Profile Project

A market survey of ROVs and decommissioning tools for the removal of monopile foundations in the offshore wind industry

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Supervisor: Jens Christian Lindaas

Master of Maritime Operations
Western Norway University of Applied Sciences

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Abstract

Offshore wind farms are under increasing development and new projects are forming around the world, as the harvesting of wind offshore to generate electricity, is proven to be a promising method of producing clean energy. The construction of wind farms offshore is a fairly new development within the renewable energy industry, with the oldest offshore wind farms in Europe just reaching/exceeding the 20-year-old mark. Only a few offshore wind farms have for this reason been decommissioned. The industry has so far been applying methods adopted from the oil and gas industry or applied a reverse instalment method, and sometimes a combination of these.

Remotely operated vehicles (ROVs) have become a reliable tool in the offshore industry in recent times, for tasks such as surveys, observations, and for diverse working purposes. For decommissioning of an offshore wind turbine (OWT), multiple types of ROVs can aid in the early stages of the project (observation/survey), in removing substructures and monitoring the site after decommissioning is complete. With the offshore wind industry moving to larger sea depths and to more remote locations, the increase and variety of use for these vehicles can be seen in the future.

The objective of this paper was to provide a market survey of existing ROVs of various types, available ROV tools and other existing tools, which can be used for decommissioning purposes, in particular decommissioning of OWTs with a monopile foundation. As well as to provide a deeper discussion over challenges and shortcomings of the applied methods and of the available tools for decommissioning, with a basis on knowledge gained in the market surveys. The findings of this report were based on an extensive literary study.

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Abbreviations

Abbreviation	Description
AC	Alternating Current
AUV	Autonomous Underwater Vehicles
DC	Direct Current
HAWT	Horizontal Axis Wind Turbine
HSE	Health, Safety & Environment
IMO	International Maritime Organization
LARS	Launch and Recovery System
MSW	Meter Sea Water
MW	Mega Watts
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
OWF	Offshore Wind Farm
OWT	Offshore Wind Turbine
O&G	Oil & Gas
ROV	Remote Operated Vehicle
TMS	Tether Management System
TP	Transition Piece
UNCLOS	United Nations Convention on the Law of the Sea
VAWT	Vertical Axis Wind Turbine

Chapter 1. Introduction

Aim of this chapter is to firstly present the research questions and objectives which this research has been derived from. Some background knowledge will be presented on the decommissioning history of offshore wind farms (OWF) and basic challenges which have been meet in the process up to present day. In the end of the chapter, the methods which have been used to solve the research questions and the limitations of the research, will be described.

1.1 Objectives and research questions

The objective of this report is to explore and review the methods for decommissioning of offshore wind farms, with an emphasis on monopile foundations. This will be achieved by formulating and describing tested and alternative methods of the substructure removal of an offshore wind turbine (OWT). This report will further make a survey of ROVs and ROV tools available on the market today, that can be used for the purpose of decommissioning these OWTs. As well as a market survey of other decommissioning tools available for monopile removal. A discussion will then be made on the possible shortcomings and challenges with the methods and tools based on the findings from the market surveys, and from the knowledge gathered by previous OWFs decommissioning operations.

Following research questions to be investigated in the report:

- *What are the processes during decommissioning of OWTs with a monopile foundation that can be aided with an ROV?*
- *What different types of ROVs are available on the market today, which can be used for decommissioning purposes of OWTs with monopile foundations?*
- *What types of ROV tools exists on the market today, which may be used for decommissioning purposes of OWTs with a monopile foundation, with emphasis on foundation cutting operations?*
- *What types of decommissioning tools exists on the market today which can aid in monopile foundation removal operations of OWTs?*
- *With a basis on previous monopile foundation removal projects, previous research on monopile foundation removal and the availability of various existing ROVs, ROV tools and decommissioning tools, is there any shortcomings or challenges present in the decommissioning of these OWTs monopile foundations?*

1.2 Background

1.2.1 OWF decommissioning challenges

The oldest offshore wind farms in Europe are now just reaching/exceeding 20 years old. Wind turbines are typically designed to have a life cycle of 20-25 years offshore. Apart from some OWTs which can extend its lifetime or be repowered, decommissioning of many of these OWFs is prominent. The OWT components will experience wear and tear over time, that is inevitable. The fatigue of the OWT stems from external factors like the surrounding environment (wind and waves), as well as internal factors such as forces created by the blades upon other components, the height of the turbine and shear weight of the structure. [15]

Decommissioning of OWFs has in the past been performed by the usage of methods derived from the Oil & Gas (O&G) industry, or by the use of a reverse instalment method, and sometimes as a combination of these. The reason for adapting methods from the O&G industry is that there are some main technical similarities with the offshore wind industry regarding the structures. Both industries include structures with a variety of foundations, such as gravity base, piles, jackets, and suction buckets. These structures also face similarities in their operating area, with challenging weather conditions, sea conditions and seabed variety. While there are also found differences between the industries, where the size and numbers of the structures are quite different. An O&G platform is typically a single heavy complex installation, whereas offshore wind farms include multiple and often identical installations. As a consequence, offshore wind operations are more challenging when it comes to logistics, especially decommissioning of multiple OWTs. Here often overlapping operations must take place with the use of several specialized vessels to make the best use out of the available weather window. [16] [20]

Within the O&G industry the role of remotely operated vehicles (ROV) and subsea tools is continuously growing and have become an important part of the industry's underwater operations. Here many of these developments can be directly transferable to the offshore wind industry, from the early stages of the project (surveys and observations) to the end of the projects lifetime (decommissioning and post-monitoring). The general aim of an ROVs is to minimise the use of divers, especially in deeper waters. Where the usage of divers for various operations may be time consuming, costly, and often with a high safety risk. [3] [11]

With the offshore wind industry being relatively young and have obtained minimal experience with decommissioning operations, there can be found high uncertainties and many unexpected challenges within the decommissioning process. The most important challenges which have been found can be categorized into four main aspects: the regulatory framework, the planning of the decommissioning process, the environmental impact, and the logistics and availability of vessels.[19] These will be addressed more in detail within chapter 3 and discussed further in chapter 6. As each OWF has it's unique location and varies in size, each farm is therefore met with different environmental conditions, which affects the availability of access for decommissioning operations and the methods available for the structure removal. The location and size often also determine how the OWT's are attached to the seabed, where both fixed- and floating foundations can be seen. With the individuality of the OWFs, general guidelines for decommissioning can be difficult to obtain. It is then important with proper planning for decommissioning from the start of operation to minimize the risk of unwelcomed challenges which can quickly become a costly affair.[19] [15]

NIRAS is a company which have been at the forefront of offshore wind farm decommissioning. As a response to the challenges related to OWF decommissioning, they released ODIN-WIND, as a tool to assist stakeholders with the decommissioning process. [15]

DecomTools is a 4-year duration project which have the main objective to seek improvement of the dismantling and recycling of OWFs for the aid of stakeholders. The DecomTools project includes 7 work packages (WPs), were research will be done on management and communication (WP1, WP2), market analysis (WP3), process optimization in technical and operational aspects (WP4), logistics (WP5), recycling (WP6), and commercialization of results found, scientific plus economic continuation, and recommendations for policy makers (WP7). [48]

1.2.2 Decommissioning projects

Only a few offshore wind farms have been decommissioned so far. In Europe, several decommissioning projects have been performed, but these have been relatively small compared to newer installations, when considering the number and size of the turbines. A summary of these past decommissioning projects up to 2019 can be found in Table 1. There are number of reasons for the removal of these installations, where some have been research projects or demonstrations, and some installations were proven not to be profitable to keep further in operation. Only a few of these turbines were decommissioned at their actual end of lifetime.[16] However, many offshore wind turbines will reach the end of the designed life span in the years to come, and here the decision between lifetime extension, repowering or decommissioning will have to be made. The expected number of OWTs in Europe that will reach the end of their lifetime, are over 1,800 between 2020 and 2030, while nearly 20.000 OWTs are expected from 2030 to 2040.[19]

Wind farm:	Number, turbine size:	Foundation:	Country:	Removal:
Nogersund	1 x 220 kW	Tripod	Sweden	2007
Robin Rigg	2 x 3 MW	Monopile	UK	2015
Yttre Strengrund	5 x 2 MW	Monopile	Sweden	2015
Hooksiel	1 x 5 MW	Tripile	Germany	2016
Lely	4 x 500kW	Monopile	Netherlands	2016
WindFloat	1 x 2 MW	Floating	Portugal	2016
Vindeby	11 x 450kW	Gravity based	Denmark	2017
Utgrunden I	7 x 1,5MW	Monopile	Sweden	2018
Blyth	2 x 2 MW	Monopile	UK	2019

Table 1 Decommissioned OWTs in Europe [16][19]

Since the location of offshore wind farms differ, with in particular the variation in water depth and soil type, multiple types of foundations exist. When looked at the existing offshore wind farms today, the monopile foundation is found to be the desired solution for several different operating conditions. Where in the Nordic Sea region, 90 percent of the installed OWTs have monopile foundations (figure 1).[4] With such a high percentage and the upcoming inevitable end of lifetime for these foundations, this report has focused on the decommissioning of monopile foundations.

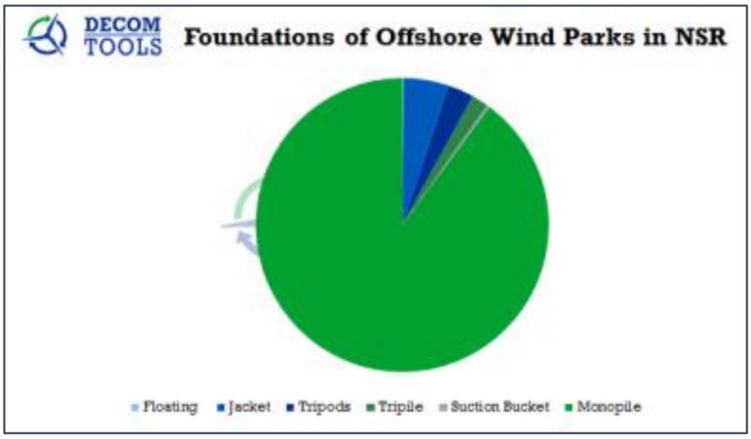

Figure 1 Foundations of OWF in the Nordic Sea Region [4]

1.3 Report methodology

This report seeks to answer the research questions stated, by performing an extensive literary study. Limitations can be found in the market surveys due to the difficulty of obtaining the technical specifications of assets from some companies. Many of these assets are specifically constructed for certain projects and considered closed information. The market surveys may for this reason have its restrictions. Detailed information was also found to be minimal/lacking for past decommissioning projects, as well as for tested and alternative methods for substructure removal.

The structure of the report is divided in 6 additional chapters. Within chapter 2, further basic knowledge upon the offshore wind turbine and its components is presented. The variety of foundations concepts for OWTs, as well as the connection of the entire OWF system (grid) is also introduced.

Chapter 3 goes more in depth about the general process of decommissioning of OWFs. Here will be described the most common methods for partial removal of the monopile foundation, as well as alternative methods for full removal. There will also be addressed the regulations for decommissioning, the economic aspect, and environmental challenges.

The finding of the market survey of the different available ROVs will be presented in Chapter 4. Here will also be a short description of the different types: Observation ROV, Inspection ROV, Survey ROV, Work class ROV, AUV and bottom crawlers.

Chapter 5 will present the findings of the market survey considering the available ROV tools which can be used for decommissioning purposes, and a short description of these. As well as, to present findings of the market survey considering other available decommissioning tools designed for monopile foundations, followed by a brief description.

Within chapter 6, a discussion can be found on the findings of the market survey, and the challenges/restrictions found here will be highlighted for future thought regarding upcoming decommissioning projects. Followed, in chapter 7, will be a conclusion of the research.

Chapter 2. Typical concepts for offshore wind farms

The intention of this chapter is to briefly describe the technical components and the design of an OWT, the different foundation concepts applied today, as well as concepts to be seen in the near future. Due to the objectives of this report, the substructure of OWT with a monopile foundation will be described in more detail. This chapter covers only the design of horizontal axis wind turbines (HAWT) since the majority of OWFs contains this structure of a turbine. Vertical axis wind turbines (VAWT) can be mentioned to have several benefits. These turbines can in principle be built larger than horizontal axis turbines offshore with power of up to 20 MW. This, due to their lower center of gravity. Today, however, no current demonstrations of VAWTs can be found in a substantial scale.[65]

2.1 Typical OWF layout

An offshore wind farm can have several different layouts, but in general the OWF consists of a number of turbines which are connected through array cables (the internal power grid), one or more onshore/offshore substations and an export cable to transmit the power to the onshore grid for further distribution. [12]

In order to transport the energy from offshore wind turbines to the onshore energy grid, cables have to be placed along the seabed. The array cables connect the wind turbines to each other and to an offshore substation if present. Array cables exits the foundation near the mudline and are buried normally 1 to 2 m below the mudline. Export cables connect the wind farm to the onshore transmission system. These are buried to avoid exposure and are in some cases covered with scour protection. An illustration can be seen in figure 2 below. [12]

The purpose of an offshore substation is to minimize transmission losses and transform the power generated at the wind turbine to a higher voltage for transmission to shore. The offshore substation can also be utilised as a convertor station, by transforming the power from alternative current (AC) to direct current (DC). [12]

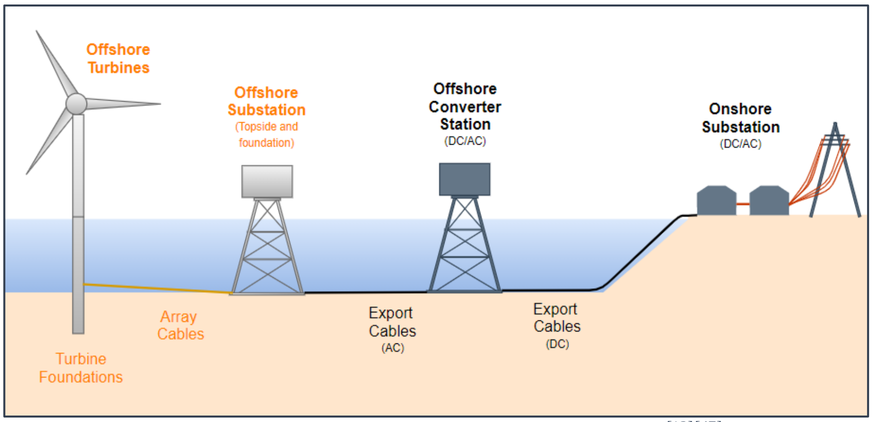

Figure 2 Illustration of OWF grid – Own illustration [12][47]

2.2 OWT components

The general objective of an OWT is to capture the wind's energy and convert the mechanical rotation of the blades into electrical power for further distribution. The offshore wind turbines are facing a much harsher environment than the wind turbines onshore. This naturally has an impact on the components of the OWT, and higher requirements are set for these components. The materials exposed to the weather conditions needs a higher resistance for corrosion, and the structure has to endure the high wind speeds and rough sea motions. The OWT components also requires a high reliability, as access to these turbines are more limited and challenged in comparison to wind turbines onshore. The limited access also affects the decommission of the turbines, as delays can be costly. The equipment and transport needed also brings with extra costs. [15]

The main components of an OWT can be divided into three categories: support structure and submerged structures, wind turbine, and electrical supplies. Figure 3 and table 2 below gives an overview of all the main components, for a monopile structured OWT. Only the support structure and submerges structures will be described further.

Support & submerged structure	Foundation
	Transition piece
	Scour protection
	J-tube
Electrical supplies	Cable
	Substation
Wind turbine	Tower
	Nacelle
	Hub
	Blade

Table 2 OWT components [12]

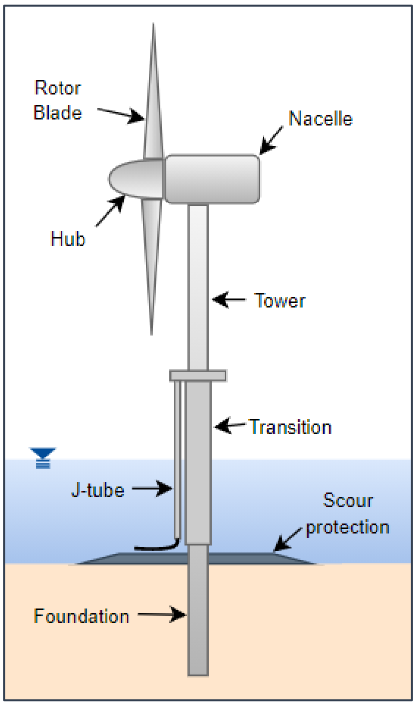

Figure 3 OWT structure and components (Monopile)- Own illustration [12][14]

The substructure and supporting structure for an OWT with a monopile structure, consists mainly of the foundation, transition piece, scour protection and j-tube. The various foundation concepts will be further addressed in chapter 2.3, with an emphasis on monopiles.

