NTNU – Trondheim
Norwegian University of
Science and Technology

Subsea surveillance unit

(Undervanns overvåkningsenhet)

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Submission date: July 2015
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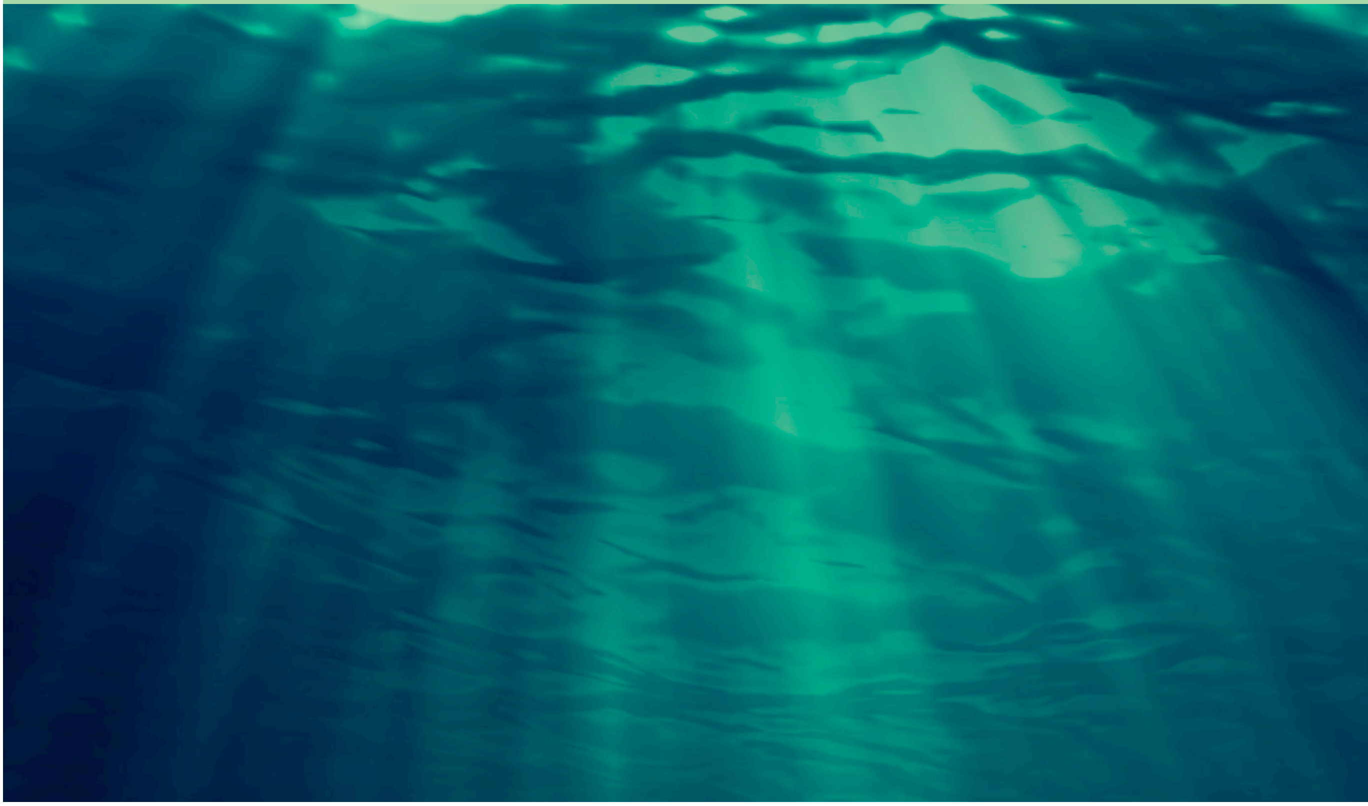
Subsea surveillance unit

Master thesis
by
Eivind Prestholt

Institute of Product design
Norwegian University of
Science and Technology

2015



Abstract

This master thesis was carried out by Eivind Prestholt during the spring 2015 in collaboration with Trollhetta AS.
The project can be seen as a concept study of a subsea surveillance unit intended for use in the oil and gas industries, where the focus mainly is monitoring tasks in areas where there are limited infrastructure, for example at a temporary abandoned well. The objective for the project has been to make it an introductory part of the development-process for the surveillance unit, providing Trollhetta AS with insight and inspiration for further development of a surveillance unit. The concept study has attempted to take on a realistic approach and tried to make the presented solutions display a certain degree of feasibility.

