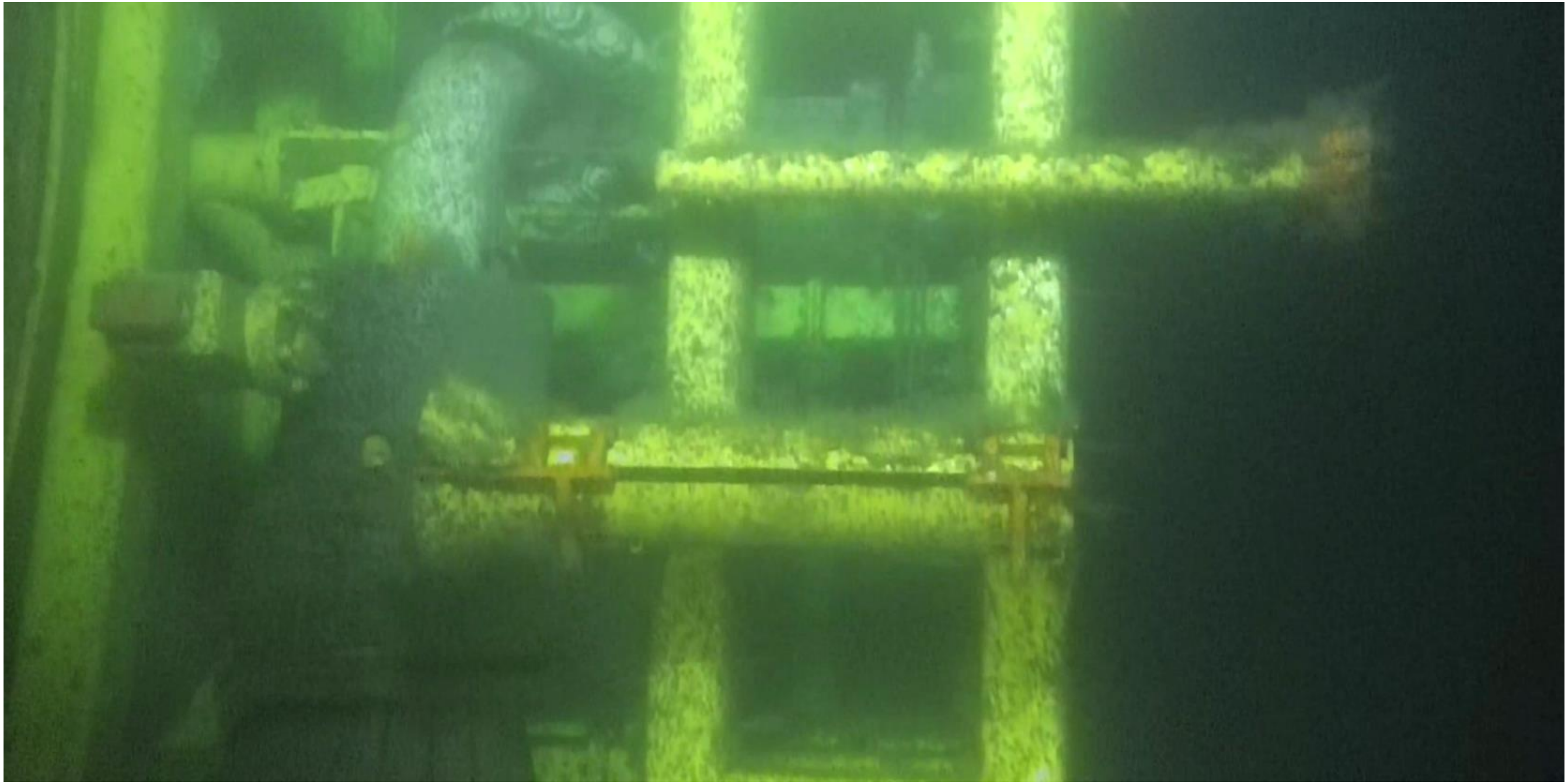
Outside inspection of structures; cables, pipes