The transition piece is placed on top of the foundation after instalment and has the task of connecting the foundation to the tower. As well as to correct any horizontal inaccuracies. The transition piece is placed just over the seabed and is found both over and below the water. The gap found between the monopile structure and the transition piece is usually filled with a cement grout. Attached to the transition piece one can find access ladders, access deck, electrical components (e.g., transformer), j-tubes, and other components, depending on the individual OWF. [12] J-tubes are basically steel tubes, which have the task to support and protect the cables between the seabed and the top part of the offshore wind foundation. [10]

Scouring is an unwanted phenomenon which can occur over time as the tidal current passes by the monopile. This current will grab particles from the seabed and move these away from the foundation. After some time, deep holes can be seen to form, and this effect is called scouring. These holes pose a major threat to the stability of the foundation and can in the worst-case scenario make the whole OWT structure sink. This phenomenon can occur in multiple environmental conditions. Foundations placed on a seabed that consists mainly of sand can be seen to be especially vulnerable. To avoid scouring, often scour protection is placed around the foundation in the form of large rocks and concrete mattresses.[16][21]

2.3 Foundation concepts

Due to the harsh offshore environment and the OWT¨s tall slender structure, several challenges are faced when designing the foundation for these turbines. The wind turbine has a natural tendency to tip over due to the shear force of the wind which creates a large moment load to the foundation. This is one of the most important factors to consider in the design and choice of the OWT's foundation. [10]

Additional parameters are needed to be taken into consideration in the design phase, which includes the water depth, size and weight of the OWT, wave loads, seabed characteristics, and the turbines frequencies in wave motions (particularly resonance frequency). Each OWF project is therefore needed to customize the foundations to its particular location. The most common used foundation types for OWT found today is fixed foundations. The use of floating foundations for OWTs is in an early development stage but can be seen to be a promising solution for locations with deeper waters. [1] [12]

2.3.1 Fixed foundations

The most common used types of fixed foundations include monopiles, jackets, tripods, gravity base, and in a few cases suction buckets. The fixed foundations are typically designed to be installed in relatively shallow waters of up to 50m, depending on the type. A listing of the designated water depth of the different foundations can be found in table 3, and an illustration of the various foundations in figure 4.

Fixed foundation types:	**Approx. Water Depth:**
Suction bucket	*Shallow water:* 0→30m
Monopile	*Shallow water:* 0→30m
Jacket, with suction buckets/piles	*Transitional water*: 30→50m
Gravity base	*Shallow water:* 0→30m
Tripod, with suction buckets/piles	*Transitional water*: 30→50m

Table 3 Fixed foundations types for OWTs [22]

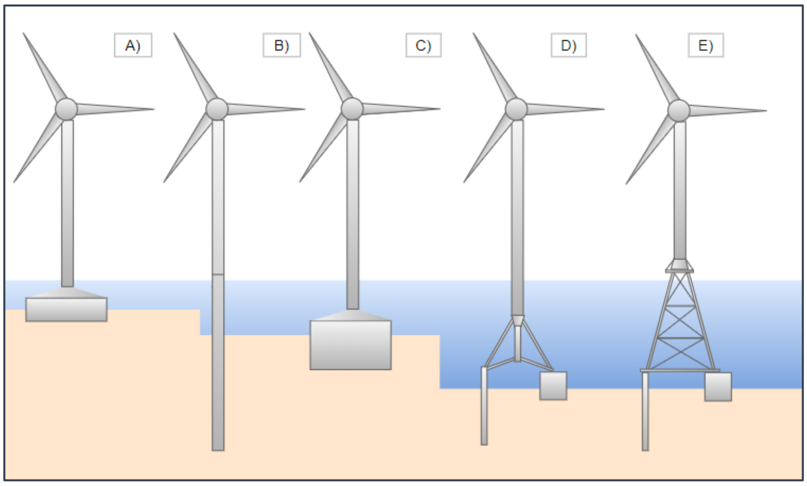

Figure 4 Fixed foundation types. A) gravity base, B) Monopile, C) Suction bucket, D) Tripod, E) Jacket – Own illustration [8]

Since the objective of this report is to look at decommissioning of monopiles, only these foundations will be further described.

Monopiles are preferred for OWF projects in areas of more shallow waters, up to 25-30m. Which is mostly for standard monopiles without any lateral support. With that said, monopiles with lateral support braces can be suitable for depths up to 40 m. A monopile is basically a cylindrical steel tube. To construct a monopile, steel plates are rolled to a round shape in the desired diameter and welded together. Multiple of these rounded plates are then welded on top of each other, to create this steel tube with its designed height. Monopiles in the offshore wind industry can have a diameter from 4 up to 11m and weigh in an approximate range of 500 to 2,000 tonnes. The length of the monopile will vary with the diameter and can be found to be from 60 to 80m. The monopiles have a relatively large wall thickness, ranging from 50–150 mm. In general, the dimensions vary within projects, and today, most monopiles are found to be of the lower range of the size scale. While newer OWTs can be seen to have increased dimensions. [22][12]

Figure 5 Monopiles for Gode Wind OWF project [66]

After the monopile has been manufactured, the pile will be transported to its operating area by either a barge type vessel or other type of vessel. The instalment method is determined by the seabed conditions. The monopiles are normally driven into the seabed by either large impact or vibratory hydraulic hammers, or the monopiles can be grouted into sockets which has been drilled into rock. The monopile is penetrated in the seabed with around 40 to 50 percent of its height, providing it with the stability needed to withstand the loading from waves and wind. The most favourable seabed conditions for monopiles are a semi-hard seabed, whereas hard seabed types can cause deformation of the piles during instalment. [22][10]

The monopile foundations are widely used because of several factors. These foundations have a simple geometric shape which is easy and relatively inexpensive to manufacture. The instalment of these piles may be less complicated and costly than other fixed foundations, and often little seabed preparations are needed. However, there are also some drawbacks. The instalment of these piles requires heavy duty equipment and specialized vessels with large cranes for lifting. The hydraulic hammers may also cause considerable noise and vibration disturbance which can have negative impact on the environment and the nearby fishing industry.[22][12] In Europe we can see that the monopile is the most commonly used type for OWT foundation. The reason behind this is mostly due to the water depths of the operation areas and soil characteristics. The majority of the OWFs in Europe have been constructed in shallow waters (>30 m depths). In the North Sea, the soil of the seabed consists mainly of sand and gravel, which has been found to be economically beneficial for drilling of monopiles as less effort is needed. [4]

2.3.2 Floating foundations

For locations with sea depths over about 60–80 m, it can be seen to be uneconomical or even be technical unfeasible to place OWTs with fixed foundations, and here other solutions must be found. As the desire for harvest of wind energy moves to deeper waters, floating foundations are entering the market to replace fixed foundations for the OWTs. A floating foundation is supporting the offshore wind turbine by being anchored to the sea. Floating wind farms can have several benefits, as now deeper waters are a possible location. This increases the available sea area significantly for OWFs. It can also minimize visual noise, provide safer accommodation for fishing and shipping lanes, and achieve stronger and more stable winds by positioning the wind farms farther offshore. [8][10]

The types of floating foundations can be classified into three main classes, according to how the foundation achieves its stability. Floating foundations can achieve its stability by mooring line (tension leg platform), ballast, and buoyancy. [1][8] Here, many variations can be seen within every class. An approximated depth rating for four of the most commonly/ promising types on the market (Spar-buoy, TLP (tension leg platform), Barge and Semi-sub), can be found in table 4, and illustrated in figure 5.

Floating foundation types:	Approx. Water Depth:
Spar-buoy	*Deep water:* >100m
Tension leg platform	*Deep waters:* > 50m
Barge	*Deep waters:* > 50m
Semi-submersible	*Deep waters:* > 50m

Table 4 Floating foundations for OWT [1][22]

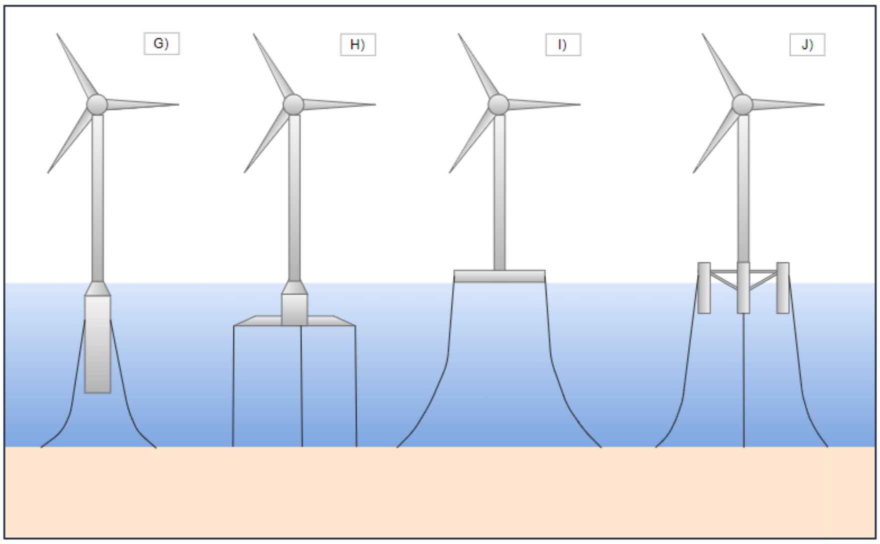

Figure 6 G) Spar-buoy, H) TLP, I) Barge, J) Semi-sub – Own illustration [1][8]

Chapter 3. Process and key aspects for OWT decommissioning

This chapter aims to describe the decommissioning process for wind farms with an emphasis on removal of the substructure and the monopile foundation. A description of some of the available methods, both tested methods and concepts, will be presented. A mentioning of the cost aspect of decommissioning, decommissioning regulations, as well as the environmental impact of foundation removal will also be made.

3.1 Overall process for decommissioning

A complete design for how the OWF will be dismantled and transported back to shore at the end of operation, should be presented to the appropriate authority, at the early stage of an offshore wind farm's development. The decommissioning of the turbines has a large impact on the economics of an OWF project, as well as an impact over the environment for the particular location of operation. Knowledge and development on removal techniques and decommissioning tools are therefore both important and urgent for the offshore wind industry to be a competitive part of the renewable energy industry.[19]

In every operation there will be uncertainties and unexpected events, and with the offshore wind industry being fairly young, there is bound to be a few of these uncertainties. Planning and managing the decommissioning process from the start and considering every sub process is important. This gives room to identify the uncertainties or challenges, and a greater opportunity to find solutions for these.[15]

The typical processes of decommissioning an OWF can be divided into three parts: decommissioning offshore, onshore operations and the dividing of gathered elements into waste and resources. For the first part regarding the offshore operations, it includes all operations such as preparations, removal of topside structure, removal of submerged structures and cables, and transport of the components to shore. Here it also requires to be planned for considerations such as the capacity of vessels for transport and removal operations, weather restrictions, and capacity of ports. For the second part, the onshore operations, here the components are received and cleaned for marine growth, stripped, sorted in groups for resources and waste, as well as being further dismantled and downsized. The last stage is the distribution of the components further, where the components will either be considered waste, threated as hazardous materials, reused, or recycled. [15]

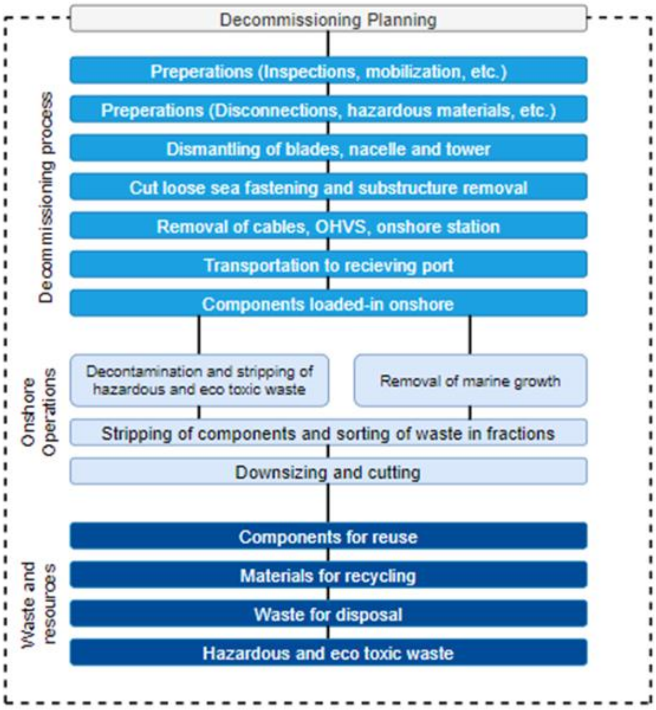

Figure 7 Decommissioning process for OWT [15]

3.2 Removal of foundation

The decommissioning process of the topside structure of the OWT has usually been performed by reversing the instalment procedure, by removing the electrical structure, the rotor, the nacelle, the tower, and then the transition piece. These components are all above the waterline and provides therefore an easy access for decommissioning. While for the foundation, there are several methods that can be applied depending on the site, contract terms, environment, and regulations. If the installation is to be completely dismantled or whether any pieces are to be left behind is the key element to be addressed in removing the substructures. It’s been common practice for removal of monopiles to cut the pile under the mudline and for the remaining part to be left in its place. While concepts for complete removal have yet to be thoroughly field-tested. [15][19]

Comprehensive planning is required prior to the start of removal operations, in order to come up with the most efficient, economical and sustainable solution. Surveys are important to check the conditions prior to removal, as well as to monitor the site recovery, post-decommissioning. At the time of removal, seabed conditions may have change dramatically from the time of installation, due to currents and marine life/growth. Hence a thorough inspection, including assessment of seabed and structural integrity checks, is required prior to the start of decommissioning. This can be done by divers or by remote operated vehicles (ROVs). Preparatory work at the site depends on the removal concepts and can include tasks such as dredging prior to a possible cutting operation, tool deployment and removal cables and other installations.[5][10]

Before removal of the monopiles, cables need to be disconnected. With the array cables, there is a debate on whether to leave these at the site, partly remove the cables or remove them entirely. If the array cables are left in place, the ends will either be cut or buried. Additional work, in form of post monitoring will have to be performed, as the cables poses a long-term liability. If the cables are to be removed, a reversed cable instalment method can be used. Another decision to be made is what to do with the array cables placed under the scour protection. Here the options are to either leave them in site or remove them along with the scour protection. Removal of the scour protection can also have a negative impact on the surrounding environment, as often marine habitats form here, where the scour protection acts like a shelter. The decision here depends heavily on what the permits allow and on which method is the most effective and convenient. When it comes to the export cables, the best case is to leave them in site, as they are buried much deeper than the array cables. Excavating these will cause a lot of damage to the environment as well as being an expensive operation. The j-tubes, if present, also needs to be removed. This is usually done by cutting the steel pipe after removal of cable and lifted unto the designated vessel.[8][12]

3.2.1 Partial removal

The first step of the partial removal method for a monopile is to inspect the piles and to decide what lifting attachments are needed. The inspection is done either by divers or ROV. Then the vessel(s) for lifting of the pile and deployment of tools and ROV/divers, is placed on site. If the pile is covered with a scour protection then this might need to be removed, same with possible j-tubes, before the cutting can take place. If grouting has been placed between the transition piece and the pile, then both these components can be lifted together. If the transition piece is attached in another manner, it might be convenient to perform two separate lifts. The crane will hook itself to the foundation, guided by diver/ROV. Often drilled holes in the pile is created as a method for attaching the lifting hooks to the pile. Before the foundation is removed, it is cut below the mudline. This is usually done 1-5 meters down, depending on the decommissioning plan. The cutting tools applied are usually either diamond wire or water jetting. The most established cutting methods for decommissioning monopiles are internal and external cutting techniques. These techniques are well proven and tested for various pile dimensions in the O&G industry. [8][12][18] Some of the decommissioning tools will be described more in detail in chapter 5.

Figure 7 shows the method for external cutting. Here the seabed around the monopile needs to be dredged down to desired level. The preferred cutting tool is then lowered down and guided into the external wall of the monopile. While during internal cutting, the soil within the monopile has to be excavated down to the level according plan, before the tool is lowered inside, and guided to the internal wall of the pile. Monitoring of the whole process in the external method can be done by diver or ROV. For the internal cutting process, ROV are the more applied approach. After the pile have been cut and lifted, the remaining part of the monopile must be covered with soil.[9] Figure 8 shows an illustration of the internal cutting method. An overview of these methods, removal of the monopile with transition piece (cut external/internal) and the removal of the monopile without the transition piece (Cut external/internal), is shown in table 5.