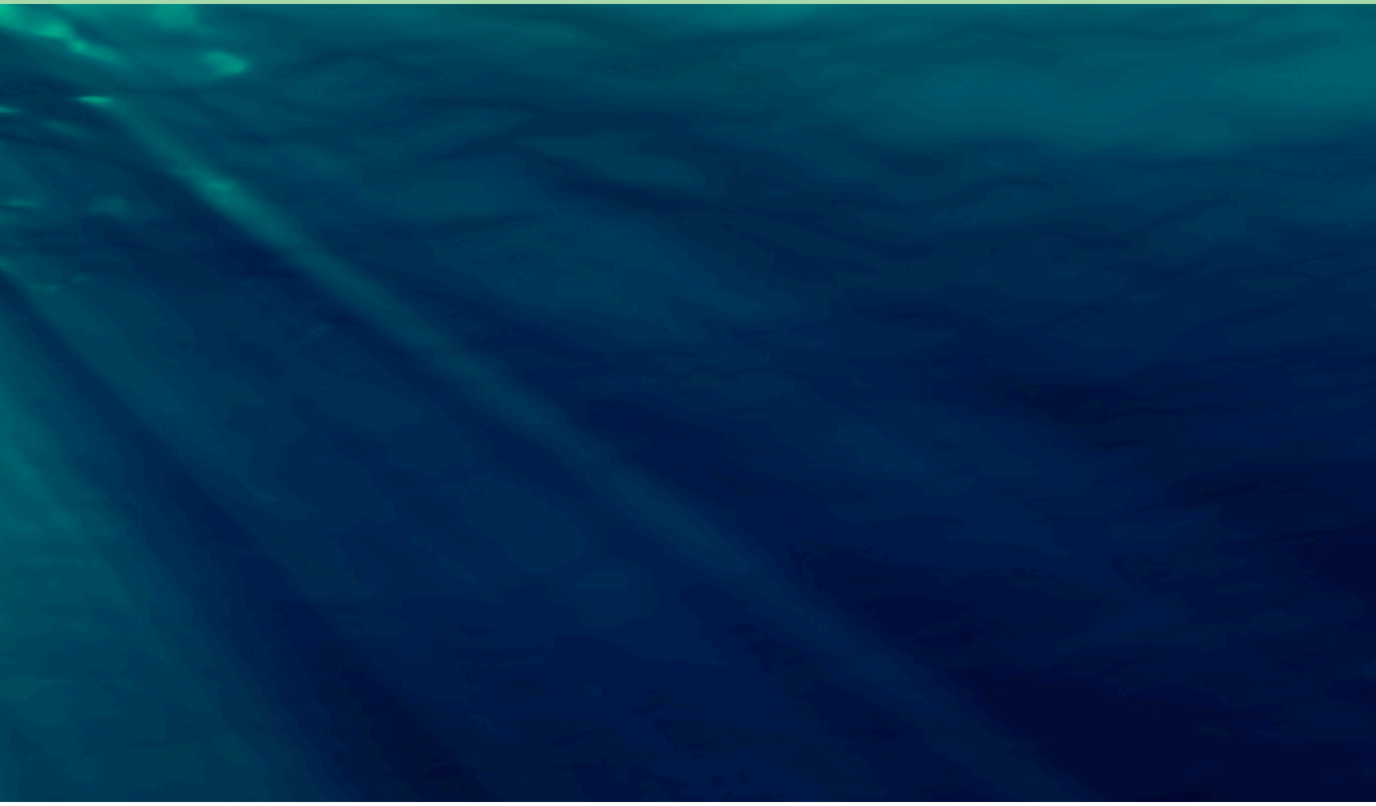
The project builds partly on a pre-project which was carried out in the autumn 2014 as part of the subject TPD 4500 Product design (PD9). However, the framework for the project was still rather open at the start of this master thesis.

Extensive research was done to obtain insight and knowledge into relevant areas such as use, market, production and technical aspects. The research was largely based on interviews and visits to relevant companies and educational institutions.
The design of the concept is based on various analyses, findings and results from the research together with requirements and wishes put down by Trollhetta. The work consisted mainly of designing the unit with main components and parts.

The final concept was developed with a focus on providing a flexible and practical standalone-solution which accommodate for optimal leak detection and monitoring.

The final concept displays features such as:

- Modularity and tailorability.
- Easy and inexpensive installation and collection.
- Sturdy anchoring and very trawl-resistant design.



Sammendrag

Denne masteroppgaven er utført av Eivind Prestholt våren 2015 i samarbeid med Trollhetta AS. Oppgaven kan sees som et konseptstudium av en undervanns overvåkningsenhet tiltenkt bruk i olje og gass industrien, med spesielt fokus på overvåkingsoppgaver i områder hvor det ikke eksisterer nevneverdig infrastruktur, for eksempel ved en midlertidig forlatt brønn. Målet for oppgaven har vært å fungere som en innledende del av en utviklingsprosess som skal gi Trollhetta AS innsikt og inspirasjon til eventuell utvikling og gjennomføring av design for en overvåkningsenhet. Så langt det har latt seg gjøre har konseptet inntatt en realistisk tilnærming og man har forsøkt å gjøre de presenterte løsningene potensielt realiserbare. Prosjektet bygger delvis på et forprosjekt utført høsten 2014 som en del av faget TPD 4500 Produktdesign (PD9), likevel hadde oppgaven et svært åpent utgangspunkt fra starten av.