Inside inspection

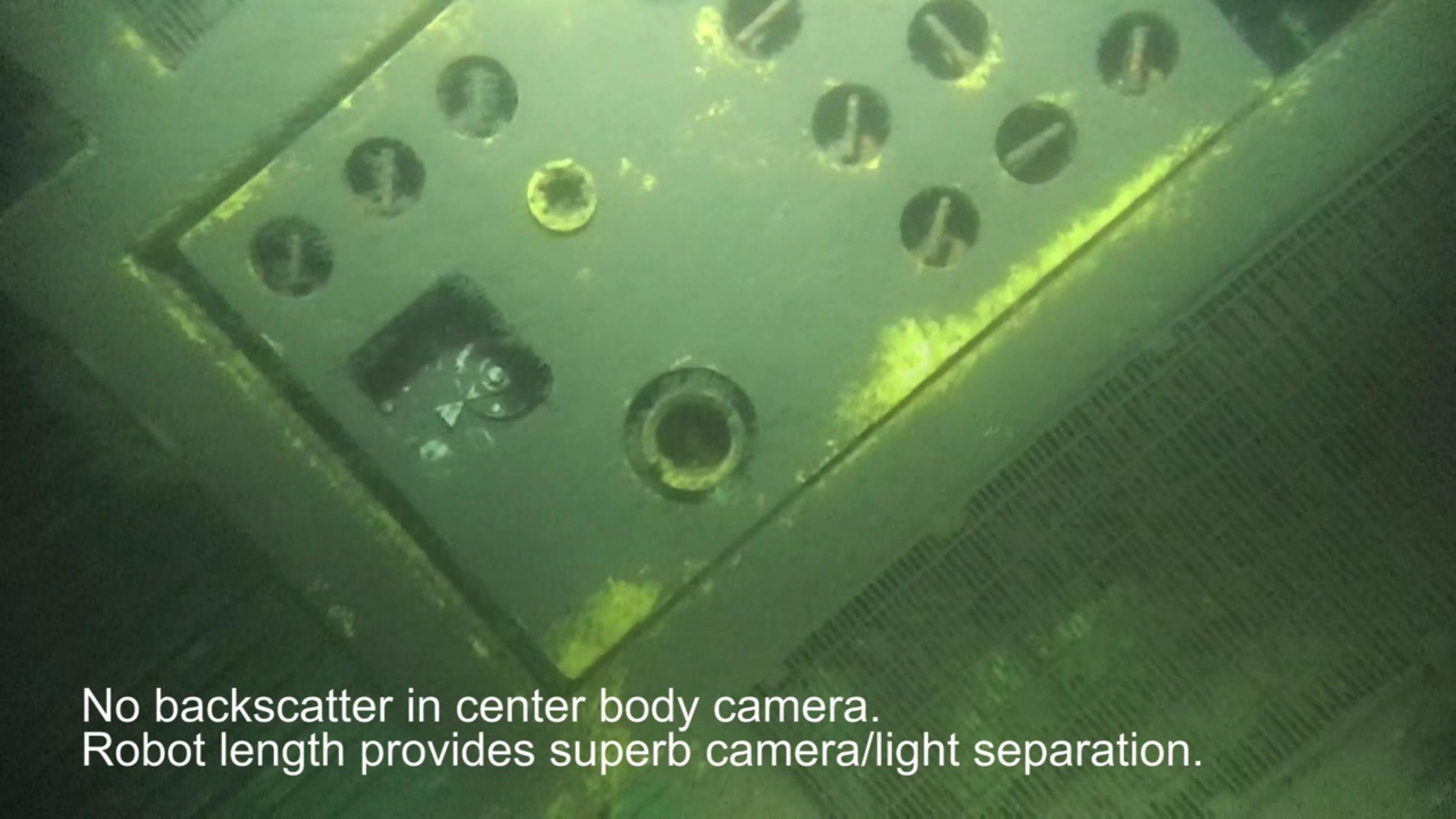



The robot can access
constrained locations

Imaging with camera in mid section, no backscatter

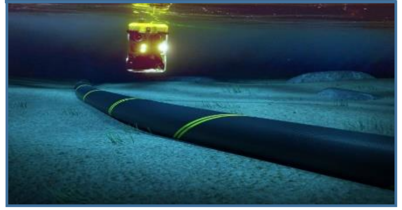


Backscatter-free video by use of camera in mid section and LEDs in head and aft section.


No backscatter in center body camera.
Robot length provides superb camera/light separation.

Several key BoP maintenance activities require subsea inspection and are highly relevant for AUVs and Eelume