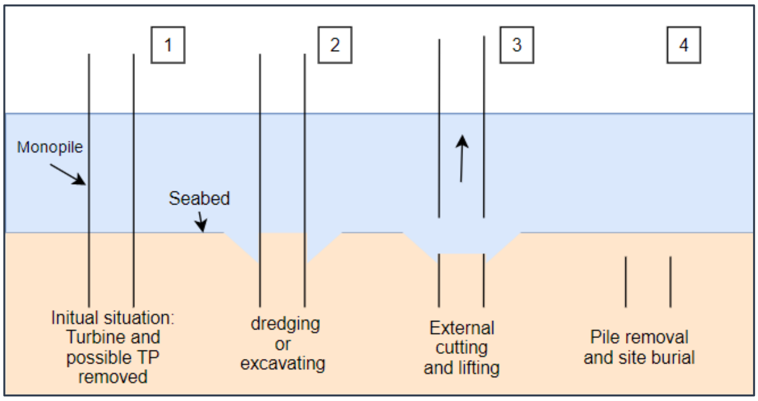

Figure 8 Cutting and pulling method – Partial removal of monopile foundation – Own illustration [9]

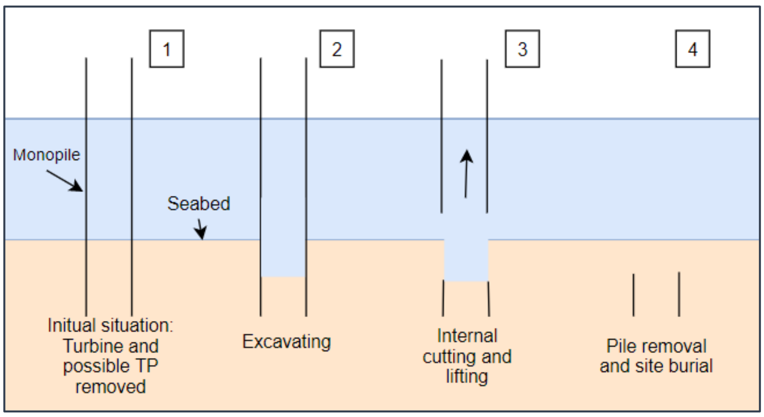

Figure 9 Internal cutting and pulling method – Partial removal of monopile foundation – Own illustration [9][12]

Decommissioning Concept:		Description:
1.	Partial removal	Substructure with transition piece in one piece cut internally below the seabed
2.	Partial removal	Substructure and transition piece in separate pieces cut internally below seabed
3.	Partial removal	Substructure with transition piece in one piece cut externally below the seabed
4.	Partial removal	Substructure and transition piece in separate pieces cut externally below seabed

Table 5 Methods for partial removal of monopile foundation [9][12]

3.2.2 Complete removal

When it comes to full removal of the monopile from the seabed, there are several ongoing projects which are working on developing new alternative concepts for decommissioning wind farms, although these are not fully commercialised yet. The uncertainties in the requirements of regulations to come in the future, concerning whether full or partial removal is the best solution, are driving alternative methods to be developed. Especially, when full removal of the monopile is needed.[9]

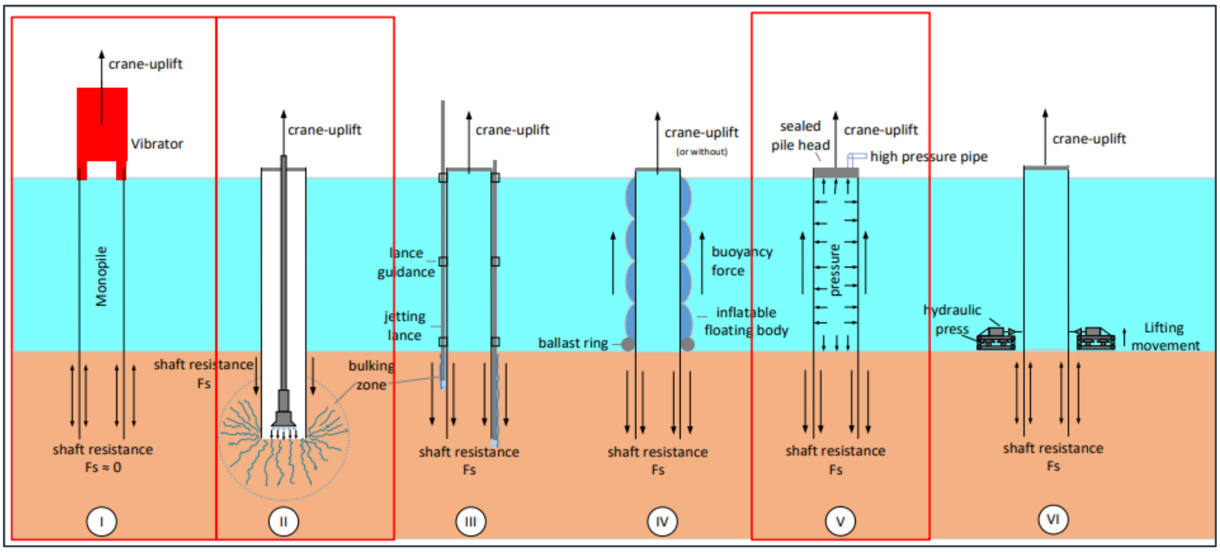

Figure 10 Alternative methods for complete removal of monopile foundation [9]

The project, Hydraulic Pile Extraction Scale Tests (HyPE-ST), has the objective to explore alternative options for sustainable removal of OWT monopiles. The HyPE-ST project aims at developing an innovative method to remove the entire monopile, in order to recycle the steel normally left behind by partial removal methods. The studied method is based on the possibility to fully remove the pile by hydraulic extraction. To achieve this, the pile is first sealed, and the empty void will, by hydraulic pressure, be pressurised using a fluid (e.g., seawater). This pressure will cause the pile to be able to rise upwards and overcome the frictional resistance forces along the monopile structure, and hence be able to be lifted out of the seabed.[64] An illustration of this concept can be seen in figure 9 (method V). The Institute of Foundation Engineering and Soil Mechanics of the Technische Universität Braunschweig (IGB-TUBS), have also run several tests on this technique, replacing fluid pressure with air pressure.[9]

The IGB-TUBS is also developing and testing other methods to remove the offshore monopiles completely, where the vibratory extraction method is one of these. Vibratory pile driving is often used for offshore monopile installation. The same principle here, can also be used for decommissioning of the monopile. The vibrator equipment is placed on top of the pile, and generates a frequent up and down movement, moving the pile and the surrounding soil. The soil can enter a state of liquefaction due to the acceleration of the soil particles across the pile, and the structure resistance is reduced drastically.[9] The vibratory extraction method has already been used at the wind farm Lely, for multiple monopiles. Although these monopiles were of small dimensions, the method can be seen to have potential for scaling up.[12] An illustration of this method can be seen in figure 9 (method I).

Another method, also studied by IGB-TUBS, is complete removal by internal dredging. This method includes a dredging tool which is deployed within the monopile. The tool excavates the soil all the way down to the end of the monopile. The structure resistance is then reduced, and the pile can be lifted up. [9] This method is illustrated in figure 9 (method II).

The last method to be mentioned is external dredging. Which works in principle in the same way as with internal dredging, only here the soil is excavated around the monopile by e.g., an ROV, before lifted.[15]

Decommissioning Concept:		Description:
1.	Complete removal	Removal of the monopile by external dredging
2.	Complete removal	Removal of monopile by vibratory extraction and lifting
3.	Complete removal	Removal of monopile by internal dredging
4.	Complete removal	Removal of monopile by air-pressure / water- pressure

Table 6 Methods for complete removal of monopile foundations [8][9][15]

3.2 Decommissioning costs

A cost estimate is an important part in the decommissioning process, and should include planning, site preparations, offshore removal, equipment and vessel day rates, transportation, dismantling and handling of the waste and resources. In decommissioning of an OWT, the removal of the foundation has been seen to take up a large part of the budget, compared to removal of the other OWT components. This depends a large deal on the method chosen, and what type of equipment, designated crew and vessel(s) that are needed, as well as the timeframe of operation. In deciding upon which method for foundation removal, all aspects of the processes mentioned above needs to be taken into consideration. The vessel's day rate is a highly uncertain cost factor, as the cost varies due to the competitive market and seasonal variations. Weather risk is an also an important factor in offshore work, where rough sea state and heavy winds can delay operations significantly. Port facilities are also to be included in the budget for decommissioning cost. The availability and capacity of the port varies, and a significant price difference can also be seen between ports. [12][15][16]

3.3 Environment

One of the most debated topics around the decommissioning of an offshore wind farm is the impact on the marine environment. Here two aspects stand in focus; the partial or full removal of the foundations and cables, as well as the handling of the materials after removal. In regard to the discussion on whether or not to fully remove the foundation, there is divided opinions. The main goal is to avoid disturbing as much of the marine environment as possible, while the operation should be economic. The main factors that contribute to this decision are the regulations, the location, and conditions of the seabed. When it comes to handling of the removed components, it is important with a sustainably strategy. As much of the materials as possible should be reused or recycled, and of course avoid a large amount of waste and hazardous materials. As the offshore wind industry evolves and the dimensions of the turbines increases, so does the amount of raw materials needed to construct these OWTs. Which can, as a result, compromise the sustainability of the following decommissioning process. [15][19]

3.4 Regulations for decommissioning

As only a few decommissioning projects for OWFs has taken place so far, only a few countries have made a fixed set of rules and procedures for the decommissioning process. Therefore, it can be seen to be some insufficiencies in regulations, and a lack of relevant guidelines. Starting points are for the most part the existing rules in the O&G industry, and the general regulations on HSE (Health, Safety & Environment) are also to be obtained concerning vessel operations. For projects in the North Sea and most of the European waters, the international regulations and guidelines from IMO (International Maritime Organization) and UNCLOS (The United Nation Convention on the Law of the Sea) should be followed, as well as regional (the OSPAR agreement) regulations, and national regulations. When it comes to the decision between partial or total removal of submerged structures, the IMO guidelines have listed 6 key components which is to be considered when making this decision. The general statement found from the IMO guidelines, the OSPAR convention and UNCLOS regulations, is that no part of a structure should remain after removal of offshore structures, as there should be no harmful impact on the marine environment. At the same time, these applies for the most part for structures above the seabed, and buried structures could be of consideration if this is proven to be the better solution for the environment. This highlights the fact that each OWF is its one unique case, and that it is up to every wind farm to adapt these regulations in the best possible way. [12][15][19]

Chapter 4. Survey of actual ROV's for decommissioning purposes

This chapter will briefly introduce the categorization of ROVS, different areas of operation and basic components of the ROV and ROV system, as well as to present the findings of the market survey. A fuller detailed listing of the available ROVs found within the market survey can be seen in appendix, A.1.

Today ROVs are found frequently applied in operations within the offshore O&G industry. The ROV aids here in important operations such as drilling, construction support (surveys, monitoring, diverse tasks), and IRM (inspection, tooling). These vehicles have now taken over many of the tasks previously performed by divers, as the ROV is proven to perform in a safe and effective way in subsea operations, especially in deep waters. This technology could, on this basis, become a viable tool for the offshore wind industry.[11]

The term remotely operated vehicle covers several variations in types of vehicles which can also have numerous options for equipment. A basic ROV has the option to be modified to carry out different tasks, and for this reason there is a large variation of ROV designs on the market today. Many ROV suppliers will make a series of ROVs based on own specifications and their targeted customers. While many suppliers will also make custom ROVs, as many companies demands certainty specific requirements the ROV due to the individuality of projects. It can also be seen within the larger ROV operating companies, that they prefer to design their own ROVs., with or without an existing ROV supplier. [3][11]

Before the investigation of possible ROVs that are available on the market today, which can aid in decommissioning operations and the removal of monopile foundations, a categorization of the ROVs was made. The remote operated vehicles were divided into 4 classes based on the vehicle's tasks, as well as two additional classes including bottom-crawling vehicles and AUVs. The market survey was for this reason based on these 6 groups:

- Survey ROV
- Observation ROV
- Work ROV
- Inspection ROV
- Bottom-Crawling Vehicle
- AUV

It should be noted that the market survey has included ROVs from a wide range, where some of these vehicles are more suitable for the removal of monopiles process than others. The findings will be further discussed in chapter 6. As an ROV can perform several different tasks and can for this reason be placed in more than one of the 6 mentioned classes, the ROV has been placed in the most relevant class.

4.1 ROV system

A regular ROV system consists normally of 4 subsystems [3]:

- The ROV itself
- Cable system, with or without a TMS (Tether Management System)
- Handling system, including a LARS (Launch And Recovery System)
- Control container, housing the ROV pilots and the control equipment.

The ROV itself can be divided into multiple components. An ROV has a frame with buoyance elements, a propulsion system, control system, electrical power supply, power transmission, pilot feedback system, as well as possible manipulators and additional tools for some.[11]

The cable system has the objective of transferring energy to the ROV, as well as signals to and from the ROV. A Tether Management System (TMS) is sometimes used, where the ROV needs to perform work which is relative stationary and at greater depths. The TMS is launched with the ROV and lowered down to the depth of operation. Here the ROV can release itself from the TMS, and only a thin cable (tether) is now connecting the TMS and ROV. The tether has neutral buoyancy and the ROV is free from the forces of the sea current which now only affects the cable from surface to the TMS and the TMS itself. Another benefit of the TMS system, is that it will protect the ROV from splash forces while launching, as the TMS acts like a protecting cage. [3][11]

The handling system has the purpose of launching and retrieving the ROV. The system usually consists of an A-frame or a crane boom, and a winch for the main cable and the possible TMS. In some cases, there is a system for heave compensation connected to the winch, which makes it easier for launch and recovery of the ROV in high waves. In some projects the moonpool of a vessel is utilized for handing of the ROV, which also have its benefits on launch and recovery in rough sea states. [3][11]

The ROV is usually controlled from a control container on the deck, or in some cases from inside the vessel in a control room. The ROV pilot manoeuvrers the ROV, and manipulators if present, by the use of joysticks. A large number of switches are also available, which can be used for adjusting e.g., the vessel winch, power supply, video cameras, lighting and sonar.

The pilot's eyes in the operations are large monitors displaying live video feed from ROV cameras and information from the subsea navigation system. A special workshop container is also taken along so that servicing and emergency repairs can be carried out on the ROV. [3][11]

4.2 Observation ROV

Observation ROVs are equipped mostly for activities of pure observation. These small sized vehicles are fitted with camera, lights, thrusters and in some situations, a sonar. Vehicles can also be fitted with simple manipulators to e.g., relocate light objects or brush sediments away. Observation ROVs are usually electrically driven, where the electrical power is transmitted through the umbilical from the surface. The propulsion system consists in most cases of thrusters, which can be based on alternating current or direct current. The vehicles within this class are typically hand launched or in some cases launched by a TMS system. [3][11]

From the market survey, 26 individual observations ROVs from 14 suppliers were found and investigated. These ranges in dimensions, weight, and water depth range, where the main goal is to provide observations task in various environmental conditions.

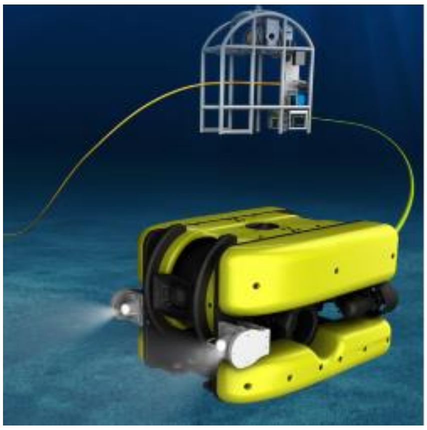

Figure 11 Observation ROV - Sea Maxx [50]

Market Survey: Observation ROVs					
ROV model:		Supplier:	ROV model:		Supplier:
1	AlphaROV D150	Eprons	14	Observer Mini-ROV	Subsea Tech
2	Argus Mini	Argus Remote Systems as	15	Omni Maxx	Oceaneering
3	Argus Rover	Argus Remote Systems as	16	ROV-500	Outland Technology
4	DeepBot	Sperre	17	ROV-1000	Outland Technology
5	DTG3	Deep Trekker	18	ROV-2000	Outland Technology
6	Falcon/Falcon DR	N sea/SAAB Seaeye/DeepOcean	19	ROV-2500	Outland Technology
			20	Sea maxx	Oceaneering
7	Gnom Baby	Gnom ROV	21	SeaOwl XTi	SAAB Seaeye
8	Gnom Pro	Gnom ROV	22	SRV-8	Oceanbotics™
9	H300V	ECA Group	23	Super Gnom	Gnom ROV
10	H300 MK2	ECA Group	24	Tiger	SAAB Seaeye
11	Lynx	SAAB Seaeye	25	Xle Spirit®	Forum
12	Mohican	DeepOcean/Forum	26	SRV-8	Oceanbotics™
13	Mojave	DeepOcean/Forum			

Table 7 Market survey – Observation ROVs

4.3 Survey ROV and Inspection ROV

Survey ROV has the objective to perform tasks such as seafloor mapping and inspection of pipelines. The equipment of these vehicles depends on the individual project. Navigation and positioning systems are especially important for survey ROVs due to their tasks. Satellite-based navigation are often used by the surface vessel, while hydro acoustic systems are used below the surface. From the bottom of the surface vessel, a transmitter sends out signals into the water (directional/omnidirectional), in order to find the position (depth, direction, and distance) of the ROV related to the vessel. The accuracy of the positioning is dependent on the water depth, where deviations will increase often significantly below a 300 meters depth. A hydro acoustic grid can be laid on the seafloor to help reduce these deviations. The ROV pilot navigates the ROV by the aid of sonar, gyrocompass, and by video camera when close to target. Speed has shown to be important for a survey ROV, more so than a regular work ROV, and often have a different thruster placement. Survey ROVs are usually operated without TMS.[3][11]

Figure 12 Survey ROV - Superior Survey ROV [26]

An inspection ROV has the natural objective of performing inspections tasks, such as inspection of submerged structures, anchoring points, and subsea production systems. There are typically three different categories, when it comes to inspection tasks. Category one includes general visual inspection, and simple measurements readings (cathodic protection measurements). The visual inspection is performed mainly with video cameras. Tasks here includes detecting if there are any damages to structures, checking the general condition of structures and search for lost objects. In addition to the visual observation, logs of the environmental conditions are also typically performed. These logs may include pressure readings, temperature readings, oxygen content levels and water salinity levels. Effective lighting is vital for these types of inspections, and same can goes for the other two categories as well. Category two includes a closer visual inspection. Here the vehicles are often equipped with rotating brushes or water jet system to clean structures before inspection. Category three entails a detailed inspection, where NDT (non-destructive testing) is performed to check the conditions of the structures. NDT equipment for these vessels can be based on ultrasound (investigate wall thickness of material), the eddy current principle (locate and depict cracks) or MPI (Magnetic Particle Inspection). The inspections ROVs is remotely controlled and receives energy from the surface. Propulsion is achieved through wheels/belts or with thrusters. These vehicles are often custom made for the individual task, concerning the propulsion and equipment. [3][11]

Figure 13 Inspection ROV - Falcon [55]

From the market survey 20 assets were found and studied from 14 suppliers, where 5 of these are mainly placed in the Inspection ROV class, and 6 are “purely” Survey ROVs, while the rest has the possibility of performing the tasks from both these classes.