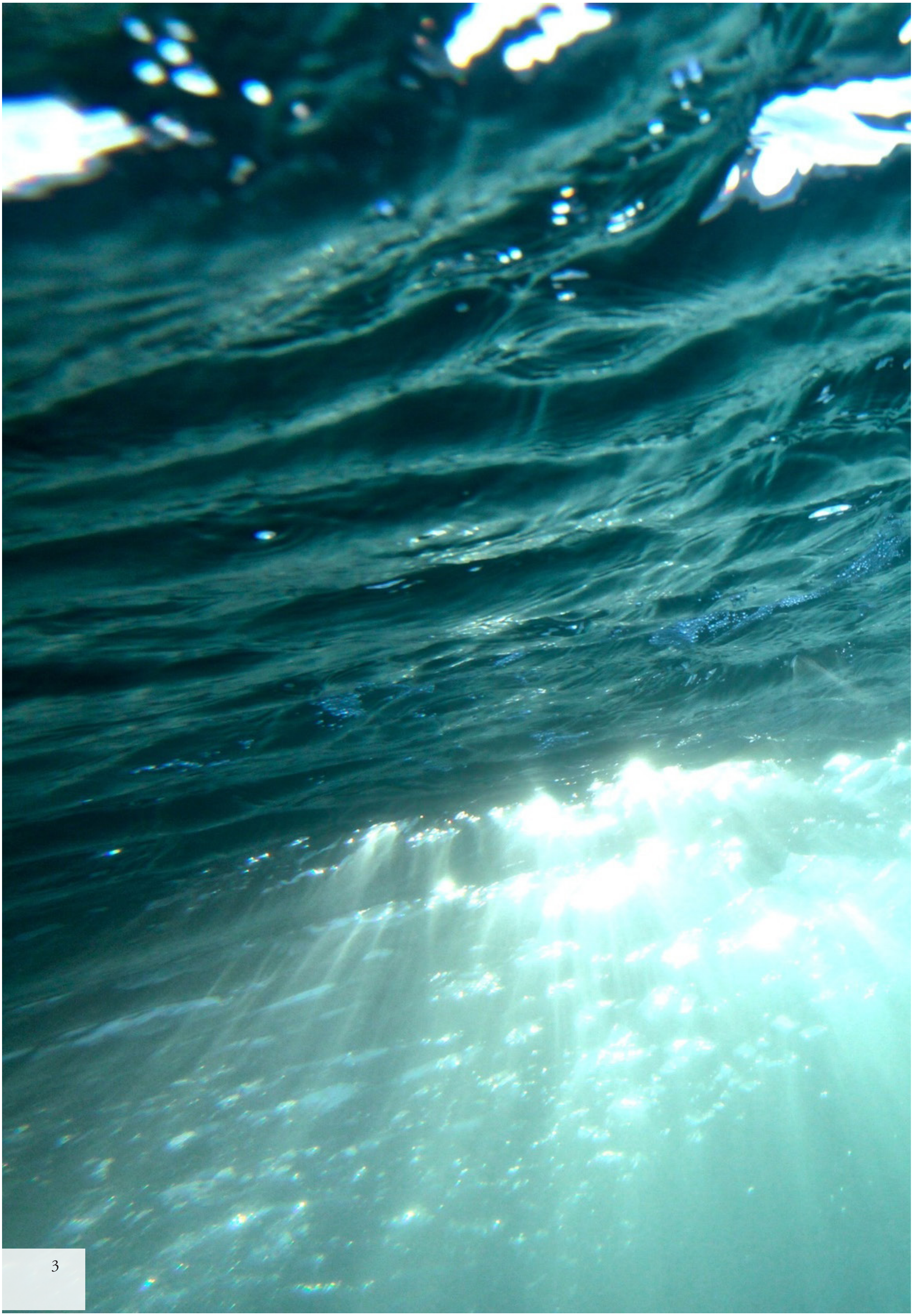
Omfattende research var nødvendig for å skaffe innsikt og kunnskap om relevante områder for oppgaven som for eksempel bruk, markedsforhold, samt faktorer for produksjon og tekniske løsninger. Anskaffelsen av denne innsikten og kunnskapen baserte seg hovedsaklig på intervjuer og besøk hos aktuelle bedrifter og kunnskapsorganisasjoner.

Utformingen av konseptet er gjort med grunnlag i ulike analyser, resultater og funn gjort under anskaffelsen av innsikt og kunnskap. I tillegg har ønsker og krav fra Trollhetta stort sett blitt tatt hensyn til. Arbeidet har i hovedsak bestått i å designe og utforme selve overvåknignsenheten og dens ulike komponenter og deler.

Det endelige konseptet er utformet med et fokus på å kunne tilby en fleksible og praktisk løsning som er frittstående og som legger til rette for optimal overkåkning og lekasjedeteksjon.

Det endelige konseptet innehar blant annet egenskaper som:

- modularitet og mulighet for skreddersying
- enkel og kostnadseffektiv installasjon og opphenting
- robust forankring samt særdeles trålsikkert design



Preface

This thesis is made as a completion of the master education in Industrial Design at IPD (Institute of Product design), Norwegian University of Science and Technology (NTNU) spring 2015.

Many persons have contributed with academic advice, professional insight and general support to this master. Firstly I would like to thank my supervisor at IPD, Jon Herman Rismoen, for his time, input and support during the master period. Furthermore, I would like to thank Torgeir Pedersen and Ketil Bø at Trollhetta AS for letting me work with them, for their collaboration and big help and support throughout the entire process.

I would also like to thank Arild Brevik at the subsea division at Kongsberg Maritime for his time, great advice, input, expertise and good conversations. A thank you also goes out to Audun Sødal at EMGS for great advice and valuable input. Special thanks are also sent out to the respective others I have received help from. Finally I would like to thank my family and friends for help and support throughout my time studying at NTNU.

Eivind Prestholt, Trondheim 2015

NTNU
Norwegian University of
Science and Technology

Faculty of Engineering
Science and Technology
Department of Product Design

Master Thesis for Eivind Prestholt

Subsea surveillance unit

Undervanns overvåkningsenhet

Trollhetta AS is a company working with cutting edge technology for solutions based on image analysis and artificial intelligence mainly directed towards oil, gas and fish farming industries. Since the beginning of subsea oil and gas extraction in the middle of the 20th century an increasing number of new oil and gas wells have been built each year, and following these wells have been or will be abandoned at some point. At this point permanent plugging of an oil or gas well is a very expensive procedure, and temporary plugging offers a cheaper alternative with the added benefit of the possibility to reopen the well if desired. However, regulations state that temporarily abandoned wells will have to be under surveillance. The goal will be to offer a system for surveillance of temporarily abandoned wells.

The task will be to design a subsea surveillance unit for monitoring oil and gas leakages in petroleum and gas industry subsea, oil wells, gas wells, pipelines etc. The subsea surveillance unit is going to be a part of a complete Safety and Environmental Monitoring System Trollhetta AS is developing. I will focus on the overall completion of the unit which will includes layout and design of the unit, trying this together with working with functionality and use of the unit. This will of course mean collaborating on development and design of components of the unit with collaboration-partners of Trollhetta.

Work tasks will amongst other include;

- -further analysis, mapping and clarifications regarding the identified problems and the indicated solutions from the pre-project
- -further analysis and mapping of the system of the unit and how this system should work
- -development of concepts for the solutions
- -development of final concept for the unit

The thesis is made according to the "Guidelines for Master's Thesis in Industrial Design".

Responsible supervisor:	Jon Rismoen
Contact person:	Torgeir Pedersen, Trollhetta AS
Starting date:	27th of February 2015
Delivery limit:	24th of July 2015

Trondheim, NTNU, 27th of February 2015

Jon Herman Rismoen
Jon Rismoen
Responsible supervisor

Casper Boks
Head of Department

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Introduction

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Redevelopment of scenarios and overview of problems

Introduction

Background for the project

Over the last decade and a half Trollhetta AS has developed and delivered safety- and environmental monitoring solutions for both the fields of petroleum and aquafarming industries, as well as various other applicable fields. They are currently in the process of developing a complete safety and environmental monitoring system for the offshore industry.