Breakdown of Offshore wind operational maintenance

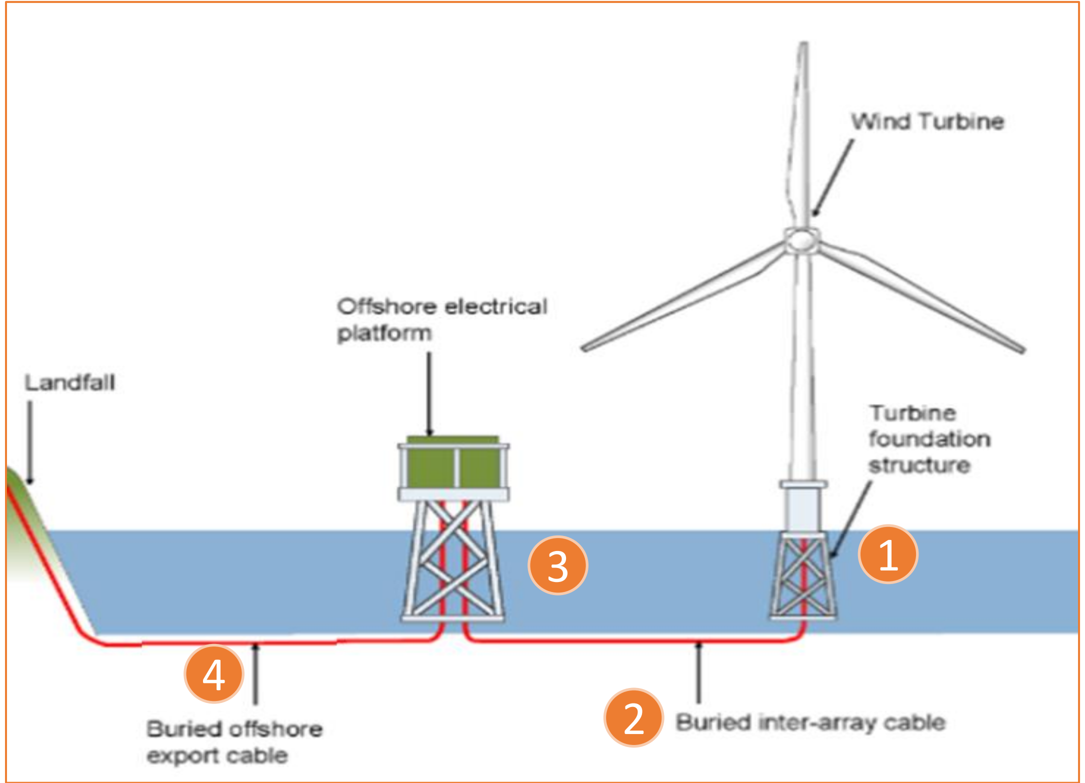
	Balance of Plant (BoP) maintenance				Turbine maintenance
	Foundation inspection & repair	Cable inspection & repair	Scour monitoring & management	Substation maintenance & service	
					
Description	▪ Identifies and addresses corrosion and structural problems above and below waterline ▪ Consist of visual inspection, non-destructive testing and sea bed survey ▪ Inspection work is managed by the operator although is often subcontracted to specialist third party	▪ Identify faults and replace whole or sections of cable ▪ Surface surveys can be used to detect substantial cable exposure, but ROV surveys will be required for more accurate burial depth data ▪ Operator responsible for monitoring, but often subcontracted to specialists	▪ Mitigate the risk of undermining sea bed movements on subsea structures ▪ Generally managed through rock (or grout, sand and gravel) dumping around the base of the foundation ▪ Operator responsible for monitoring and management although is often subcontracted to specialist	▪ Ensures there is no interruption to transmission from electrical failures or structural problems with the offshore platform ▪ Operator responsible, heavier maintenance often subcontracted	▪ Ensures the long-term productivity of the turbines ▪ OEMs has historically had monopoly on of the O&M, but experienced operators have now started to insource during and/or after warranty period
Value chain comment	*Maintenance strategies still fairly immature in this industry, but starting to see innovations – for example in terms of contractual agreements with third party specialists*				*OEM's strong foothold, but "hands-on" owners seeking to take on more inhouse*
Avg. annual spending[1)] (for 1GW farm)	*3-5 mGBP*	*5-7 mGBP*	*5-7 mGBP*	*1-3 mGBP*	*25-35 mGBP*
Eelume Relevance	*Highly relevant*	*Highly relevant*	*Relevant*	*Partly relevant*	*Not relevant*

1) Source: BVG Associates, Scottish Enterprise and The Crown Estate

Areas where AUVs can improve efficiency and reduce cost

Example of Offshore wind installation and associated technologies required for their inspection

Simplified illustration of an Offshore wind installation



Types of assets	*Potential failures (non exhaustive list)*		*Potential relevant technologies (examples)*		
1 Turbine foundation	Corrosion	Scour[1]	Visual inspection	NDT[2]	Sea-bed survey work
	Structural instability	Slope failure			
2 Inter-array cable	Insufficient burial	Cable damage	Visual inspection	NDT[2]	Protective mattress-ing
	Mechanical stress	Insufficient insulation			
3 Substation foundation	Corrosion	Scour[1]	Visual inspection	NDT[2]	Sea-bed survey work
	Structural instability	Slope failure			
4 Export cable	Insufficient burial	Cable damage	Visual inspection	NDT[2]	Protective mattress-ing
	Mechanical stress	Insufficient insulation			