Market Survey: Survey / Inspection ROVs			
ROV model:		Supplier:	Type:
1	AC-ROV 3000	AC-CESS	Inspection
2	AC-ROV 100	AC-CESS	Inspection
3	ALPHAROV PROF D200	Eprons	Observation / Inspection
4	ALPHAROV PROF D300	Eprons	Observation / Inspection
5	ALPHAROV PROF D500	Eprons	Observation / Inspection
6	Barracuda	Shark Marine	Observation / Inspection
7	Cougar XT Compact	SAAB Seaeye	Inspection
8	Focus-2	DOF/MacArtney	Survey
9	Focus 3	MacArtney	Survey
10	Mini-ROV Guardian	Subsea Tech	Inspection
11	Mohawk	DeepOcean/Forum	Observation / Inspection / Survey
12	Perseo GTV	Lighthouse/Ageotec	Observation / Inspection
13	Surveyor Interceptor	Reach subsea	survey
14	Seaeye Marine Tiger	DOF	Observation / Inspection
15	Sea-Wolf 5	Shark Marine	Observation / Inspection
16	SRS FUSION	Strategic Robotic Systems	Survey
17	Superior Survey ROV	DeepOcean/Kystdesign	Survey
18	Surveyor Plus	DeepOcean/Kystdesign	Inspection / Survey
19	Tortuga	Subsea Tech	Inspection
20	Triaxus	MacArtney	Survey

Table 8 Market survey – Survey ROV and Inspection ROVs

4.4 Work-class ROVs

For the work-class ROVs, the vehicles can be relatively large in size, and capable of performing complicated mechanical operations. While this class also contains smaller vehicles, which can execute more simple work tasks. These ROVs are often equipped with one or two manipulator arms and numerous tools are also available. Skids can be added to the ROVs which makes it possible to attach specific tools to the vehicle. Work-class ROVs can perform tasks of a vast variety, such as cutting, cleaning, grinding, lifting, drilling, and bolting. The propulsion system is usually electrohydraulic powered, which enables the usage of different hydraulic tools. The transformer in the ROV receives a high-voltage alternating current from the cable and TMS. The electric power is here distributed to electrical motors for hydraulic pumps and to the different ROV functions. The hydraulic energy coming from the hydraulic pump is then divided by the thrusters and hydraulic tools.[3][11]

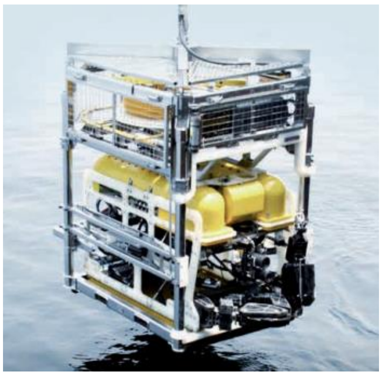

Figure 14 Work-class ROV - Panther Plus[26]

The market survey found and investigated 57 number of work-class ROVs, ranging from small work-class to heavy duty work-class. These were gathered from 14 suppliers.

Market survey: Work-class ROV					
ROV model:		Supplier:	ROV model:		Supplier:
1	Argus Mariner	Argus Remote Systems as	30	Millennium Plus ROV	Oceaneering
2	Argus Mariner XL	Argus Remote Systems as	31	Nexxus ROV	Oceaneering
3	Argus Worker	Argus Remote Systems as	32	Panther Plus	DeepOcean/SAAB Seaeye
4	Argus Worker XL	Argus Remote Systems as	33	Panther-XT	DeepOcean/Fugro
5	Atom/EV	SMD	34	Quantum/EV	SMD
6	Constructer	DeepOcean/Kystdesign/Reach subsea	35	Quasar	SMD
7	Constructer 220 HP	DeepOcean	36	Robotics Gemini ROV	TechnipFMC
8	Comanche	Forum Energy Technologies	37	Robotics HD ROV	TechnipFMC
9	eNovus	Oceaneering	38	Robotics ISOL-8 Pump	TechnipFMC
10	E-ROV	Oceaneering	39	Robotics UHD II	TechnipFMC
11	Freedom	Oceaneering	40	Robotics UHD III	TechnipFMC
12	FCV 600	Fugro	41	Seaeye Cougar XT	SAAB Seaeye
13	FCV 1000	Fugro	42	Seaeye Cougar Xti	DOF/Fugro/SAAB Seaeye
14	FCV 1000d	Fugro	43	Seaeye Leopard	DeepOcean
15	FCV 2000	Fugro	44	Shilling Robotics HD	DOF
16	FCV 3000	Fugro	45	Sub fighter 10k	Sperre
17	FCV 4000	Fugro	46	Sub-fighter 15k offshore	Sperre
18	HD WROV	Reach subsea	47	Sub-fighter 15k standard	Sperre
19	H800	ECA Group	48	Sub-fighter 30k	Sperre
20	H1000	ECA Group	49	Sub-fighter 3000	Sperre
21	H2000	ECA Group / DOER Marine	50	Sub-fighter 4500	Sperre

22	H3000	DOER Marine	51	Supporter	DeepOcean/Kystdesign/DOF/reach subsea
23	H6500	DOER Marine	52	Triton XL	DeepOcean
24	Installer	DeepOcean	53	Triton XLS 150	DOF
25	Isurus	Oceaneering	54	Triton XLX	DOF
26	Jaguar	SAAB Seaeye	55	UHD ROV	DeepOcean
27	Magnum Plus ROV	Oceaneering	56	XLX-C	Forum Energy Technologies
28	Maxximum ROV	Oceaneering	57	XLX Evo	Forum Energy Technologies
29	Merlin UCV R	IKM			

'Table 9 Market survey – Work-class ROVs

4.5 Bottom-Crawling Vehicles

Bottom-crawling vehicles stands out due to their propulsion system. Apart from some who can swim short distances, these are mainly constructed to move along the seabed. To achieve this, the ROV is designed with belts, wheels or so-called Archimedes screws. The power supply and controlling of the ROV comes from the surface. These vehicles are typically large and heavy vehicles and are often designed for one specific task only. Typical tasks for the bottom-crawlers includes cable burial and trenching. Another version of this type of vessel to be mentioned are the immersed structure crawlers, which are mainly used for observations, cleaning and NDT tasks. [3][11]

Figure 15 Bottom-crawler - XT300[32] (to the left) , Immersed structure crawler – Rovingbat (to the right) [28]

11 bottom-crawling vehicles were found in the market survey, where each are equipped and designed for various operations but mainly for trenching purposes. The vehicles were discovered from 3 different suppliers and can be found in the table 10 below.

Market survey: Bottom-crawling vehicles			
ROV model:		Supplier:	Task/Type:
1	Rovingbat	ECA Group	Observation / Inspection
2	T1	Enshore	Mechancial and Jet Trenching
3	T2	Enshore	Mechancial and Jet Trenching
4	T1000	Enshore	Jet trenching
5	T3200	Enshore	Mechancial and Jet Trenching
6	UT-1	Enshore	Jet Trencher
7	XT300	Forum Energy Technologies	Trencher
8	XT500	Forum Energy Technologies	Trencher
9	XT600	Forum Energy Technologies	Trencher
10	XT1200	Forum Energy Technologies	Trencher
11	XT1500	Forum Energy Technologies	Trencher

Table 10 Market survey – Bottom-crawling vehicles

4.6 AUV

Conventional ROVs have a great disadvantage when it comes to great depths, since the forces on the cable increase with depth and range due to ocean currents and gravity. It is therefore desirable to develop vehicles that are free-swimming, meaning they are not connected to a surface vessel through a cable. Autonomous underwater vehicle, AUV, and have no physical link to the surface. They have to bring their own energy or generate it themselves. Collected data is stored on board for later processing on the surface. Experiments are being done with regards to acoustic transfer of video signals to the surface. AUV’s can also manoeuvre in three dimensions and are either following a pre-programmed route / pattern or are acoustically controlled from the surface. Task performed by AUVs today are mostly observation and survey related.[11][17]

Figure 16 AUV: EELUME (to the left)[40] , HUGIN 1000 AUV (to the right)[26]

The marked survey identified 13 AUVs from 7 suppliers combined, which can be found in table 11 below.

Market Survey: AUVs		
ROV model:		Supplier:
1	Alistar 3000	ECA Group
2	A9-E/AUV	ECA Group
3	A9-M/AUV	ECA Group
4	A18D/AUV	ECA Group
5	A18-E/AUV	ECA Group
6	A18TD	ECA Group
7	EELUME	Kongsberg
8	Gavia Offshore Surveyor AUV	Lighthouse
9	Glider AUV	DOF
10	H-ROV	ECA Group
11	HUGIN 1000 AUV	DeepOcean / DOF / Kongsberg
12	Sabertooth	SAAB Seaeye
13	Sabertooth double hull	SAAB Seaeye

Table 11 Market survey – AUVs

Chapter 5. Survey of actual decommissioning tools for monopile removal

5.1 ROV tools

Today there exists an ocean of available tools that can be operated by an ROV, where the majority of these tools are designed for the offshore O&G industry. The objective of this survey was to investigate possible tools which can be transferred to offshore wind industry for decommissioning purposes. Due to lack of technical specifications of tools, and due to the fact that many of these tools are custom designed for individual projects, the market survey was shown to lack in magnitude and diversity. However, some examples of these tools which may be used or could be scaled up/customized for the Offshore wind industry are illustrated in this subchapter. The focus here is mainly on cutting tools operated by ROV, to aid in the removal process of monopile foundations. Extensive cutting work is required during these projects. There are several options available, of which two are mentioned here. These include diamond wire cutting and water jetting.

Diamond wire tools can be both operated by ROV as well as to be deployed by e.g. cranes and operated from the surface while guided/monitored by an ROV/diver. These tools ranges in sizes, after their operational task. If operated by an ROV, smaller dimensions can be seen, as the work-class ROVs on the market today have its power limitations. The diamond wire tool cuts a structure by friction produced by the wire when forced upon the structure. Advantages of this tool are that there are minimal vibrations, it is less pollutant, cost effective and it can in principle be applied to most sizes of piles. A drawback of this tool is that it requires a good access to and around the area of which to be cut. [3][13]

Figure 17 Diamond wire cutting tool [50]

Cutting operations by the use of water jetting, entails that a jet of water and an abrasive substance are released upon the structure at a high pressure. This tool can cut most materials and can be applied for larger wall thickness dimensions. This tool has greater impact on the environment as material can be scattered during the process. Water jet cutting technique is often used for pile removal in the O&G industry and the method works both over and under water. Even though it is used for smaller diameters here, it can in principle be scaled up to the pile diameters and wall thicknesses required for offshore wind monopiles. With this cutting method, the monopile can be cut either externally or internally. [3][13]

Figure 18 Abrasive water jet cutting tool [50]

Market survey: ROV tools – Cutting			
ROV tool:		Supplier:	Type:
1	ECT – ROV operated external cutting tool	Oceaneering	Abrasive water jet cutter
2	Pipe cutter and Beveling	Oceaneering	Diamond wire cutter

Table 12 Market Survey: ROV tools - Cutting

5.2 Other decommissioning tools

This part of the market survey consists mostly of investigating other decommissioning tools, that cannot be directly operated with an ROV. Here, the focus was on cutting tools for partial removal of the monopiles and on vibratory hammer tools for a reverse instalment method for complete removal of the pile.

5.2.1 Partial removal of monopile

As mentioned within chapter 3, there are multiple methods for partial removal of monopiles, where the most applied methods include cutting the pile under the mudline either internally or externally. Here the focus was on investigating the available cutting tools for this purpose, with the emphasis on diamond wire and water jetting.

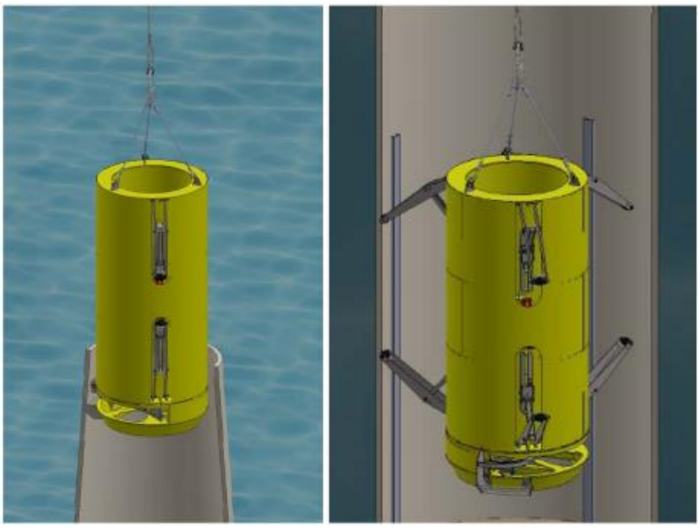

Figure 19 Internal jet cutting [52]

Market survey: Decommissioning tools – Partial removal method			
Decommissioning tool:		Supplier:	Task:
1	Internal Cutting Tool (ICT 6090)	Oceaneering	Internal cutting by abrasive water jet
2	Drill Cut Remediation	Oceaneering	Dredging
3	Abrasive water jet well cutting	Oil States	Internal jet cutting manipulator
4	Vertical Wire Diamond cutter	SubC	Diamond wire cutting

Table 13 Market Survey: Decommissioning tools - Partial removal method

5.2.2 Complete removal of monopile

When it comes to methods and tools for complete removal of the monopile little information was found, which might stem from that the methods mentioned within chapter 3 are mostly concepts. While removing the monopile by vibratory pile hammers, would be to reverse the instalment method of many piles. Therefore, several vibratory hammers exists on the market today.

Figure 20 Vibratory extraction of monopile (decommissioning of Lely wind farm) [16]

Market survey: Decommissioning tools – Complete removal method			
Decommissioning tool:		Supplier:	Task:
1	PTC Vibrodrivers	PTC Fayat Group	Multiple versions and dimensions of Vibratory hammers
2	Deep water Pile dredge	Oceaneering	Internal dredging
3	Hydrohammer	IHC IQIP	Monopile installer
4	Waterhammer	IHC IQIP	Monopile installer
5	CPE Impact hammer	IHC IQIP	Monopile installer

Table 14 Market Survey: Decommissioning tools – Complete removal method

Chapter 6. Discussion

In this chapter, a discussion will be made on the findings from the market survey to provide further thought for decommissioning operations regarding monopile foundations for the OWF industry in the future. Where ROVs, ROV cutting tools and other available decommissioning tools may aid in the process of removing the piles.

6.1 Available ROVs

For the case of decommissioning monopiles, this takes place in relative shallow waters as most wind farms with this type of foundations are at a depth of less then 50 meters. In order to compete with the usage of divers, the vehicles most accomplish the same tasks in a more economic and safe manner, and preferably within a shorter timeframe.

Observations ROVs today can be deployed in both shallow waters and deep waters, where the ROVs operating in shallow water are smaller, lighter, have low power demand and are overall cost beneficial. With the vast variety and customization, the observation ROV can aid with quality imagery of the structure, seabed, and monitoring of processes.

Survey ROVs can cover a vast area at a relative high speed, ranging around 3-5knots. This means that within a relative short time span, the ROV can map the seabed around the monopile, scour protection and cables, as well as to monitor the site after removal. Providing vital information for planning of decommissioning method with which actions to undertake and to provide information of the conditions of the site after removal.

By incorporating inspection ROVs, detailed information can be achieved in the condition of the monopile, as structure weaknesses and corrosion is of likelihood to occur after many years submerged. This information can have an impact on the method used for removing the monopile.

The market survey uncovered a large variety in work-class ROVs which can aid in more active operations, like trenching, guiding of cutting tools and lifting tools, as well as some that might have cutting possibilities itself, if customization to a heavy duty ROV is applied. With that said, the ROVs will today be more beneficial to be given the task of cutting e.g. the connecting array cables. Both electric/hydraulic ROVs and fully electric ROVs were found. The development of fully electric ROVs can have the benefits with increased reliability as any hydraulic systems are avoided. However, this also has an impact on the power output of the ROV. The depth rating of the ROVs, showed that a large focus of ROV design is directed to deep waters. This will have upsides for OWF that are being placed at deep water sites, but for the wind farms with monopile foundations these ROVs are somewhat redundant. The overall findings showed that there are multiple possibilities on the market today which can be a promising asset for small work tasks, monitoring, guidance, and dredging/trenching. Bottom-crawlers, ranging from mid-sized vessel to large constructions, can aid in the process of observation, inspection, and excavation of the monopile. Where the most useful and important task of these vessels would be to excavate the external surrounding soil of the monopile and burial after removal is complete.

AUVs are a fairly new development where tasks of observation and surveys can be performed without attached cables, and from a certain distance. This has its benefits in rough sea states, where the problem of forces applied from the current and wave motions on a cable is avoided. There are on the other hand, several challenges with these vessels. They have limitations in the amount of data per unit time which can be transferred back with hydro acoustics. A challenge can also be found within the energy storage system, where these have a limited capacity.[3][11]

6.2 ROV tools

Sub-sea cutting methods are a key element that can be transferred from the O&G sector to offshore wind. Some challenges were however met when investigating the market for these cutting tools. One of the challenges faced is a lack in standardized equipment. Often custom ROV tools are developed for every project. Another challenge was the lack of information to be gathered, as many of the previous decommissioning projects have put a “classified” stamp on the details of their applied tools. When searching to implementing methods and tools from the O&G industry for underwater cutting to the offshore wind industry, several challenges were also here found. As the supporting pile structures in the O&G industry have a diameter of up to 2-3m, the monopiles supporting the OWTs are much larger. This means, in regards to cutting tools, that an increase in parameters would have to be made, in order for these tools to be operational for the OWT monopiles.

The abrasive water jet method could easily in principle be adapted to the offshore wind sector, as it uses the same cut for all diameters and thicknesses. A drawback could be the timeframe, as it is the thickness of the pile and the pressure of the water jet that will determine how long the cutting will take. Benefits can be seen by performing internal cutting, as less soil needs to excavated and the monopile itself will act as a shield for ocean current forces. [3][11]

Diamond wire cutting is often a preferred method for cutting cables in challenging conditions as this method can be set up from an ROV, and divers can be avoided. For monopile cutting, this method is discussed whether it is suitable, as cuts of large diameters in a horizontal direction can cause a jamming risk for the wire. Within offshore wind decommissioning operations, diamond wire cutting might rather be selected for cutting of array cables at their exit point from the monopile instead. It should also be noted that ROVs today are mainly capable to guide the tooling rather than operating it itself, at the dimensions of the OWTs monopiles, due to power restrictions.[3][11]

6.3 Decommissioning tools

Partial removal can be achieved by diverse cutting tools. As mentioned, the preferable cutting tools are diamond wire (mostly for external cutting) and water jet for both internal and external cuts. When it comes to complete removal, little information was found for tools for the different methods (vibratory extraction, Water/air-pressure removal, and internal dredging). However, there exist already in smaller scales dredging tools and vibratory hammers, mostly derived from the O&G industry. The Lely wind farm is an example of which several monopile removal operations have been performed by the usage of vibratory hammers, although in a smaller scale.[9] These two methods show promising prospects. If the dimensions of the equipment are increased, these can easily be transferred to the offshore wind industry where complete removal is required.