A growing issue in the petroleum industry is plugging and abandonment of subsea oil and gas wells. In particular temporary abandoned wells which may represent an environmental risk with regards to leakage unless kept under regular surveillance. The issue identified above, seen together with tendencies and indications of amendments in the regulations for petroleum activity in Norway regarding safety and monitoring of temporary abandoned wells, provides identification of a protruding market (these matters will be further clarified on a later point). With this in mind, and the aim to deliver a complete safety and environmental monitoring system intended for the offshore industry, Trollhetta AS wants to develop an autonomous, wireless, subsea surveillance unit. The Department of Product Design at NTNU was contacted regarding design and development of the unit and as a result, this master project presented itself.

An open framework

As a company without any previous experience with development of hardware, it was seen as beneficial for Trollhetta to initiate the process of mapping solutions for the development the system and design of the unit with this master thesis. A preliminary design brief (which will be more thoroughly reviewed on a later point) declaring the initial idea of the unit; autonomous, wireless, subsea surveillance unit with releasable alarm-buoy intended for oil and gas leakage detection, was provided with the invitation to be creative and free-thinking. In other words one can say that the framework for this master thesis was rather open to begin with.

Objective

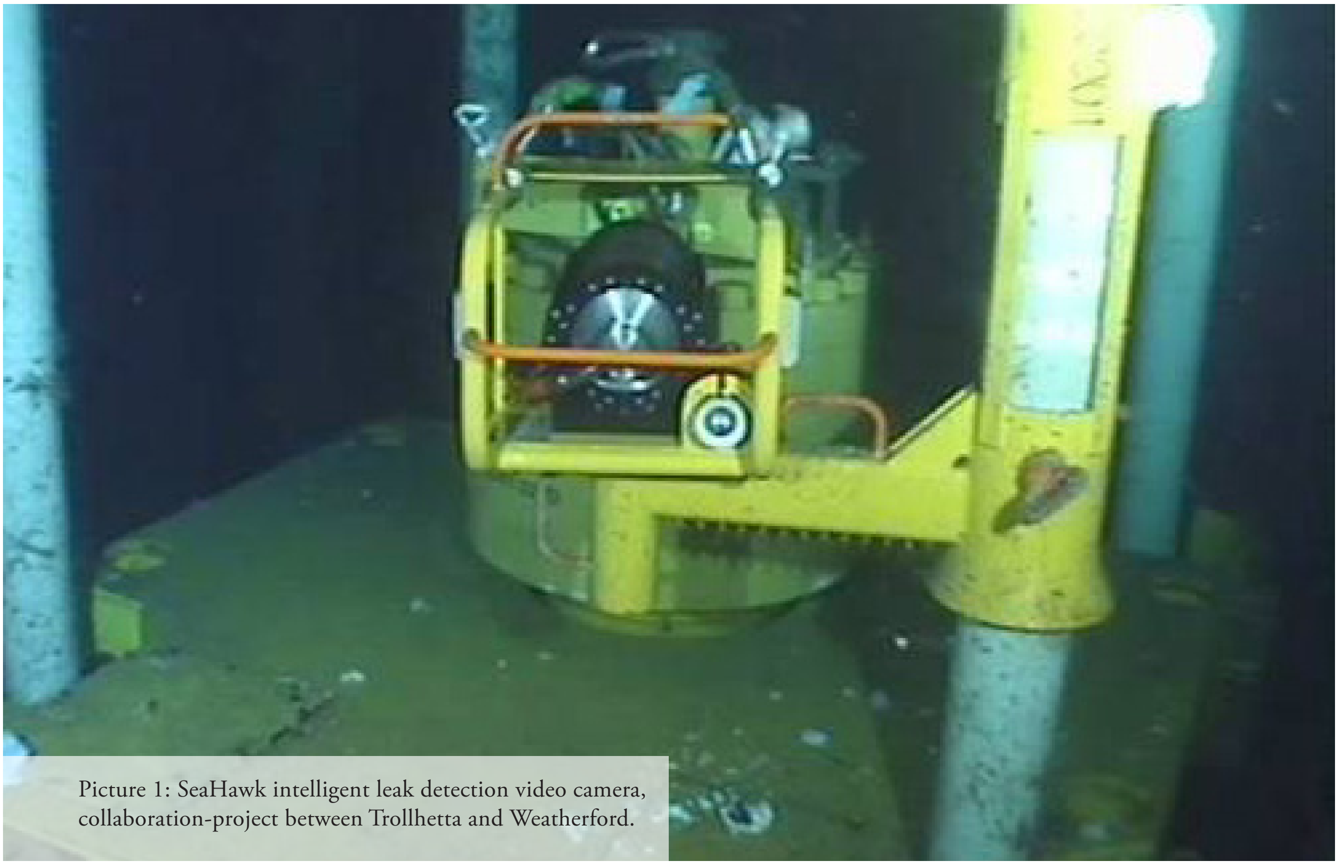
The objective for this project is to make it an introductory part of the development-process for the surveillance unit; providing Trollhetta AS with valuable insight and recommendations for the realization and completion of their surveillance unit. The project should further contribute to the development of a product satisfying the needs and requirements found in its intended market. The project is expected to result in a specification of requirements together with concepts highlighting ideas and possible solutions for the design of parts of the unit as well as a final concept for the design of the unit.

Trollhetta AS - project initiator and collaboration partner

Trollhetta AS is a company working with cutting edge technology for monitoring solutions based on image and video analysis and artificial intelligence mainly directed towards oil, gas and fish farming industries.