Comment on inspection trends in Offshore wind

*"The requirements for environmental and **technical inspection of the subsea elements** of wind projects are an already **significant aspect of O&M provision, and are likely to increase going forward**"* — GL Garrad Hassan

*"Inspection class ROVs are used to inspect the foundation below the water line and the cable route, particularly in areas at risk of scour or other seabed movements, and other high-risk locations, such as crossings with other cables. **The development and use of UAVs is an area of innovation**"* — BVGassociates

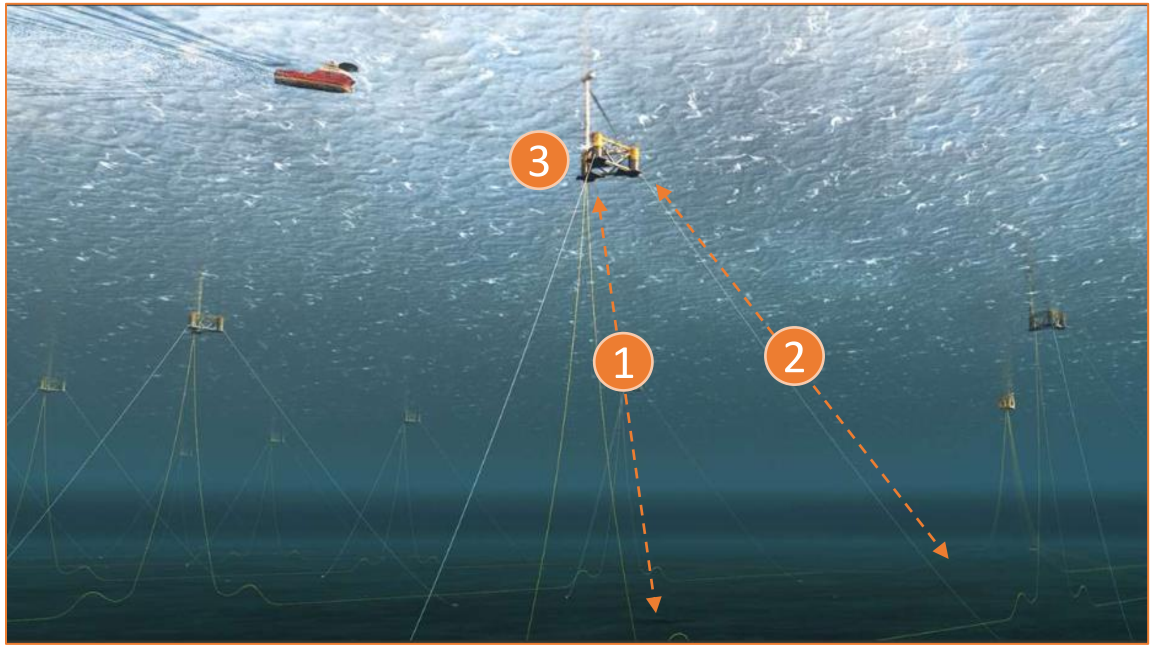
Visual inspection and NDT is key inspection techniques for all Offshore wind subsea installations, and is well suited for Eelume

1) Scour = Sentiment erosion, 2) NDT = Non-destructive testing
Source: BVG Associates, GL Garrad Hassan, Arkwright research

In floating offshore wind use of AUVs is probably even more relevant

Example of floating Offshore wind installation

Simplified illustration of a floating Offshore wind installation



1 *Array cable* 2 *Mooring system* 3 *BoP[1)] system*

Comments on Eelume's business case within floating Offshore wind

*"**Floating Offshore wind can be a solid business case for a player like Eelume.** The subsea infrastructure, everything from the mooring system, cable system, BOP system and anode system, will need to inspected on a regular basis. In contrast to fixed Offshore wind, floating Offshore wind is located in remote areas with depths that eliminates the possibility for using divers. **Compared to the use of ROV's, Eelume's solution will likely be way more cost efficient**"* **(Ocean Installer)**

*"Marine vegetation growing on the infrastructure will be a big issue for floating Offshore wind, especially in warmer waters. If they were to be grow freely, they will add tens of tons to the structure. **If the Eelume can do some light intervention work by removing the vegetation regularly, substantial CAPEX costs can potentially be saved in the structural design of the infrastructure**"* **(Ocean Installer)**