Chapter 7. Conclusion

This report had the objective of performing a market survey on possible ROVs, ROV tools and decommissioning tools, in the aid of understanding the grasp of technology which is available today, and if there were any shortages or challenges present.

It was found to be a variety of ROVs available, which can be customized for each individual project. ROVs can become a viable part of the removal of OWT monopile foundations, as the technology is evolving and becoming more reliable. But with the market today, the tasks of the ROVs includes mostly support of the removal process itself in guiding possible cutting tools, excavate soil around the monopile, inspecting the seabed conditions and conditions of structure, as well as to monitor and observe the processes. The power and capacity of ROVs today are limited when it comes to cutting and lifting operations of the OWT monopiles due to the large monopile dimensions, where the scale of the wall thickness, the diameter, height, and weight, places its restrictions. However, the tools and solutions today might be scaled up in the future to assist monopiles also within the offshore wind industry.

Other decommissioning tools are also available on the market today for partial/complete removal of monopiles, were these tools are mainly developed for the O&G industry. While methods for complete removal are for the most part concepts, these may become viable options in the future. Today, complete removal by reversing the instalment method with vibratory hammers, can be seen to a promising solution when scaled up. For partial removal, the most common methods include cutting of the monopile (internally/externally) and here water jetting and diamond wire tools are techniques which can be adapted to the offshore wind industry.

The biggest challenge for methods, tools, and techniques for removal of OWT monopiles are the large pile dimensions, and the growth rate of these as the turbines are expected to produce more energy. The methods and tools, and their evolvement, also depends heavily on regulations concerning the environmental aspect. Where approaches for partial or complete removal are debated, regarding which of these will have the smallest negative impact on the marine environment. Planning of the decommissioning process with method used and coherent tools, is seen to be vital, in order to obtain a safe, sustainable, and economical solution for the foundation removal.

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Appendix

A.1 Market Survey: Table of details – ROVs

A.2 Market Survey: Table of details – ROV Decommissioning Tools

A.3 Market Survey: Table of details – Decommissioning Tools

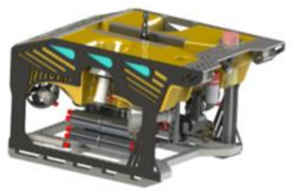
A.4 Technical Specification links – ROVs

A.5 Technical Specification links – ROV Decommissioning Tools

A.6 Technical Specification links – Decommissioning Tools

A.1 Market Survey: Table of details – ROVs

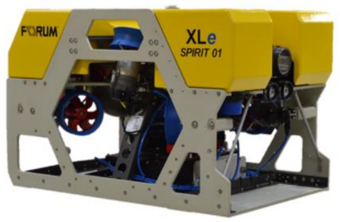
*Links to the asset's technical specifications can be found within appendix A.4

Market Survey: Observation ROV													
Model	**Supplier**	**Dimensions (LxWxH)**			**Mass in air**	**Payload**	**Depth rating**	**Max speed**	**Propulsion**	**TMS**	**Standard equipment**	**Optional equipment**	**Elec/ Hyd:**
AlphaROV D150 	Eprons	-	-	-	-	-	150msw	-	4 Brushless thrusters: 2 Horizontal; 1 Vertical; 1 Lateral.	-	Full HD 1080P 2MP Colour camera Operated with an easy to use digital joystick from the control case. The console is build in a professional Pelican case and contains all electronics for the remote control, power supply and video processing including video text overlay	Additional equipment possibility: Manipulator; Metal thickness measurement equipment; Around viewing navigation sonar; CP measurement equipment; USBL positioning system; Water quality sensors; Multi-beam sonar; Side scan sonar	Elec.
Argus Mini 	Argus Remote Systems as	0.9m	0.65m	0.6m	100kg	5kg	600msw	Speed fwd:3kn Speed vert:2kn	6 x electric, 4 Horizontal and 2 vertical thrusters	-	Argus HD camera, 2 x Argus 150W LED Lights	Control Console: Stand alone panel or Pilot chair, Surface Control box	Elec.
Argus Rover 	Argus Remote Systems as	1.45m	0.95m	0.93m	350kg	15kg	1000msw	Speed fwd:>3kn Speed vert: 2kn	6 x electric, 4 Horizontal and 2 vertical thrusters	-	Argus HD camera, 1 x Super wide-angle camera 2 x Argus 150W LED Lights	Control Console : Stand alone panel or Pilot chair, Surface Control box	Elec.
DeepBot 	Sperre	0,5m	0,5m	0,7m	80kg	-	11000msw	-	4 x thrusters	Yes	– LED lights – Camera – Depth Sensor	Typically consists of 1 DeepBots Control Module Remote controlled from topside software	Elec.
DTG3 	Deep Trekker	0,279m	0,325m	0,258m	8,5kg	-	200msw	-	Thrusters	-	Video : UHD 4K – 3840X2160 | 720p – 1280x720, 30FPS 0.001 Lux, 280° Total Range of View Picture : JPG 8mp Lights : High Efficiency LED | Fully Dimmable, 1000 Lumens Tracking with Camera Optional: 1000-4400 Lumens Add-ons	Screen: 178 mm (7") Wide-Angle LCD Controller: 16:9 Up to 4K Recording Waterproof Connectivity USB, SD, HDMI and Ethernet	Elec.
Gnom Baby 	Gnom ROV	0,21m	0,18m	0,15m	1,5kg Total system: 5kg	-	60msw	2knots	Thrust Forward:1 kgf Thrust Vertical:0.5 kgf	-	- 3 thrusters - Tether 35 m - Color videocamera - Camera tilt servo - 2 clusters of LEDs - Depth sensor - Compass - Surface control/power supply unit - Joystick - Cable connectors set	-	Elec.

Gnom Pro 	Gnom ROV	0,52m	0,44m	0,347m	25kg	5kg	150/300msw	Cruising speed (forward) up to 4 knots Lateral speed (optional)up to 0.5 knots	Thrust Forward:12 kgf Thrust Vertical:10 kgf 4 magnetically coupled thrusters. 2 horizontal, 2 vertical	-	- 4 thrusters - Tether 10 mm, 200 m (up to 400) - Compass - Depth sensor - 2 colour video cameras - Camera tilt servo ±50° - Lights (front and rear) - LCD TV monitor 15” - Manipulator 1 or 2 function (option) - Sector scan sonar (option) - USBL positioning system (option) - Hand reel with slip ring connector - Surface control/power unit - Protective polypropylene frame - Joystick - Cable connectors set	-	Elec.
H300V 	ECA Group	0,84m	0,6m	0,53m	70kg	8kg	300msw	3,5 knots	4 horizontal vectored thrusters Vertical: 1 thruster	-	-	-	-
H300 MK2 	ECA Group	0,9m	0,6m	0,47m	70kg	8kg	300msw	3,5 knots	Horizontal: 2 thrusters forward thrust: 34kgf • Vertical: 1 thruster; thrust: 17 kgf • Lateral: 1 thruster; thrust: 17 kgf	-	-	-	-
Lynx – *Observation & Inspection* 	SAAB Seaeye	1,23m	0,815m	0,605m	200kg	35kg	1500msw	3 knots	Thrust forward: 66 kgf Thrust lateral: 47 kgf Thrust vertical: 43 kgf	Yes	-	-	Elec.
Mohican 	DeepOcean	1,15m	0,77m	0,80m	290 kg	35kg	2000msw	Speed fwd: 3,5kn Speed bwd: 3,5kn Speed vert: 3.5kn Speed lat: 2kn	4 x Sub-Atlantic SPE180 Horizontal thrusters 2x Sub-Atlantic SPE180 vertical thrusters FWD/BWD thrust:110kg Lateral thrust: 110kg Vertical thrust: 110kg	Yes	4 x 250 W Halogen lamps, dimmer controlled on 2 circuits Tilting bracket for mounting two cameras (SIT size) and lamp Tilt position angle on video overlay	-	Elec.
Mojave 	DeepOcean	1,75m	1,06m	1,22m	500kg	105kg	1500msw	3,5knots	Forward thrust:220kgf Vertical thrust: 75kgf	-	1x Tilt Unit with Basic Camera LED Lighting Depth Sensor Compass / Pitch / Roll Survey Jbox	Transportable Rack including: Control unit Video screen Analog to digital converter HD/DVD Video recorder	Elec.

Observer Mini-ROV 	Subsea Tech	0,49m	0,27m	0,21m	6,4kg	-	150msw	2 knots	3 magnetic coupling thrusters : 2 horizontal and 1 vertical	-	-	-	Elec.
Omni Maxx 	Oceaneering	1,27m	0,8m	0,51m	270kg	20kg	3000msw	Forward: 1.5 m/s Lateral: 1.0 m/s Vertical: 0.5 m/s	Forward: 489 N Lateral: 410 N Vertical: 275 N	Yes	-	-	Elec.
ROV-500 	Outland Technology	0,51m	0,31m	0,27m	9,5kg	1,3kg	300msw	-	-	-	- 4 ea. 350W Brushless, Flooded Thrusters - 1 ea. Tilting Color 1080p Video Camera - 2 ea. High-Powered LED Lights 3000 lumens total (1500 lumens each) - 1 ea. Single function manipulator	-	-
ROV-1000 	Outland Technology	0,66m	0,38m	0,27m	17,7kg	2,3kg	300msw	-	-	-	- 4 ea. 1/3 HP Brushless Thrusters - 1 ea. UWC-360/d Dual SD&HD Color Camera - 1 ea. Rear Fixed Color Video Camera w/Lights - 2 ea. High-Powered UWL-505 LED Lights 8600 lumens total (4300 lumens each)	-	-
ROV-2000 	Outland Technology	0,71m	0,46m	0,38m	25kg	4,5kg	300msw	-	--	-	- 4 ea. 1 HP Brushless Thrusters - 1 ea. UWC-360/d Dual SD&HD Color Camera - 1 ea. Rear Fixed Color Video Camera w/Lights - 2 ea. High-Powered UWL-505 LED Lights 8600 lumens total (4300 lumens each)	-	-
ROV-2500 	Outland Technology	0,71m	0,52m	0,38m	29,5m	4,5kg	300msw	-	-	-	-5 ea. 1 hp Thrusters (41 lbs. thrust ea.) -UWC-360, tilting, Fixed Focus Color (750 line .001 lux) Camera -Fixed Focus Camera and LED Lights built into rear ROV Control Bottle -2 EA. UWL-505, NEW HIGH POWERED LED LIGHTS -C-3405, 500 ft. Neutrally Bouyant, cable w/all connectors -Consoles, Power supply, Joy-Stick, Keyboard, 15” 2000 nit Monitor -Depth and Compass Video Overlay	-	-

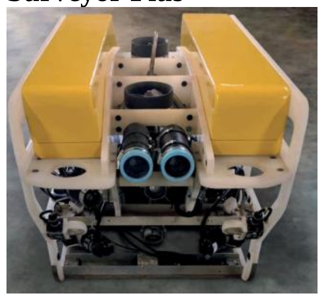
											-Auto-Hover/Heading		
Sea Maxx 	Oceaneering	0,81m	0,6m	0,45m	104kg	3,6kg	3000msw	Forward: 1.3 m/s Lateral: 0.5 m/s Vertical: 0.6 m/s	Forward: 145 N Lateral: 45 N Vertical: 64 N	Yes	-	-	-
SeaOwl Xti- *Observation&Inspection* 	SAAB Seaeye	1,38m	0,815m	0,56m	250kg	30kg	2000msw	>3knots	Thrust forward: 66 kgf Thrust lateral: 47 kgf Thrust vertical: 60 kgf	-	-	-	-
SeaOwl MK IV 	DeepOcean	1,4m	0,8m	0,6m	100kg	12kg	500msw	Speed fwd: 1,9kn Speed bwd: 0,8kn Speed vert: 0,8kn Speed lat: 0,8kn	FWD/BWD: 300N Lateral: 120N Vertical: 280N	yes	-	-	-
SRV-8 	Oceanbotics	0,5m	0,43m	0,33m	17,7kg	-	305m	4 knots	8 brushless DC thrusters	-	- 8 Dynamic Vectored ThrustersLED Lights (1,500 Lumens each) - Battery Modules (2) - Ruggedized Frame - Frame Rails for Mounting Accessories - Navigation System Connection Port - Ruggedized FloatationDual Mode Camera (HD/Analog) - Tether Support Ring and Strain Relief - Robotic 3-Jaw Grabber - Ventral Connectors	-	Elec.
Super Gnom 	Gnom ROV	0,36m	0,22m	0,2m	5kg	0,5kg	150msw	3 knots	Thrust Forward:2 kgf Thrust Vertical:1 kgf	-	-Tether 150 m (up to 250) -Digital compass with the auto-heading mode (data on screen) -Depth sensor (auto-depth mode) -2 color videocameras (front and rear) -Camera tilt servo ±50° -LCD TV monitor 15" -DVR -Hand reel with slip ring connector -Surface control/power unit -Protective polypropylene frame with buoyant module -Sector sonar (option) -USBL positioning system (option) -Joystick -Cable connectors set	-	Elec.

Tiger – *Observation&Inspection* 	SAAB Seaeye	1,03m	0,7m	0,59m	150kg	32kg	1000msw	3 knots	Thrust forward: 62 kgf Thrust lateral: 43 kgf Thrust vertical: 22 kgf	Yes	-	-	Elec.
Xle Spirit® 	Forum	1,1m	0,725m	0,715m	200kg	35kg	1000msw	Forward: 2.9 knots Lateral: 1.8 knots Vertical: 1.7 knots	fwd/aft: 72 kgf port/stbd: 42 kgf vertical (up): 40 kgf	Opt.	-	Surface Control System • Utilizes the Forum ICE™ Integrated Control Engine • Windows® based HMI Computer • Dedicated real-time controller • Intuitive Graphic User Interface (GUI), user configurable • Advanced interactive graphical diagnostics • Ergonomic pilot hand control unit	Elec.

Market Survey: Survey/Inspection ROV													
Model:	**Supplier:**	**Dimensions (LxWxH):**			**Mass in air:**	**Payload:**	**Depth rating:**	**Max speed:**	**Thrust:**	**TMS:**	**Standard equipment:**	**Optional equipment:**	**Elec/ Hyd:**
AC-ROV 3000 	AC-CESS	204mm	151mm	168mm	3.6kg	-	3000msw	-	6 thrusters (4 vectored and 2 x vertical)	Yes	-USBL Positioning & Tracking -Rear View Camera and Light -Depth Sensor -2 Function Manipulator – Grip and - Continuous 2 Way Rotate – 2 and 3 jaw grips -Slip Ring Tether Deployment System -Thickness Gauge -Laser Scaling Roller Kit)	5 axis 3D grip (LH or RH)	-
AC-ROV 100 	AC-CESS	204mm	151mm	146mm	3kg	0,2kg	100msw	-	6 thrusters (4 vectored and 2 x vertical)	Yes	-USBL Positioning & Tracking -Rear View Camera and Light -Depth Sensor -2 Function Manipulator – Grip and - Continuous 2 Way Rotate – 2 and 3 jaw grips -Slip Ring Tether Deployment System -Thickness Gauge -Laser Scaling Roller Kit	-Custom Tether Deployment Systems -Alternative or Additional Monitors -Tethers to 120m	-
AlphaROV Prof D200 	Eprons	-	-	-	-	-	600msw	-	5 Brushless thrusters: 2 Horizontal; 2 Vertical; 1 Lateral.	-	-Tether length 200 meters (up to 600 m). -Full HD 1080P 2MP Color camera.	-2 functions (Open/Close and rotation) manipulator -Metal thickness measurement equipment -Around viewing navigation sonar -CP measurement equipment -USBL positioning system -Water quality sensors -Multi-beam sonar -Side scan sonar	-

AlphaROV Prof D300 	Eprons	-	-	-	-	-	300msw	-	7 Brushless thrusters: 4 Horizontal A Vertical 1 Lateral	-	Tether length 300 meters (up to 1200 m) Front: Color Full HD and B/W cameras. Rear: additional color/BW camera Full HD 1080P 2MP	-2 functions (Open/Close and rotation) manipulator -Metal thickness measurement equipment -Around viewing navigation sonar -CP measurement equipment -USBL positioning system -Water quality sensors -Multi-beam sonar -Side scan sonar -Cleaning brush -Rope cutter	-
AlphaROV Prof D500 	Eprons	-	-	-	-	-	500msw	-	7 Brushless thrusters: 4 Horizontal A Vertical 1 Lateral.	-	Tether length 500 meters (up to 5000 m) Front: Color Full HD and B/W cameras. Rear: additional color/BW camera Full HD 1080P 2MP	-2 functions (Open/Close and rotation) manipulator -Metal thickness measurement equipment -Around viewing navigation sonar -CP measurement equipment -USBL positioning system -Water quality sensors -Multi-beam sonar -Side scan sonar -Cleaning brush -Rope cutter -4K color camera and RGB LED lights or other equipment.	-
Barracuda 	Shark Marine	0,877m	0,53m	0,31m	39kg	-	300msw	-	2x Horizontal, 2x Transversal Forward Thrust: 36.3 kg	-	2x Shark Marine Aurora LED lights: 3700 lumens	SD/HD Cameras, Digital Still Cameras, Laser Scaling System, Recovery Reels, Electric Manipulators, Launch and Recover Systems, USBL Positioning, Multi-Beam Imaging Sonar, Scanning Sonar, Radiation Detectors	-
Cougar XT Compact 	SAAB Seaeye	1,3m	0,9m	0,784m	270kg	60kg	300msw	3,8 knots	Thrust forward 170 kgf Thrust lateral 120 kgf Thrust vertical 110 kgf	-	• Cameras • Manipulators, cutters • Sonar systems (obstacle avoidance, multibeam, side scan) • CP probe • Auxiliary connections (RS232/RS485/STP and optional Ethernet) • Emergency strobe • Tracking system • Tooling motor	-	-
Falcon/Falcon DR – *Observation&Inspection* 	N sea/ SAAB Seaeye/ DeepOcean	1m 1,055m	0,6m 0,6m	0,5m 0,555m	60kg 100kg	14k 15kg	300msw 1000msw	Speed (both): >3knots	For both: Horizontal thrusters: 4 Vertical thrusters: 1 Forward thrust (kgf): 50 Lateral thrust (kgf): 28 Vertical thrust (kgf): 13	-	- Cameras with tilt option - Lighting - Manipulator - Sonar	-	-