The Trondheim-based company was established in March 2001 by Dr. Ing Ketil Bø and Dr. Ing Agnar Aamodt, both professors at The Norwegian University of Technology and Science (NTNU). Founded with the following goals; to produce, sell and marked computer software and services, Trollhetta AS has since the start up been concentrated on providing tailor made solutions based on their development tools DynamicImager, TrollEye and TrollBrain. Their solutions offer monitoring and detection such as oil and gas leakage detection, monitoring of aquaculture facilities, traffic monitoring and intruder detection in security surveillance.

As Trollhetta AS is seeking to deliver a complete safety and environmental monitoring system intended for offshore industry it may be beneficial for the company to expand beyond software development and get involved in development of hardware solutions completely tailored and configured to the specific needs of their customers.



Picture 1: SeaHawk intelligent leak detection video camera, collaboration-project between Trollhetta and Weatherford.

Limitations for this project

"I see it as important to point out my own limitations in this project and since design for subsea is a completely new and unploughed field for me. This should be kept in mind when reading this master thesis" – The undersigned, Eivind Prestholt.

In context of the above statement one might ask oneself; why then undertake a project like this? With the premises for the assignment, such as a very open framework and Trollhettas lack of experience with development of material products, it was clear that the project called for help defining the product as much as pure product development and as an industrial designer this is an interesting starting point for a project. Furthermore, it can be valuable with a person with different background as one are more likely to look at challenges and problems with new eyes and see creative solutions different from what is commonly used.

Method and process

The approach with respect to design process has been a rather common one for product design. Getting acquainted with a completely new field (subsea) has required extensive research and following, the first phase of the project have been focusing on gathering information. The research has been largely based on interviews, visits/meetings and excursions to persons, organizations and companies of interest, but also reports, documents and literature found on the internet have been useful sources of information. Development and sketching of ideas were done continuously throughout the whole project both by hand and CAD. This provided the opportunity to pitch some selected ideas to competent people, i.e. during interviews or through email, to get valuable feedback and weed out which solutions to continue working with or not.

Preparatory phase

Project status at beginning

The work with this master thesis did not start entirely from square one. A pre-project had previously been carried out in the autumn 2014 as part of the subject TPD 4500 Product design (PD9). The project roughly outlines design requirements and potential solutions for the conceptualization of the unit and its system. Working through and evaluating the report from this pre-project was a natural place to begin together with setting up a tentative project plan to get a better picture of the time aspect of the work with the master thesis.

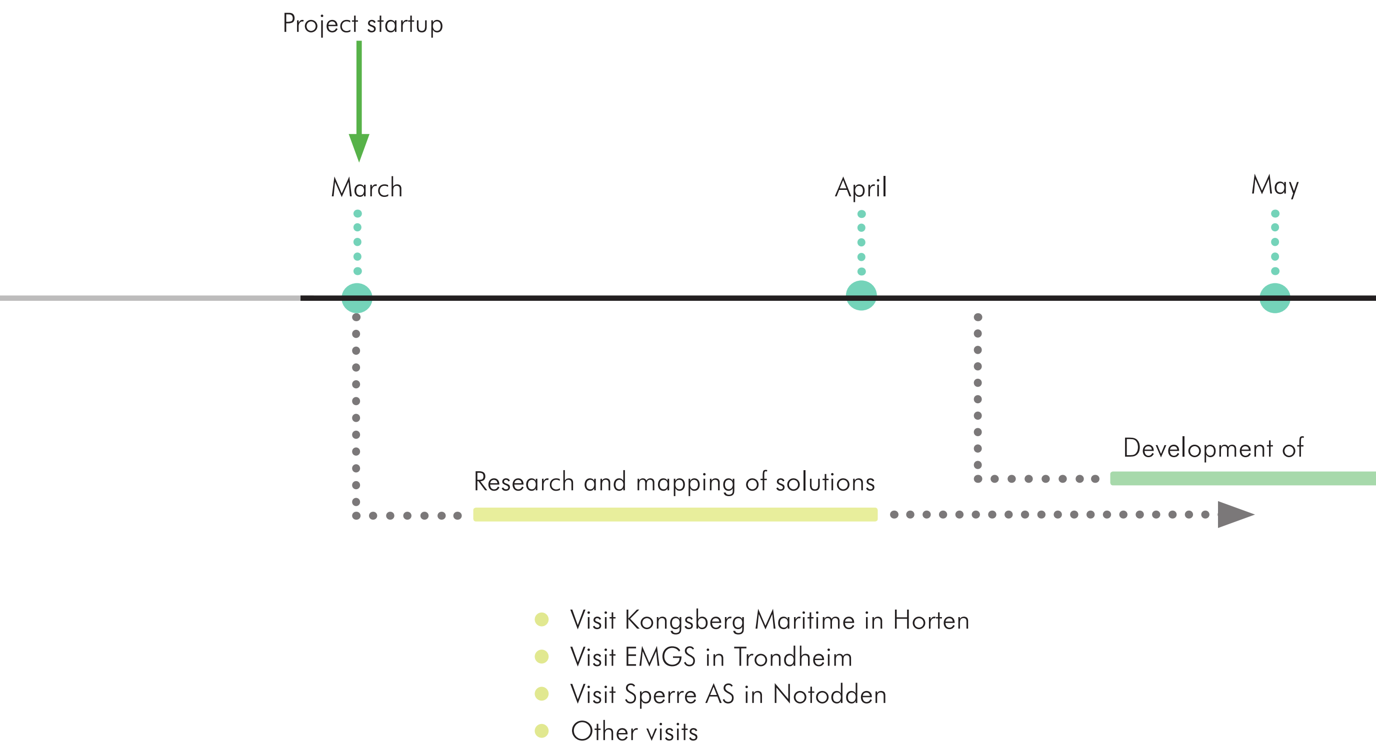
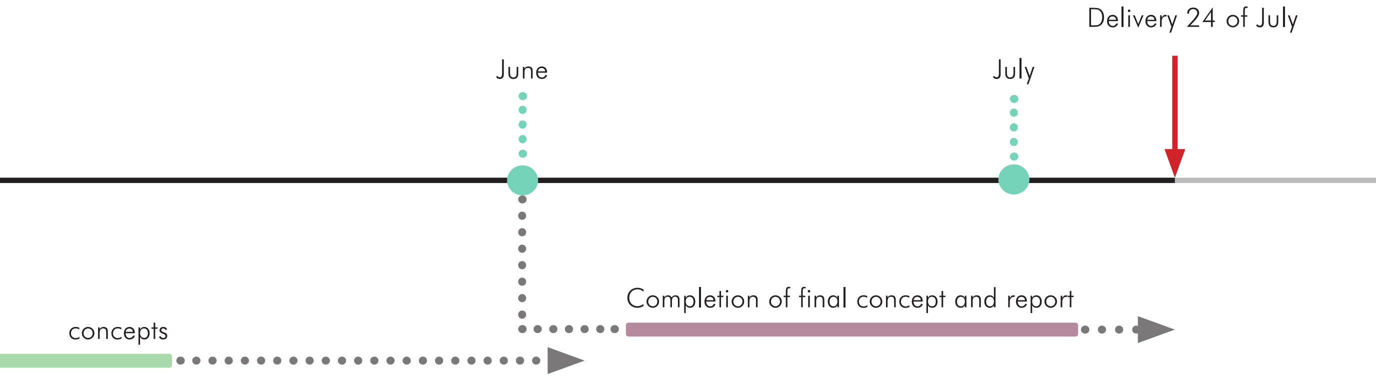