*"The dynamic nature of floating Offshore wind makes inspection and light intervention a vital part of the O&M activity. **Cables, mooring system, BoP system and anode system** are exposed to dynamic forces and thus **needs to be monitored closely. If it was possible to weld critical worn parts with an Eelume, it could prolong the part's lifetime and save a lot of repair costs."*** UNITECH

*"**AUV's could be very relevant for both ad-hock and regular O&M inspection services** within offshore wind, e.g. cables and subsea structures. In addition, they could be used during installation, for example to check that the cables have been installed correctly. **AUV's have the potential to cut OPEX significantly** compared to traditional use of ROV's, **and its beneficial that they can operate independently of weather conditions**. We are currently in discussions with Eelume to test their AYV in the upcoming offshore wind farms "* sagasubsea

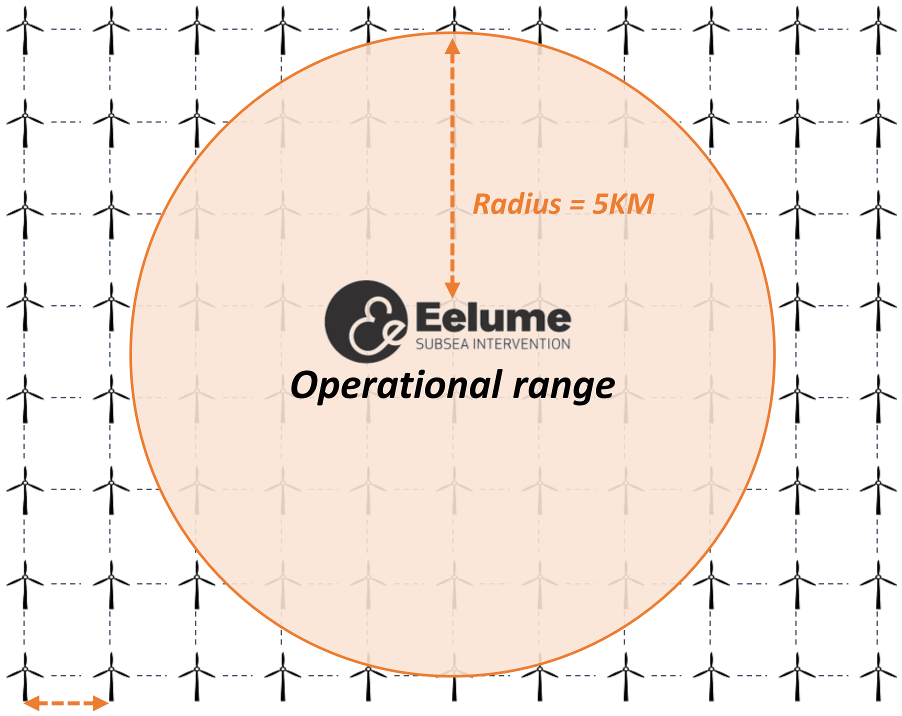
The dynamic nature of floating Offshore wind makes inspection and light intervention a vital part of the O&M activity, and Eelume is highlighted by industry players as highly competitive and likely disruptive to current solutions with ROV's

1) BoP = Balance of plant

One Eelume has an operational range of about 5 - 8 km. This gives a coverage of 80 km^2 to 200 km^2 and 40 – 200 turbines.

Subsea AUV demand calculation per Offshore wind farm

Simplified illustration of an Offshore wind layout



Radius = 0.5-2.0 km, depending on the rotor blade diameter.

Parameter	*Value*	*Assumptions / comments*
Subsea AUV operational range	80 [km^2]	▪ A relevant robot configuration is a robot with 5 battery modules. ▪ By allocating 4 battery modules for propulsion and 1 battery module for O&M work, this will give a travelling distance of 15-20 km and an operational range of up to 10 km. ▪ Taking into account tides, currents etc. a conservative operational range is 5 km resulting in a 80 km^2 operational coverage (40-80 turbines)
Wind farm capacity density	5 [MW/km^2]	▪ The current capacity density on the installed base in Europe is in the range of 5.0 – 5.4 [MW/km^2][1)] ▪ Industry trends, such as taller turbines, better placing and reduced influence of the wake can increase the capacity density factor. ▪ However, capacity density factor is not a purely techno-economical decision, it also heavily influenced by regulatory framework[2)]

Subsea AUV demand **=** ***Wind farm capacity [MW]*** **÷** ***Capacity density [MW/km^2]*** **÷** ***Eelume operational range [km^2]***

We foresee that the largest wind farms on >400MW will need two subsea AUVs to secure full operational coverage. Smaller wind farms will in theory only need one robot

1) Source: European MSP Platform, 2) In some regions, high energy density is the primary incentive for subsidies, while in others low LCOE is the primary incentive

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