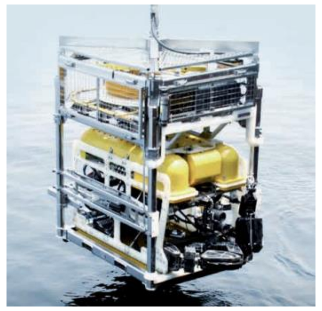
Focus 2 	DOF/ MacArtney	2m	1,2m	1,2m	160kg	-	-	6knots	-	-	Survey equipment -Side scan sonar (analogue and digital) -Multibeam sonar -Synthetic aperture sonar -Mechanical, forward-looking sonar -Mechanical, scanning profiling sonar -Subbottom profiler -Video camera -Laser line scan camera -Fibre optic gyro -Motion sensor -Bottom tracking doppler log -Responder for USBL	-	-
Focus 3 	MacArtney	1,95m	1,85m	1,25m	250kg	80kg	1000msw	5/10knots	-	-	Survey equipment -Side scan sonar -Multibeam sonar -Synthetic aperture sonar -Mechanical forward-looking sonar -Mechanical scanning profiling sonar -Subbottom profiler -Magnetometer -Video camera -Laser line scan camera -Fibre optic gyro -Inertial navigation system -Bottom tracking doppler log -Responder for USBL	-	-
Mini-ROV Guardian 	Subsea Tech	0,47m	O,254 m	0,16m	4,5kg	-	150msw	3 knots	5 magnetic coupling thrusters : 4 horizontal and 1 vertical	-	-	Acoustic camera 2D imaging sonar Teledyne Blueview M900 or BluePrint Oculus Mechanical sonar Tritech Micron DST or equivalent Acoustic posit. BluePrint Seatrac USBL Thickness measurement Cygnus US gauges CP measurement Buckleys CP probes Physico-chem. Measures Salinity, pH, turbidity gauges Manipulator 2 functions manipulator Samplers Water and sediments samplers Defect scaling Laser pointer scaling tool with software Video enhancement LYYN Hawk Board (integrated or external) WiFi link Wifi video transmission on external screen	-
Mohawk 	DeepOcean	0,93m	0,77m	0,62m	165kg	35kg	1000msw	3knots	5x CTE01 Thrusters 4x Single propeller vectored 1x Twin propeller vertical Forward thrust: 80 kgf Reverse thrust: 68kgf Lateral thrust: 60 kgf Vertical thrust: 30 kgf	Yes	1x Integral CCD Color Camera 3x Variable intensity 250/500W Tritech Seaking Sonar	-	Elec.

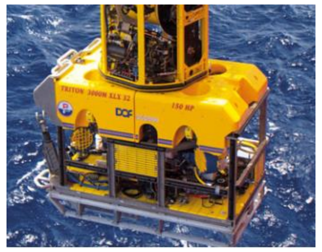
Perseo GTV 	Lighthouse/ Ageotec	1,1m	0,71m	0,857m	-	25kg	600msw	-	-	-	-	-	-
Surveyor Interceptor 	Reach Subsea / Kystdesign	5,5m	2m	1,2m	4700kg	700kg	2000msw	8 knots	220HP power pack 4 x SA420 Longtitudal A x SA380 Lateral 3 x SA380 Vertical	-	-	-	-
Superior Survey ROV 	DeepOcean / Kystdesign	5,562m	2,5m	1,3m	4950kg	700kg	3000msw	6 knots	THRUSTERS FORWARD 4 x Sub Atlantic SA-420 THRUSTERS LATERAL 2 x Sub Atlantic SA-380 THRUSTERS VERTICAL 3 x Sub Atlantic SA-380	-	-	-	-
Surveyor Plus 	DeepOcean	1,45m	0,82m	0,92m	250kg	50kg	600msw	3,5knots	-	-	-	-	-
Seaeye Marine Tiger 	DOF	1,1m	0,7m	0,59m	140kg	-	1000msw	3knots	-	-	-	-	-
Sea-Wolf 5 	Shark marine	0,977m	73,7m	55,9m	95kg	18kg	600msw	-	2 thrusters – 30 kg 4 thrusters – 60 kg	-	-	SD/HD Cameras, Digital Still Cameras, Laser Scaling System, Recovery Reels, Electric or Hydraulic Manipulators, Launch and Recover Systems, Doppler Navigation System, USBL and LBL Positioning, Shark Marine Total Navigation System (TNS), Multi-Beam Imaging Sonar, Scanning Sonar, Sediment Sampling Systems, Radiation Detectors	-

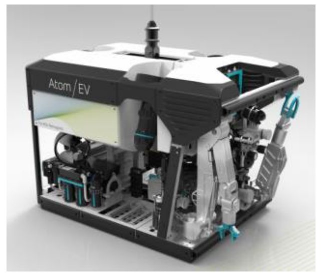
SRS Fusion 	Strategic Robotic Systems	6,86m	4,77m	2,75m	27,5kg	-	300msw	-	4 vectored, 2 vertical, 1 pitch	-	-	AUV option	-
Tortuga 	Subsea Tech	0,996m	0,43m	0,461m	45kg	-	500msw	4,2 knots	4 horizontal thrusters manually adjustable (Lite) or with azimuthal control (17kgf per thruster) and 2 vertical thrusters (10 kgf per thruster)	-	-	-	-
Triaxus 	MacArtney	1,85m	1,25m	1,25m	160kg	50kg	-	8 knots	-	-	Survey equipment - CTD - Optical plankton counter - PAR and radiation sensor - Fluorometer - Transmissometer - Video plankton recorder - Camera and light - Other oceanographic sensor	-	-

Market Survey: Work-Class ROV													
Model:	Supplier:	Dimensions (LxWxH):			Mass in air:	Payload	Depth rating:	Max speed:	Propulsion system:	TMS:	Standard equipment:	Optional equipment:	Elec/ Hyd:
Argus Mariner 	Argus Remote Systems as	1,8m	1,18m	1,2m	780kg	50kg	2000msw	Speed fwd:>3kn Speed vert: 2kn	6 x electric, 4 Horizontal and 2 vertical	-	Argus HD camera, 1 x Super wide-angle camera 2 x Argus 150W LED Lights	-	-

Argus Mariner XL 	Argus Remote Systems as	2.15 m	1.35m	1.4m	1500kg	50kg	2000msw	Speed fwd: 3kn Speed vert: 1,5kn	11 x electric, 4 Horizontal and 3 vertical Bollard pull fwd : 275kg Bollard pull lat : 230kg Bollard pull vert : 260kg	-	Cameras : 1 x HDTV 1080p F/Z Colour Camera 1 x Lowlight Black & White camera 7 x Utility camera Lights : 4 x Argus 130W LED Lights	-	-
Argus Worker 	Argus Remote Systems as	2,5m	1,6m	1,7m	3000kg	150kg	3000msw	Speed fwd :3kn Speed Lat :2kn Speed vert :2kn	11 x electric, 4 Horizontal and 3 vertical Bollard pull fwd : 600kg Bollard pull lat : 500kg Bollard pull vert : 535kg	-	Manipulators :1x5 function Schilling Rigmaster or Atlas 1x7 function Schilling T4 1 x F/Z HDTV 1080p camera 1 x Lowlight Black & White camera 8 x Utility cameras Sonar : Mesotech MS1000 or Tritech Lights : 6 x 130W LED	-	Elec.
Argus Worker XL 	Argus Remote Systems as	2,5m	1,6m	1,7m	4500kg	150kg	6000msw	Speed fwd :3kn Speed Lat :2kn Speed vert :2kn	11 x electric, 4 Horizontal and 3 vertical Bollard pull fwd : 600kg Bollard pull lat : 500kg Bollard pull vert : 760kg	-	Manipulators :1x5 function Schilling Rigmaster or Atlas 1x7 function Schilling T4 1 x F/Z HDTV 1080p camera 1 x Lowlight Black & White camera 9 x Utility cameras Sonar : Mesotech MS1000 or Tritech Lights : 6 x 130W LED Lights,	-	Elec.
Constructer 220 HP 	DeepOcean	3,22 m	1,7m	2,16 5m	4500kg	600kg	3000msw	Speed fwd :3,1kn Speed Lat :1,7kn	HORIZONTAL 4 x Sub Atlantic SA-380 VERTICAL 3 x Sub Atlantic SA-380 Bollard pull fwd : 800kg Bollard pull lat : 540kg Bollard pull vert up: 360kg Bollard pull vert down: 670kg	-	1 X LOW LIGHT CAMERA 1 X NORTH SEEKING GYRO 2 X COLOUR ZOOM CAMERA 1 X 5 FUNCTION GRABBER 1 X 7 FUNCTION MANIPULATOR ARM 2 X COLOUR MINI CAMERA	-	Hyd.
Constructer 	DeepOcean	3,22 m	1,7m	2,16 5m	4500kg	600kg	3000msw	Speed fwd :3,1kn Speed Lat :1,7kn	HORIZONTAL 4 x Sub Atlantic SA-380 VERTICAL 3 x Sub Atlantic SA-380 Bollard pull fwd : 800kg Bollard pull lat : 540kg Bollard pull vert up: 360kg Bollard pull vert down: 670kg	-	1 X LOW LIGHT CAMERA 1 X NORTH SEEKING GYRO 2 X COLOUR ZOOM CAMERA 1 X 5 FUNCTION GRABBER 1 X 7 FUNCTION MANIPULATOR ARM 2 X COLOUR MINI CAMERA	-	Hyd.
Installer 	DeepOcean	3m	1,5m	1,9m	3100kg	300kg	2500msw	Speed fwd: 3kn Speed Aft: 3kn	Horizontal 4 x horizontally vectored Vertical 3 x vertically vectored Bollard pull fwd : 800kg	-	MANIPULATORS Left hand side Schilling Rigmaster 5F Right hand side Schilling T4 7F Low Light Camera (1) North Seeking Gyro (2) Colour Zoom Camera (1) Colour mini camera (1) Obstacle Avoidance Sonar (1) Wire Cutter 38mm (2)	-	Hyd.

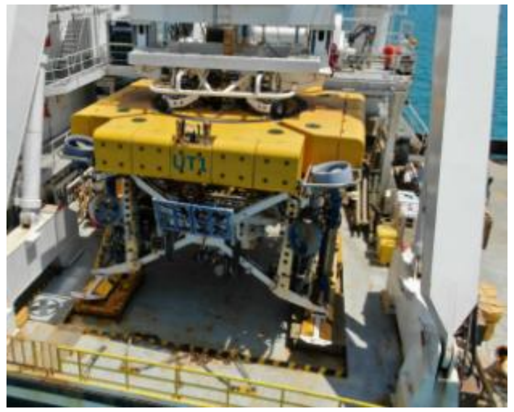
											250W Lights		
Panther Plus 	DeepOcean	1,75 m	1,06m	1,22 m	500kg	105kg	1500msw	3,5knots	Forward thrust: 220kgf Vertical thrust: 75kgf	Yes	11 x Colour CCD Camera 1 x Black & White Low Light Camera 11 x 150w each quartz-halogen on tilt unit (Optional up to 6) Manipulators: 1 x 7 function manipulator 1 x 5 function grabber with electro-hydraulic power pack	-	-
Panther-XT 	DeepOcean	-	-	-	-	-	-	-	-	-	-	-	Elec.
Seaeye Leopard 	DeepOcean	2,15 m	1,16m	1,17 4m	1200kg	205kg	3000msw	3,5knots	Thrust forward: 493kgf Thrust lateral: 377kgf Thrust vertical: 225kgf 11 vectored SM9 500v brushless DC thrusters	-	-	-	Elec.
Supporter 	Deepocean Kystdesign DOF	-	-	-	2450kg	200kg	2000msw	-	Thrusters Horizontal 4 x Sub Atlantic SA-300 Thrusters Vertical 3 x Sub Atlantic SA-300	-	-	-	-
Triton XL 	DeepOcean	-	-	-	-	-	-	-	-	-	-	-	-
UHD ROV 	DeepOcean DOF Schilling	-	-	-	-	-	-	-	-	Yes	-	-	-

Triton XLX 	DOF	3,2m	1,8m	1,95 m	4900kg	-	3000msw	-	-	-	-	-	-
Triton XLS 150	DOF	-	-	-	-	-	-	-	-	-	-	-	-
Seaeye Cougar Xti	DOF	1,52 m	1m	0,91 m	580kg		300msw	3knots	-	-	-	-	-
Seaeye Cougar XT	SAAB Seaeye	-	-	-	-	-	-	-	-	-	-	-	-
Shilling Robotics  HD 	DOF	2,5m	1,7m	1,9m	3500kg	-	4000msw	3knots	-	-	-	-	-
Spectrum	Oceaneering	-	-	-	-	-	-	-	-	-	-	-	-
Triton XLS 150 	DOF	3,5m	1,78m	1,93 m	4400kg		3000msw	3knots	-	-	-	-	-
H3000	DOER Marine	-	-	-	-	-	-	-	-	-	-	-	-
H6500	DOER Marine	-	-	-	-	-	-	-	-	-	-	-	-
H2000 	ECA Group	-	-	-	-	-	-	-	-	-	-	-	-
H1000	ECA Group	-	-	-	-	-	-	-	-	-	-	-	-

													
H800 	ECA Group	-	-	-	-	-	-	-	-	-	-	-	-
Quantum/EV 	SMD	-	-	-	-	-	-	-	-	-	-	-	-
Atom/EV 	SMD	-	-	-	-	-	-	-	-	-	-	-	-
Quasar 	SMD	-	-	-	-	-	-	-	-	-	-	-	-
Merlin UCV R-ROV 	IKM	-	-	-	-	-	-	-	-	-	-	-	-

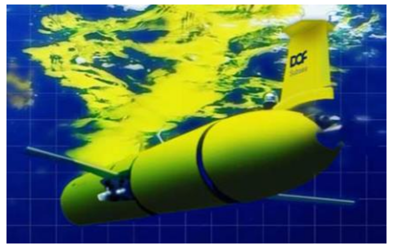
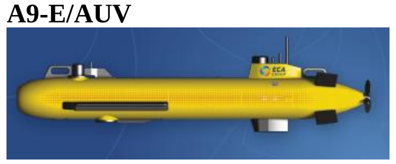
XLX Evo Ultra Heavy Duty ROV 	Forum	3,605 m	1,905 m	2,282 m	-	300kg	3000msw	-	-	-	-	-	-
XLX-C Heavy Duty ROV 	Forum	2,8m	1,7m	1,9m	-	200kg	3000msw	-	-	-	-	-	-
Comanche 	Forum	-	-	-	-	-	3000msw	-	-	-	-	-	-
eNovus	Oceaneering	-	-	-	-	-	-	-	-	-	-	-	-
E-ROV	Oceaneering	-	-	-	-	-	-	-	-	-	-	-	-
Freedom	Oceaneering	--	-	-	-	-	-	-	-	-	-	-	-
FCV 600	Fugro	-	-	-	-	-	-	-	-	-	-	-	-
FCV 1000	Fugro	-	-	-	-	-	-	-	-	-	-	-	-
FCV 1000d	Fugro	-	-	-	-	-	-	-	-	-	-	-	-
FCV 2000	Fugro	-	-	-	-	-	-	-	-	-	-	-	-
FCV 3000	Fugro	-	-	-	-	-	-	-	-	-	-	-	-
FCV 4000	Fugro	-	-	-	-	-	-	-	-	-	-	-	-
HD WROV	Reach subsea	-	-	-	-	-	-	-	-	-	-	-	-
Millennium Plus ROV	Oceaneering	-	-	-	-	-	-	-	-	-	-	-	-
Nexxus ROV	Oceaneering	-	-	-	-	-	-	-	-	-	-	-	-
Robotics Gemini ROV	Technip FMC	-	-	-	-	-	-	-	-	-	-	-	-
Robotics HD ROV	Technip FMC	-	-	-	-	-	-	-	-	-	-	-	-
Robotics ISOL-9 Pump	Technip FMC	-	-	-	-	-	-	-	-	-	-	-	-
Robotics UHD II	Technip FMC	-	-	-	-	-	-	-	-	-	-	-	-
Robotics UHD III	Technip FMC	-	-	-	-	-	-	-	-	-	-	-	-