Figure 1: Masterplan.

A rough project plan sketched during the startup of the assignment. Although it was not possible to strictly follow this plan, it gives a good impression of the general workflow in the project.


Delivery 24 of July
June
July
Completion of final concept and report
concepts

Preliminary design brief and scenario from Trollhetta

A preliminary design brief and a scenario stating Trollhettas initial idea was provided when first starting to work with the pre-project. Apart from the guidelines sketched in the preliminary design brief and the scenario, together with other more implicit constrains (expenses, etc.), there were not given any further restrictions regarding development and design of the unit.

Scenario

"Trollhetta AS is a company that does condition based surveillance and monitoring related to safety and environment using image analyses, pattern recognition and artificial intelligence.

Surveillance of subsea installations for condition monitoring and leak detection is required by law in many countries and is considered best practice by the oil and gas industry. Many of the subsea installations are in remote locations and working communication is not available.

When oil and gas wells are no longer in use, the wells must be plugged. Permanent plugging of a well is very costly and future use is not possible. For this reason, the operators often go in for only temporarily plug the well. Temporary plugged wells require continues monitoring. Often these sites are abandoned and establishing or maintaining communication could be very costly.

Trollhetta is developing a wireless autonomous condition monitoring and leak detection solution that will operate standalone. In case of an alarm that needs immediate attention, a communication device is released and will float to the surface and initiate communication using a satellite system.

Operators of oil and gas fields today are using wired solutions that provide the monitoring equipment with power and communication. This makes the installation very costly and, if the site is in a remote location, maybe even impossible."

TROLLHETTA
CONTRIBUTING WITH EXPERIENCE

Design brief

Autonomous wireless leak detection unit with releasable alarm buoy

This surveillance unit is going to monitor oil and gas leakages in subsea petroleum and gas industry, it is also going to be a part of a complete Safety and Environmental Monitoring System Trollhetta AS is developing. The working ranges of the device should be deeps up to and including 3000 meters, with an anticipated working period of approx. 1 year before maintenance or replacement. The unit will have a camera with light/flash (and/or other needed equipment for gathering valuable data), a central processing unit, a battery unit with sufficient capacity and necessary cables and connectors. A crucial part of the system of the unit will be a releasable alarm-buoy. The buoy, which contains information regarding the detected leakage situation, will be released and float up to the surface to send information in case of an emergency situation. The unit should be trawl resistant and will have to be adequately anchored at the deployment site.

- Scheduled video recording
- Low TCO.
    - Low cost of deployment
    - Long maintenance intervals
- Image processing in unit/system
- Communication initiated on alarm
- Built-in battery pack lasting 1 year of surveillance
- Efficient notification when alarm
- Perfect in remote locations and/or locations with bad infrastructure