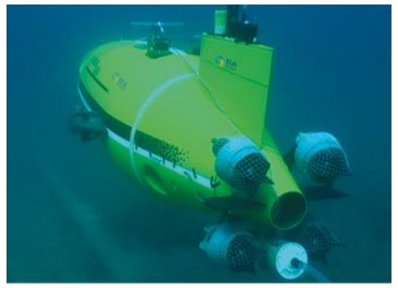
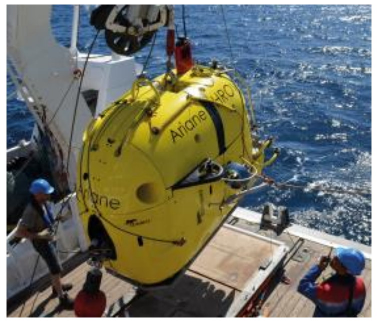
Sub-fighter 10k	Sperre	-	-	-	-	-	-	-	-	-	-	-	-
Sub-fighter 15k offshore	Sperre	-	-	-	-	-	-	-	-	-	-	-	-
Sub-fighter 15k standard	Sperre	-	-	-	-	-	-	-	-	-	-	-	-
Sub-fighter 30k	Sperre	-	-	-	-	-	-	-	-	-	-	-	-
Sub-fighter 3000	Sperre	-	-	-	-	-	-	-	-	-	-	--	-
Sub-fighter 4500	Sperre	-	-	-	-	-	-	-	-	-	-		-
Irius	Oceaneering	-	-	-	-	--	-	-	-	-	-	-	-
Jaguar	SAAB Seaeye	-	-	-	-	-	-	-	-	-	-	-	-
Magnum Plus ROV	Oceaneering	-		-	-	-	-	-	-	-	-	-	-
Maxximum ROV	Oceaneering	-	-	-	-	-	-	-	-	-	-	-	-
Merlin UCV R	IKM	-	-	-	-	-	-	-	-	-	-	-	-

Market Survey: Bottom-Crawling ROV								
Model:	Supplier:	Dimensions:	Mass in air:	Depth rating:	Max speed:	Propulsion:	Features:	Description:
Rovingbat 	ECA Group	Length: 1,105m Width: 1,085m Height: 0,646m	135kg	100msw	Flying mode: 3knots Crawling mode: 20 m/min	8x dc thrusters: 4x horizontal vectored 4x vertical	-Telemetry systems - Viewing systems - Sensors - Cleaning system -NDT	Hybrid ROV for operations on immersed structures → swims, tilts, rolls, sticks and crawls → 2 sets of motorized tracks → cleans, inspects and measures → dedicated to FPSO'S hulls, offshore windfarms, hydro power plants, rig legs
T3200 	Enshore	-	-	-	-	-	-Trench depths up to 3.5m -Combined cutting and jetting for hard or soft soils -Fanbeam positioning in shallow water -Active heave compensated launch and recovery	T3200 is the world's most powerful and sophisticated subsea trenching system. With 3200 HP of effective trenching power it offers unrivalled capability for the burial of pipelines and cables in challenging ground conditions.
UT-1 	Enshore	-	-	-	-	-	-Configurable for a wide range of applications -Unique sword design for ultra deep trenching -High sea state deployment -Sophisticated drive motors to control pressure and flow	The UT-1 is the world's most powerful jetting ROV with 2.1MW of total power. Fitted with sophisticated drive motors, which allow precise control of pressure and flow, giving a high degree of flexibility when undertaking workscopes in varied environmental conditions and a competitive edge.

T1 	Enshore	-	-	-	-	-	-Unique capability for offshore and onshore burial -Variable modes for enhanced burial -Simultaneous lay and burial -Trench depths to 1.3m wheel cutter mode -Trench depths to 2.0m jetting mode	T1 is a recently upgraded mechanical trenching system with the unique ability to deliver trenching capability both subsea and onshore. The trencher has 520kW of total power and can be adapted to operate in cutting and jetting mode for multiple soil and environmental conditions. Enhanced burial depths to 1.3m in cutting mode and 2.0m in jetting mode can be achieved. T1 is a solution for the burial of pipelines, flowlines, umbilicals and power cables on the beach, in the surf and offshore anywhere in the world.
T2 	Enshore	-	-	-	-	-	-Dual-mode cutting and jetting system -Easily and quickly adaptable for a varied range of modes including cutting and jetting -Backfill attachment -Trench depths up to 2.0m cutting and 3.0m jetting -Modular and flexible for worldwide operations	The T2 trencher is a dual-mode tracked vehicle with a proven track record for the burial of pipelines, flowlines, umbilicals and submarine cables. T2 can be adapted to operate in 2m chain cutting mode, 2m jetting or a 3m jetting mode with backwash capability. This offers numerous solutions for product burial and to meet specific client requirements.
T1000 	Enshore	-	-	2000msw	-	-	-Configurable for a wide range of applications -High sea state deployment -3m maximum burial capability -Sophisticated sensors for accurate and controlled cable burial indication and recording	The T1000 is an advanced Jet Trenching ROV suitable for deployment in water depths to 2000m. The 1000 Horse Power (750kW) subsea power system is capable of 3.5 knots manoeuvring performance and 3m maximum burial capability, providing a leading solution for burial of cables, umbilicals and flexible pipes. The adjustable 3m jet tool allows for varying diameter products and burial splice burial up to a maximum width of 1050mm, whilst downward-facing nozzles provides the capability for burial in all cohesive soils (up to 80kPa) and all sand grades. The burial arm is fitted with sensors for accurate and controlled cable burial. This high specification ensures that the T1000 is one of the most versatile and reliable Jet Trenching ROVs available. Equipped with a High Sea State LARS Launch and Recovery System, the T1000 can be deployed in harsh weather conditions with up to 4.57m significant wave height.
XT300 	Forum	Length: 4,2m Width: 3,73m Height: 3,1m	9250 kg	3000msw	Forward: 3 knots Lateral: 2.3 knots	Bollard pull Forward: 1100 kgf Lateral: 1100 kgf Vertical: 900 kgf Thrusters Horizontal: 4 Thrusters Vertical: 4	• Gyro / Fluxgate Compass • Pitch / Roll Sensor • Digiquartz Depth Sensor • Sonar (Dual Frequency) • Altitude Sensor • Product Location / Tracking System (TSS 440/350) • Responders (Provision for 2 off) • Manipulators (2x TA40 Rate) • Optional Emergency RDF Beacon • Optional Emergency Strobe Flasher • Optional Profiler Dual Frequency	-

XT500 	Forum	Length: 4,67m Width: 3,73m Height: 3,12m	10420 kg	3000msw	Forward: 3 knots Lateral: 2.3 knots	Bollard pull Forward: 1100 kgf Lateral: 1100 kgf Vertical: 900 kgf Thrusters Horizontal: 4 Thrusters Lateral: 4	• Gyro / Fluxgate Compass • Pitch / Roll Sensor • Digiquartz Depth Sensor • Sonar (Dual Frequency) • Altitude Sensor • Product Location / Tracking System (TSS 440/350) • Responders (Provision for 2 off) • Manipulators (2x TA40 Rate) • Optional Emergency RDF Beacon • Optional Emergency Strobe Flasher • Optional Profiler Dual Frequency	-
XT600 	Forum	Length: 5,89m Width: 3,6m Height: 3,3m	16750 kg	3000msw	Forward: 1.55 knots Lateral: 1.0 knots	Bollard pull Forward: 2000 kgf Lateral: 2000 kgf Vertical: 3000 kgf Thrusters Horizontal: 4 Thrusters Vertical: 4	• Gyro / Fluxgate Compass • Pitch / Roll Sensor • Digiquartz Depth Sensor • Sonar (Dual Frequency) • Altitude Sensor • Product Location / Tracking System (TSS 440/350) • Responders (Provision for 2 off) • Manipulators (2 off TA40 Rate) • Optional Emergency RDF Beacon • Optional Emergency Strobe Flasher • Optional Profiler Dual Frequency	-
XT1200 	Forum	Length: 9,4m Width: 6,1m Height: 3,86m	32000 kg	1500msw	Forward: 2.5 knots Lateral: 2.0 knots	Thrusters Horizontal: 4 Thrusters Vertical: 4	• Gyro / Fluxgate Compass • Pitch / Roll Sensor • Digiquartz Depth Sensor • Sonar (Dual Frequency) • Altitude Sensor • Product Location / Tracking System (TSS 440/350) • Responders (Provision for 2 off) • Manipulators (2 off TA40 Rate) • Optional Emergency RDF Beacon • Optional Emergency Strobe Flasher • Optional Profiler Dual Frequency • Optional DVL (Auto Positioning)	-
XT1500 	Forum	Length: 9,4m Width: 6,1m Height: 3,86m	32000 kg	1500msw	Forward: 2.5 Knots Lateral: 2.0 Knots	Thrusters Horizontal: 4 Thrusters Vertical: 4	• Gyro / Fluxgate Compass • Pitch / Roll Sensor • Digiquartz Depth Sensor • Sonar (Dual Frequency) • Altitude Sensor • Product Location / Tracking System (TSS 440/350) • Responders (Provision for 2 off) • Manipulators (2 off TA40 Rate) • Optional Emergency RDF Beacon • Optional Emergency Strobe Flasher • Optional Profiler Dual Frequency • Optional DVL (Auto Positioning)	-

Market Survey: AUVs								
Model:	Supplier:	Dimensions (LxWxH):	Mass in air:	Depth rating:	Max speed:	Propulsion:	Features:	Description:
HUGIN 1000 AUV 	DeepOcean DOF	Length: 5,27 m Diameter: 0,75 m	1200 kg	1000msw	6knots	-	• UP TO 18H BATTERY CAPACITY • 1000M DEPTH RATING • GREAT MANOEUVRABILITY AND STABILITY • HYDRODYNAMIC • VISUAL, BATHYMETRIC AND SONAR SURVEY DATA	The HUGIN Autonomous Underwater Vehicles (AUV) is a free-swimming autonomous vehicle with extreme survey capability
Glider AUV 	DOF	Length: 188,3cm Diameter: 22cm Width: 100,3cm	56.2 kg	1000msw	-	-	-	The Skandi Explorer Gliders are ultra-efficient, low-power autonomous underwater vehicles which collect ocean environmental data for months at a time without need of a support vessel. Total operational control is accomplished remotely by on-shore staff using piloting and data processing proprietary software. Glider observations measure strong ocean currents, collect environmental baselines, and detect oil in water.
A18TD 	ECA Group	Length: 4,7m Width: 1,8m	1200kg	3000msw	6 knots	-	ENERGY SECTION: 28kWh • NAVIGATION: Inertial Navigation System (INS), USBL, LBL, Doppler Velocity Log (DVL), Global positioning System (GPS) • COMMUNICATION: WiFi, Ethernet, Acoustic, Satellite • SAFETY: Flashing light, Obstacle avoidance sonar • RIGHT PAYLOAD: right Synthetic Aperture Sonar antenna, Multibeam Echosounder, 1 vertical camera • LEFT PAYLOAD: left Synthetic Aperture Sonar antenna, Laser profiler, Turbidity / fluorimeter / dissolved gas sensors, wireless transceiver, 1 vertical camera • Air transportable according to UN38.3 standard	Deep water survey and inspection AUV → high manoeuvrability → structure and seabed inspection → easy launch and recovery in bad sea state condition → extended coverage and endurance capacities → wireless deep water operations
A9-E/AUV 	ECA Group	Length: 2/2,5m Diameter: 0,23m	70/100kg	200msw	5 knots	-	ENERGY SECTION: 2.1 or 4.2 kWh • N A V I G AT I O N : I N S (I n e r t I a l Navigation System), DVL, depth sensor and GPS • COMMUNICATION: Radio (UHF), WiFi, Ethernet, Acoustic • SAFETY: Emergency pinger, Strobe light, Fault and leak detection, on request: Obstacle Avoidance System, Iridium, Local Remote Control for surface recovery • PAYLOAD: Interferometric Side Scan Sonar, Video, CTD, environmental sensors (e.g. turbidity, PH, DO or fDOM	Light AUV, IHO S44 compliant → high resolution data acquisition → 3D acquisition → shallow waters
A18-E/AUV 	ECA Group	Length: 3,8m Diameter: 0,465m	370kg	300msw	6 knots	-	• ENERGY SECTION: 10.6 kWh • NAVIGATION: Inertial Navigation System (INS), Doppler Velocity Log (DVL), RTK/PPP GPS • COMMUNICATION: WiFi, Ethernet, Acoustic, Satellite • SAFETY: Emergency pinger, Strobe light, Fault and leak detection, on request: Obstacle Avoidance System, Iridium, Local Remote Control for surface recovery • PAYLOAD: Side Scan Sonar, MultiBeam Echo Sounder, Video, Forward Looking Sonar, CTD, environmental sensors (Turbidity) • Air transportable according to UN38.3 standard	IHO S44 compliant mis size AUV → high resolution bathymetry and imagery → rapid environment data acquisition → easy deployment for overseas missions → extended coverage and endurance capabilities → user friendly mission management system → endurance: 24h

A18D/AUV 	ECA Group	Length: 4,5-5,5m Diameter: 0,5m	500-690kg	3000msw	6 knots	-	ENERGY SECTION: 14.4 kWh • NAVIGATION: Inertial Navigation System (INS), Doppler Velocity Log (DVL), USBL transponder, Global positioning System (GPS) • COMMUNICATION: WiFi, Ethernet, Acoustic, Satellite • SAFETY: flashing light, Obstacle avoidance sonar • PAYLOAD: Side Scan Sonar, Multi Beam Echo Sounder, Video, Forward Looking Sonar, CTD, environmental sensors • Air transportable according to UN38.3 standard	Mid-sized deep water AUV → easy launch and recovery in rough sea state → easy deployment over seas →user friendly mission management → flexibility of sensors payload → endurance: 24h
A9-M/AUV 	ECA Group	Length: 2m Diameter: 0,23m	70kg	300msw	5 knots	-	BODY DIAMETER: 9 inches (23 cm) • LENGTH: 200 cm • WEIGHT: 70 Kg • ENERGY SECTION: 2.1kWh • NAVIGATION: INS (InertIal Navigation System), DVL, depth sensor and GPS • COMMUNICATION: Radio (UHF), WiFi, Ethernet, Acoustic, Iridium on request • SAFETY: Emergency pinger, Strobe light, Fault and leak detection, on request: Obstacle Avoidance System, Local Remote Control for surface recovery • STANAG 1364 compliant (submitted to French export regulations) • PAYLOAD: Side Scan Sonar, Video, SVP	MEN portable low signature autonomous underwater vehicle → easy to use, easy to deploy → High-resolution side scan sonar → accurate inertial navigation system → modular architecture for easy maintenance → low magnetic and acoustic signature → endurance up to 20h
Alistar 3000 	ECA Group	Length: 4,8m/5.8m	2100/3000kg	20-3000msw	4 knots	-	• NAVIGATION: Inertial Navigation System (INS), Doppler Velocity Log (DVL), USBL transponder, Global positioning System (GPS) • COMMUNICATION: Radio (UHF), WiFi, Ethernet, Acoustic, Satellite • SAFETY: Emergency pinger, Strobe light, Fault and leak detection, on request: Obstacle Avoidance System, Iridium, Local Remote Control for surface recovery • PAYLOAD: Video camera, MBES, Side Scan Sonar, Sub-Bottom Profiler • Air transportable according to UN38.3 standard	Mid size AUV for accurate 3D survey → Search for pipeline → Automatically detect and lock onto pipe → follow the pipe 1 to 2 meters above it → Detect Debris or anomalies → Perform visual inspection → record video and sonar images → post process the data
H-ROV 	ECA Group	Length: 2,8m Width: 1,85m Height: 2,3m	1550/1780kg	300msw / 2500msw	Forward: 2 knots Vertical: 1,7 knots	H vectored thrusters H lateral thrusters 2 vertical thrusters	Equipment: • Horizontal and vertical DVL • Multiple PTZ video cameras • Synchronized strobe lights • One 5 axis electric arm • One 7 axis electric arm Options: • Side Scan Sonar (SSS) • Multi Beam Echo Sounder (MBES) • Recovery net • Others on request	Autonomous or Remotely Operated Vehicle for accurate Inspections & Intervention. → Compact, modular and flexible → Deployable from ship of opportunity → No need for DP platform → Hybrid deep water vehicle → Scientific & SAR operations → Endurance up to 12h
EELUME 	Kongsberg	Length: 2,5m Diameter: 0,2m	70kg	500msw	4 knots	-	-	Eelume marine robots will be permanently installed on the seabed being ready 24/7 for planned and on-demand inspections and interventions regardless of weather conditions. This solution will dramatically save costs by reducing the use of expensive surface vessels, which are needed to support such operations today. Eelume underwater intervention vehicles can be installed on both existing and new fields where typical jobs include; visual

								inspection, cleaning, and operating valves and chokes.
Gavia Offshore Surveyor AUV 	Lighthouse	-	-	1000msw	-	-	-	Gavia Offshore Surveyor AUV is a self contained, low logistics, modular survey platform, capable of delivering high quality data while operating from vessels of opportunity or from shore. The equipment comprises of MBES, SSS and SBP and will allow LIGHTHOUSE to perform detailed surveys down to 1000m water depth and to work very close to platforms and targets. Very easy deployment, great data quality and fast survey execution are the main benefits of this AUV.
Sabertooth 	SAAB Seaeye	Length: 3,6m Width: 0,66m Height: 0,45m	800kg	1200msw	5 knots	-	-	Extremeversatility with deep water capability, long excursion range, advanced AUV functionality and a six degrees offreedom control system has behaviour-based architecture, supported by an inertial navigation system and Doppler velocity. Features include mission-planning software with the possibility for the customer-intelligent payload to take control, plus Saab's API means that customer/third-party software can act as a backseat drive
Sabertooth double hull 	SAAB Seaeye	Length: 4m Width: 1,34m Height: 0,67m	2000kg	3000msw	4 knots	-	-	Extremeversatility with deep water capability, long excursion range, advanced AUV functionality and a six degrees offreedom control system has behaviour-based architecture, supported by an inertial navigation system and Doppler velocity. Features include mission-planning software with the possibility for the customer-intelligent payload to take control, plus Saab's API means that customer/third-party software can act as a backseat drive

A.2 Market Survey: Table of details – ROV decommissioning tools

*Links to the asset's technical specifications can be found within appendix A.5

Market Survey: ROV decommissioning tools – Cutting						
Tool model:	Supplier:	Dimensions:	Mass:	Depth:	Features:	Description:
ECT – ROV-operated external cutting tool 	Oceaneering	-	-	-	-	ROV-operated external cutting tool (ECT) enables external cutting of jacket legs, pipelines, and bracing, as well as subsea window cutting of tubulars. The tool uses a high-pressure slurry hose from the surface to feed the abrasive material. The ECT cuts 16-in to 72-in OD pipe, and can cut more than 10-in wall thicknesses (or several layers) at speeds up to 20 in/min.
Pipe Cutting and Beveling 	Oceaneering	-	-	-	-	-

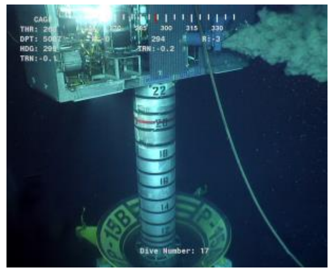
A.3 Market Survey: Table of details – Decommissioning tools

*Links to the asset's technical specifications can be found within appendix A.6

Market Survey: Decommissioning tools – Partial removal methods						
Tool model:	**Supplier:**	**Dimensions:**	**Mass (in air):**	**Depth:**	**Features:**	**Description:**
Internal Cutting Tool (ICT 6090) 	Oceaneering	Outer diameter: 1,4m Length: 4,2m	2100kg	-	- Suitable for pile outer diameters of 60 in to 90 in (Adapter up to 120in). Equipment: - High pressure water pump - Abrasive mixer unit (AMU) (separated for easier transport) - Internal cutting tool - Hydraulic power unit - Control/workshop container - Transport basket	The Internal Cutting Tool (ICT) is based on Oceaneering's powerful abrasive water jet cutting (AWJC) technology and is ideal for efficient internal cutting of piles. The AWJC method uses a high-energy jet of water-borne abrasive particles to cut even the hardest steel alloys quickly and safely. The ICT produces a clean cut, which makes it easy to lift piles, steel jackets, and other subsea structures.
Drill Cut Remediation 	Oceaneering	-	-	-	-	Deeper wells and larger wellhead structures have increased drill cutting deposits, sometimes affecting nearby existing infrastructures. Oceaneering dredging equipment collects and transports drill cuttings to designated disposal areas. Subsea dredges with attached collection buckets keep drill sites clear of debris. The ROV makes subsea connections, and the drill cutting collection tool can be deployed without a rig.