TROLLHETTA
CONTRIBUTING WITH EXPERIENCE

Findings form the pre-project

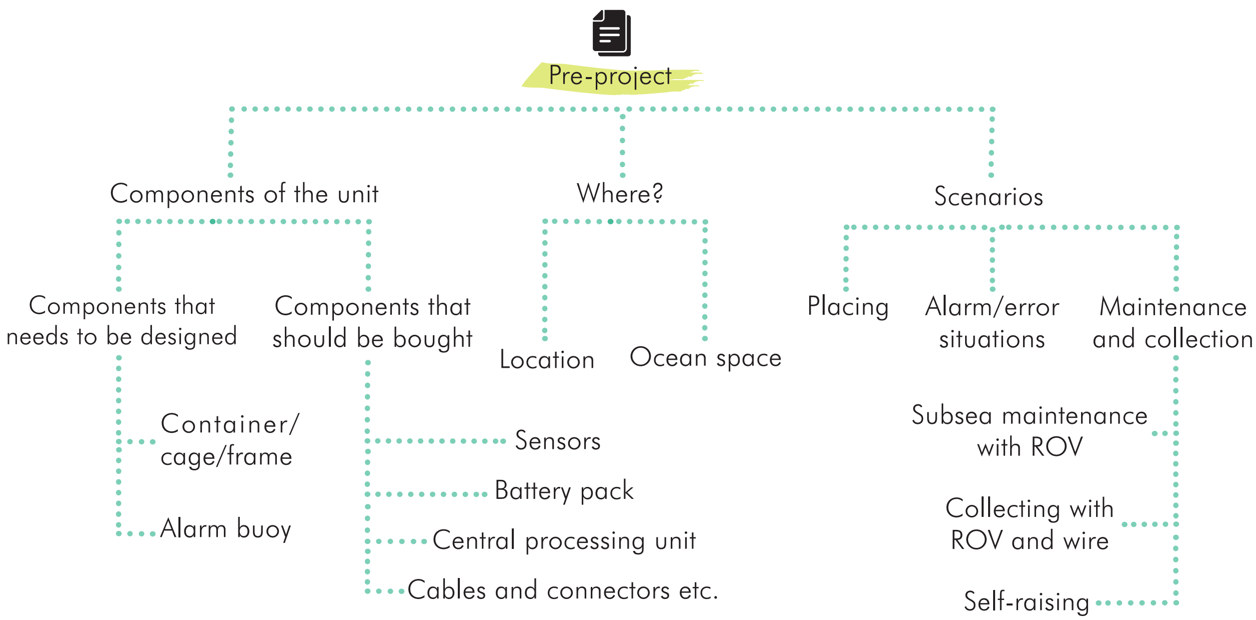


Figure 2: Overview over pre-project and relevant touchpoints

As stated earlier, this master thesis partly builds on a pre-project which was initiated by the undersigned in the autumn 2014. The pre-project highlights some crucial challenges, problems as well as possible solutions regarding the design of the surveillance unit. The findings from the pre-project served as a starting point for the project and some of the most relevant results can be found in the table to the left together with comments from the evaluation done during this preparatory phase.

Item	Result	Comment
Scenarios	Life of the unit Placing Alarm/error situation Collecting/maintenance	Partly incomplete, i.e. placing scenario does not take into account where to place the unit.
Components of the unit	Components that needs to be designed Components that can be bought	It is made clear that the components that should be designed are mainly a frame/pod (for holding the equipment/sensors) and the releasable alarm-buoys. Sensors and other equipment already exists "off the shelf" ready with pressure rated housings etc. for subsea deployment.
Where?	Deeps from 0-3000 meters Marine growth Corrosion Conditions at deployment site	Important problems are pointed out, but the information is sparse and further research could be needed.
Placing	Wire + cable (for camera feed) is suggested down to 1000 meter and placing with ROV is needed at greater depths (expensive)	Solution does not fully take into account where to place/install the unit. States that lease of ROV is expenisve
Collection/maintenance	Subsea maintenance is deemed too difficult. Self-raising is pointed out as an interesting solution	Solutions for collection are implied but not properly justified. Subsea maintenance is deemed too difficult/expensive.
Trawl resistance	Unit caught in net Unit hit by trawl-door or bottom gear	Provides basic information regarding trawling activity, states that further research is needed.
Self-recovery	Principal with buoyancy foams and counter weight is explained	Decided to investigate further, a promising option.
Standard equipment	Central processing unit, camera, hydrophone, transponder, battery	Partly defined by design brief, ok.
Data transmission from CPU to alarm-buoy	Optical solution, Wi-Fi, cable	Some methods are suggested, no definite conclusion.

Figure 3: Results and findings from the pre-project with comments

Defining boundaries

Introduction

Seeing as the framework for the project was initially very open it was necessary to narrow down the scope of the project to such a degree that it would be possible to complete during the time limit of the master thesis. For this reason defining boundaries for the design and conceptualization of the unit and its solutions was an important part of this project and had to be done continuously throughout the development process. As new findings were discovered, i.e. from research, they were evaluated and decisions were made either by the student alone or together with Trollhetta.

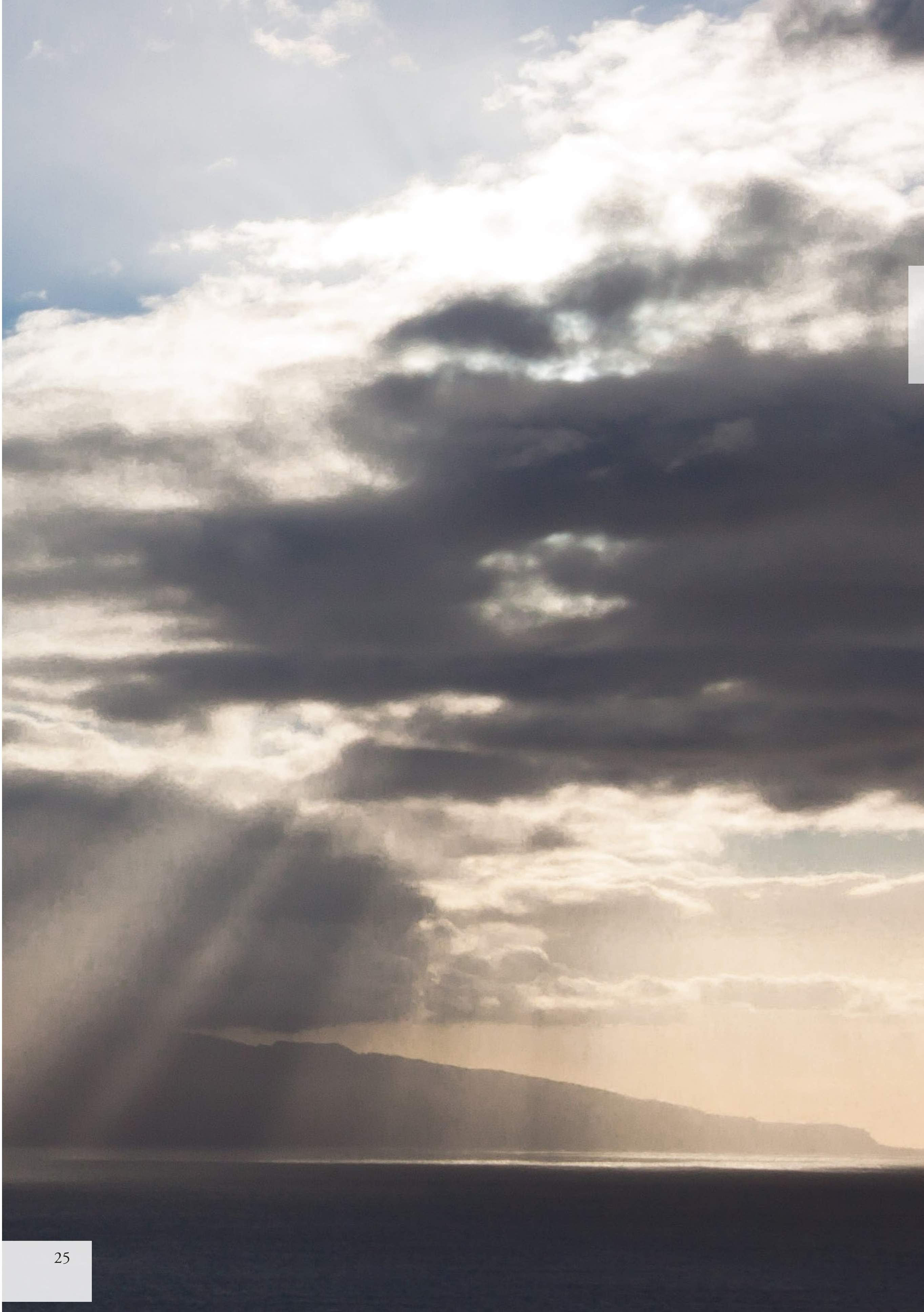
Some boundaries were decided on during the preparatory phase (see alarm buoy and market) and some had already been discussed and agreed upon in the pre-project. For example maintenance should happen "on land" and subsea recharging of batteries or cleaning of camera lenses/other sensors was not needed to think of in the development of solutions and design. Furthermore, it was decided to use commercially available solutions for sensors and equipment, and design of pressure housings etc. for these devices could also be left out from the final solution.