Abravise Water jet well cutting 	Oil states	-	-	-	-	Oil States has developed a range of internal cutting tools to facilitate the removal of platform and subsea well multiple casing assemblies. The tools, which utilize abravise water jet cutting technology, can be configures to run insede standard $9^{3/8”}$. $13^{3/8”}$ and 20” casing sizes or stand alone 30” conducters
Vertical Diamond wire cutter 	SubC	-	-	-	-	Original, is the Wire Diamond Cutter designed to cut and decommission tubulars on spider decks. The application is thereby suited for decommission jobs as well as removal of tubulars such as caissons, risers etc. Jobs are done safely and controlled; one section at a time. The Vertical Diamond Wire Cutter can be used for decommissioning of surplus steel structures on tubulars – at a fixed distance leaving a minimal drag profile and thereby limiting the forces on the structure.

Market Survey: Decommissioning tools – Complete removal methods						
Tool model:	**Supplier:**	**Dimensions:**	**Mass (in air):**	**Depth:**	**Features:**	**Description:**
PTC Vibrodrivers 	PTC Fayat Group	Multiple	-	-	Multiple options	PTC Vibrodrivers are efficient hydraulic vibratory hammers that produce vertical vibrations to drive or extract piles. The Vibrodrivers work free hanging on crawler cranes and mobile cranes with telescopic booms.

Deepwater Pile Dredge 	Oceaneering	Outer diameter: 50inches Height: 336 inches	11,500lb	10.000ft	- Removes soil plugs from piles and discharges into the water column - Tool consists of: SHPU, main body, suction/ jetting head - Electrically driven from topside via umbilical - Controlled and operated via topside control station	The Oceaneering Deepwater Pile Dredge is an electrically driven system with pumps that provide water jetting and suction to excavate piles at any depth. The jetting provides a 360° pattern to fluidize the soil inside the pile, and then suction pumps remove the soil from the pile.
Hyrdohammer (S-400) 	IHC IQIP	-	-	-	-	The Hydrohammer is a hydraulic impact hammer used for driving steel piles. With its unique design the hammer makes it suitable for all types of onshore and offshore piling and foundation work, ranging from starter piles to the biggest monopiles in the world.
Waterhammer 	IHC IQIP	-	-	-	-	The Waterhammer is a hydraulic impact piling hammer that is controlled with a radical hydraulic system that uses water instead of oil. It's designed for piling jobs in (ultra) deep water. The Waterhammer can be used at water depths up to 2,000 meters. By using water, we eliminate the need to return the liquid medium back to surface, which saves on energy and makes it efficient. The Waterhammer can be used in every type of water (Salt or Fresh water) and is suitable for all piling jobs, like driving pipeline initiation piles, PLEM foundation piles, subsea template foundation piles, piles for jackets, conductors and mooring systems of FPSO's, FSO's and SMP's.
CPE Impact hammer 	IHC IQIP	-	-	-	-	Our CPE hydraulic impact hammer is especially designed for piling jobs with restricted access. This hydraulic piling machine is suitable to drive concrete, timber piles and also steel casings and H-beams. It is easily attachable to one of the compact piling or compact drilling rigs in our range and to an excavator by means of a leader.

A.4 Technical Specification Links – ROVs

AC-ROV 100	http://ac-cess.com/index.php/products/ac-rov-100/ac-rov-100-technical-specifications
AC-ROV 3000	http://ac-cess.com/index.php/products/ac-rov-3000/ac-rov-3000-technical-specification
Alistar 3000	https://www.ecagroup.com/en/solutions/autonomous-underwater-vehicle-platform-surveillance
AlphaROV D150	https://eprons.lv/en/rov-production/rov-products/rov-models/alpharov-d150/
AlphaROV PROF D200	https://eprons.lv/en/rov-production/rov-products/rov-models/
AlphaROV PROF D300	https://eprons.lv/en/rov-production/rov-products/rov-models/
AlphaROV PROF D500	https://eprons.lv/en/rov-production/rov-products/rov-models/
Argus Mariner	https://www.argus-rs.no/media/fm/6c2545554c.pdf
Argus Mariner XL	https://www.argus-rs.no/media/fm/6c2546b7fa.pdf
Argus Mini	https://www.argus-rs.no/media/fm/6c254dda5c.pdf
Argus Rover	https://www.argus-rs.no/media/fm/6c254bd93c.pdf
Argus Worker	https://www.argus-rs.no/media/fm/6c2543c885.pdf
Argus worker XL	https://www.argus-rs.no/media/fm/cbd2812cf7.pdf
Atom/EV	https://www.smd.co.uk/wp-content/uploads/2020/09/SMD_ATOM_EV_Aug20.pdf
A18-E/AUV	https://www.ecagroup.com/en/solutions/autonomous-underwater-vehicle-pipeline-inspection
A18D/AUV	https://www.ecagroup.com/en/solutions/autonomous-underwater-vehicle-pipeline-inspection
A18TD	https://www.ecagroup.com/en/solutions/autonomous-underwater-vehicle-platform-surveillance
A9-E/AUV	https://www.ecagroup.com/en/solutions/autonomous-underwater-vehicle-pipeline-inspection
A9-M/AUV	https://www.ecagroup.com/en/solutions/autonomous-underwater-vehicle-platform-surveillance
Barracuda	http://www.sharkmarine.com/products/rovs/barracuda/
Constructer	https://deepoceangroup.com/wp-content/uploads/2015/11/539eaee378bd4.pdf
Constructer 220 HP	https://deepoceangroup.com/wp-content/uploads/2016/03/DeepOcean_Constructor_16_LOW.pdf
Comanche	DOWNLOAD DATASHEET (f-e-t.com)
Cougar-XT Compact	https://www.saabseaeye.com/solutions/underwater-vehicles/cougar-xt-compact
DeepBot	https://sperre-as.com/wp-content/uploads/2016/04/deepbots_specsheet_ROV.pdf
DTG3	https://ocean-innovations.net/companies/deep-trekker/products/underwater-rov/dtg3/
EELUME	https://www.kongsberg.com/globalassets/maritime/km-products/product-documents/eelume----underwater-intervention-vehicle
eNovus	-
E-ROV	-
Falcon/ Falcon DR	https://deepoceangroup.com/wp-content/uploads/2018/02/FALCON-SEAROV-Specifications-21-02-2018.pdf
FCV 600	FCV 600 (125HP) EQUIPMENT FLYER (fugro.com)
FCV 1000	FCV 1000 (100HP) EQUIPMENT FLYER (fugro.com)
FCV 1000d	FCV 1000D (125HP) EQUIPMENT FLYER (fugro.com)
FCV 2000	FCV 2000 (125HP) EQUIPMENT FLYER (fugro.com)
FCV 3000 (150HP)	FCV 3000 (150HP) EQUIPMENT FLYER (fugro.com)
FCV 3000 (200HP)	FCV 3000 (200HP) EQUIPMENT FLYER (fugro.com)
FCV 4000	FCV 4000 (200HP) EQUIPMENT FLYER (fugro.com)
Focus-2	https://www.macartney.com/what-we-offer/systems-and-products/rotv/
Focus-3	https://www.macartney.com/what-we-offer/systems-and-products/rotv/
Freedom	-
Gavia Offshore Surveyor	-
Glider AUV	http://www.dof.no/en-GB/DOF-Fleet/Subsea-Assets/Glider-AUV
Gnom Baby	https://gnomrov.com/products/gnom-baby/
Gnom Pro	https://gnomrov.com/products/super-gnom-pro/
HD WROV	-
HUGIN 1000 AUV	https://deepoceangroup.com/wp-content/uploads/2015/11/550058f07a910.pdf
H-ROV	https://www.ecagroup.com/en/solutions/autonomous-underwater-vehicle-platform-surveillance

H300 MK2	https://www.ecagroup.com/en/solutions/h300-mk2-rov-remotely-operated-vehicle
H300V	https://www.ecagroup.com/en/solutions/h300v-rov-remotely-operated-vehicle
H800	ECA-Group-ROV-H800
H1000	ECA-Group-ROV-H1000
H2000	ECA-GROUP-H2000
H3000	-
H6500	
Installer	https://deepoceangroup.com/wp-content/uploads/2015/11/5016b4f481a08.pdf
Isurus	-
Jaguar	-
Lynx	https://www.saabseaeye.com/uploads/seaeye_tiger_and_lynx.pdf
Magnum Plus ROV	-
Maxximum ROV	-
Merlin UCV R-ROV	Merlin UCV R-ROV (ikm.com)
Millennium Plus ROV	-
Mini-ROV Guardian	https://www.subsea-tech.com/mini-rov-guardian/
Mohawk	https://deepoceangroup.com/wp-content/uploads/2018/02/MOHAWK-SEAROV-Specifications-21-02-2018.pdf
Mohican	https://deepoceangroup.com/wp-content/uploads/2015/11/5016b53887bc1.pdf
Mojave	https://deepoceangroup.com/wp-content/uploads/2018/02/MOJAVE-SEAROV-Specifications-21-02-2018.pdf
Nexxus ROV	-
Observer Mini-ROV	https://www.subsea-tech.com/mini-rov-observer/
Omni Maxx	https://www.oceaneering.com/rov-services/rov-systems/
Perseo GTV	https://www.l3harris.com/all-capabilities/ageotec-rov-series-full-range-remotely-operated-vehicles
Panther Plus	https://deepoceangroup.com/wp-content/uploads/2018/02/PANTHER-Plus-SEAROV-Specifications-21-02-2018.pdf
Panther-XT	-
Robotics Gemini ROV	-
Robotics HD ROV	-
Robotics ISOL-8 Pump	-
Robotics UHD II	-
Robotics UHD III	-
Rovingbat	https://www.ecagroup.com/en/solutions/
ROV-500	http://www.outlandtech.com/rovs?product_id=104
ROV-1000	http://www.outlandtech.com/rovs?product_id=102
ROV-2000	http://www.outlandtech.com/rovs?product_id=103
ROV-2500	http://www.outlandtech.com/rovs/rov-2500-model
Sabertooth	https://www.saabseaeye.com/solutions/underwater-vehicles
Sanertooth double hull	https://www.saabseaeye.com/solutions/underwater-vehicles
Seaeye Couger XT	-
Seaeye Cougar Xti	-
Seaeye Leopard	https://deepoceangroup.com/wp-content/uploads/2015/11/DeepOcean_SeaEye-Leopard_2016.pdf
Seaeye Marine Tiger	http://www.dof.no/en-GB/DOF-Fleet/Subsea-Assets/Seaeye-Marine-Tiger
Sea Maxx	https://www.oceaneering.com/rov-services/rov-systems/
SeaOwl XTi	https://www.saabseaeye.com/uploads/seaowl-xti-rev2.pdf
SeaOwl MK IV	https://deepoceangroup.com/wp-content/uploads/2016/04/DeepOcean_Seaowl-MK-IV-12.pdf
Sea-Wolf 5	http://www.sharkmarine.com/products/rovs/sea-wolf-5/
Shilling Robotics HD	-
Spectrum	https://www.oceaneering.com/rov-services/rov-systems/
SRS Fusion	https://www.srsfusion.com/srs-fusion
SRV-8	https://ocean-innovations.net/companies/rje-oceanbotics/srv-8/
Sub-Fighter 10k	-
Sub-Fighter 15k offshore	-

Sub-Fighter 15k standard	-
Sub-Fighter 30k	-
Sub-Fighter 3000	-
Sub-Fighter 4500	-
Super gnom	https://gnomrov.com/products/super-gnom/
Superior Survey ROV	https://deepoceangroup.com/wp-content/uploads/2016/02/2016-FINAL-DEP150295-DeepOcean_Superior-Survey_ROV_LOW.pdf
Supporter	https://deepoceangroup.com/wp-content/uploads/2015/11/5016b749ce4eb.pdf
Surveyor Intercepter	http://reachsubsea.no/assets/surveyor/
Surveyor Plus	https://deepoceangroup.com/wp-content/uploads/2018/02/SURVEYOR-Plus-SEAROV-Specifications-21-02-2018.pdf
Tiger	https://www.saabseaeye.com/uploads/seaeye_tiger_and_lynx.pdf
Tortuga	https://www.subsea-tech.com/tortuga/
Triaxus	https://www.macartney.com/what-we-offer/systems-and-products/rotv/
Triton XL	https://deepoceangroup.com/wp-content/uploads/2018/02/TRITON-XL-SEAROV-Specifications-21-02-2018.pdf
Triton XLS 150	-
Triton XLX	-
T1	https://www.enshoresubsea.com/assets/mechanical-trencher
T2	https://www.enshoresubsea.com/assets/mechanical-trencher
T1000	https://www.enshoresubsea.com/assets/jet-trencher
T3200	https://www.enshoresubsea.com/assets/mechanical-trencher
UHD ROV	https://deepoceangroup.com/wp-content/uploads/2015/11/53ecbfcb299f9.pdf
UT-1	https://www.enshoresubsea.com/assets/jet-trencher
Quantum/EV	https://www.smd.co.uk/wp-content/uploads/2020/05/SMD_Quantum-EV_Brochure-2020_Web-edit-FINAL.pdf
Quasar	https://www.smd.co.uk/wp-content/uploads/2016/12/SMD_2685_ROV_Brochure_pps_low_res.pdf
XLe Spirit®	https://www.f-e-t.com/wp-content/uploads/2019/10/xle-spirit-datasheet.pdf
XLX-C Heavy Duty	https://f-e-t.com/subsea/vehicles/work-class-rovs/
XLX Evo Ultra Heavy Duty	https://f-e-t.com/subsea/vehicles/work-class-rovs/
XT300	https://f-e-t.com/subsea/vehicles/trenchers/
XT500	https://f-e-t.com/subsea/vehicles/trenchers/
XT600	https://f-e-t.com/subsea/vehicles/trenchers/
XT1200	https://f-e-t.com/subsea/vehicles/trenchers/
XT1500	https://f-e-t.com/subsea/vehicles/trenchers/

A.5 Technical Specifications Links – ROV decommissioning Tools

ECT – ROV operated external cutting tool	https://www.oceaneering.com/decommissioning/topside-and-jackets/cutting-solutions/
Pipe cutter and Beveling	https://www.oceaneering.com/decommissioning/topside-and-jackets/

A.6 Technical Specifications Links – Decommissioning Tools

Deepwater Pile Dredge	https://www.oceaneering.com/decommissioning/subsea-removals/dredging/
Internal Cutting Tool (ICT 6090)	https://www.oceaneering.com/decommissioning/topside-and-jackets/cutting-solutions/
Drill Cut Remediation	https://www.oceaneering.com/decommissioning/subsea-removals/
VIBRODRIVERS – PTC Fayat Group	http://www.ckk-net.com/vibrodrivers.pdf

Hydrohammer	https://www.ihciqip.com/en/products/piling-equipment
Waterhammer	https://www.ihciqip.com/en/products/piling-equipment
CPE Impact hammer	https://www.ihciqip.com/en/products/piling-equipment
ECT - Deepwater Abrasive Waterjet Cutting	https://www.oceaneering.com/decommissioning/topside-and-jackets/cutting-solutions/
Drill Cut remedy	https://www.oceaneering.com/decommissioning/topside-and-jackets/
Vertical Wire Diamond Cutter	https://www.subcpartner.com/assets/Dokumenter/1247811c8b/Crawler-brochure.pdf
Abrasive water jet well cutting	http://oilstates.com/wp-content/uploads/OilStatesWellCutting.pdf