Alarm buoy

Even if the alarm buoy is an essential part of the surveillance unit it was initially decided not to include ideas or concepts for the design for the alarm buoy in this master thesis. The main reason for this was that Trollhetta already were in contact with possible collaboration partners regarding the design of the buoy and it was seen as more important to concentrate the work around the design of the unit itself. In addition, developing a final concept for the unit and developing a final concept for the buoy, although connected, can be seen as two different projects. This would, simply put, be too large a burden for the scope of this master thesis.

Market

Although it is not mentioned in the design brief or scenario from Trollhetta it became clear during meetings and discussions that the company were also hoping the final solution would cover needs in the aquaculture market as well as in the offshore and petroleum market. The requirements to a surveillance unit for these two industries most likely differ greatly and would potentially result in contradictions in design needs and concept development. It was therefore decided to only focus on the offshore and petroleum industries since this provides the most promising market opportunities. Another point was deciding on aiming the product at the Norwegian market. Seeing as Trollhettas initial plan, if they proceed with the project, is to firstly launch their product in Norway this became natural choice to make. The decision helped reducing the need for research considerably, i.e. rules and regulations regarding subsea appliances and petroleum activities in other parts of the world differ from Norwegian regualtions etc. This did not rule out considering the international market entirely, but less attention was given towards preparing the final concept for an international introduction.



Redevelopment of scenarios and overview of problems

After working through and evaluating the results from the pre-project it was seen as necessary to get a better overview of the challenges and problems connected to developing a concept for the surveillance unit. It was decided to perform a redevelopment of the three scenarios, placing, deployment (alarm/error situation) and collection, since they describe the most important cases of interaction and use of the product.

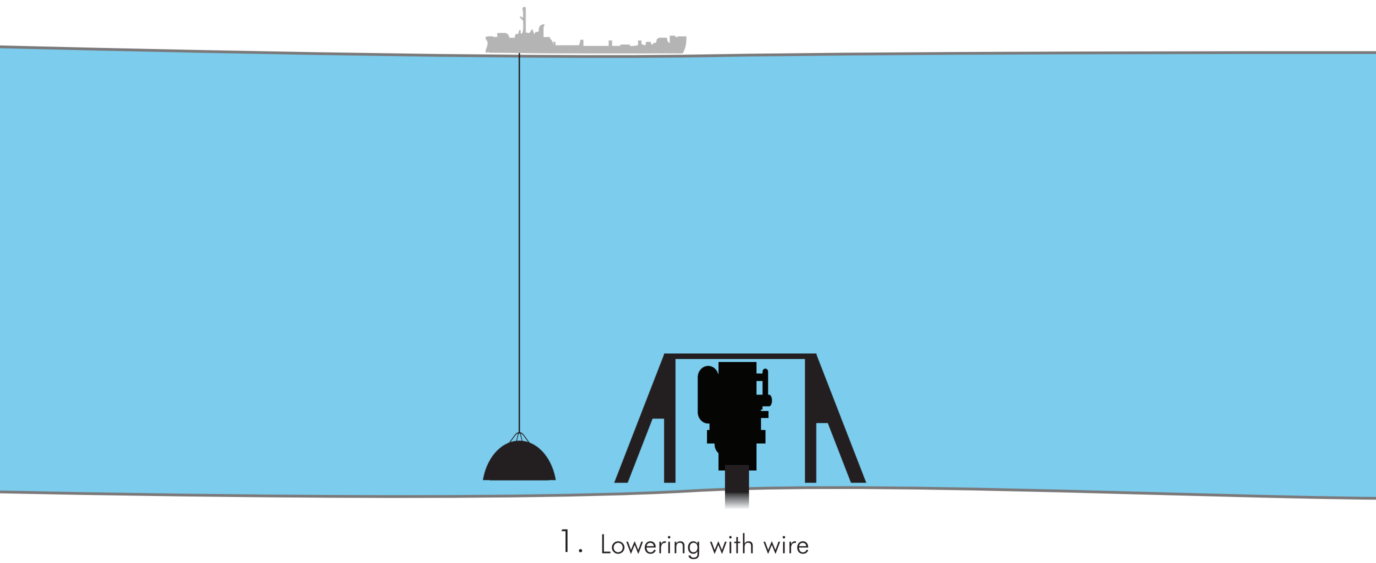
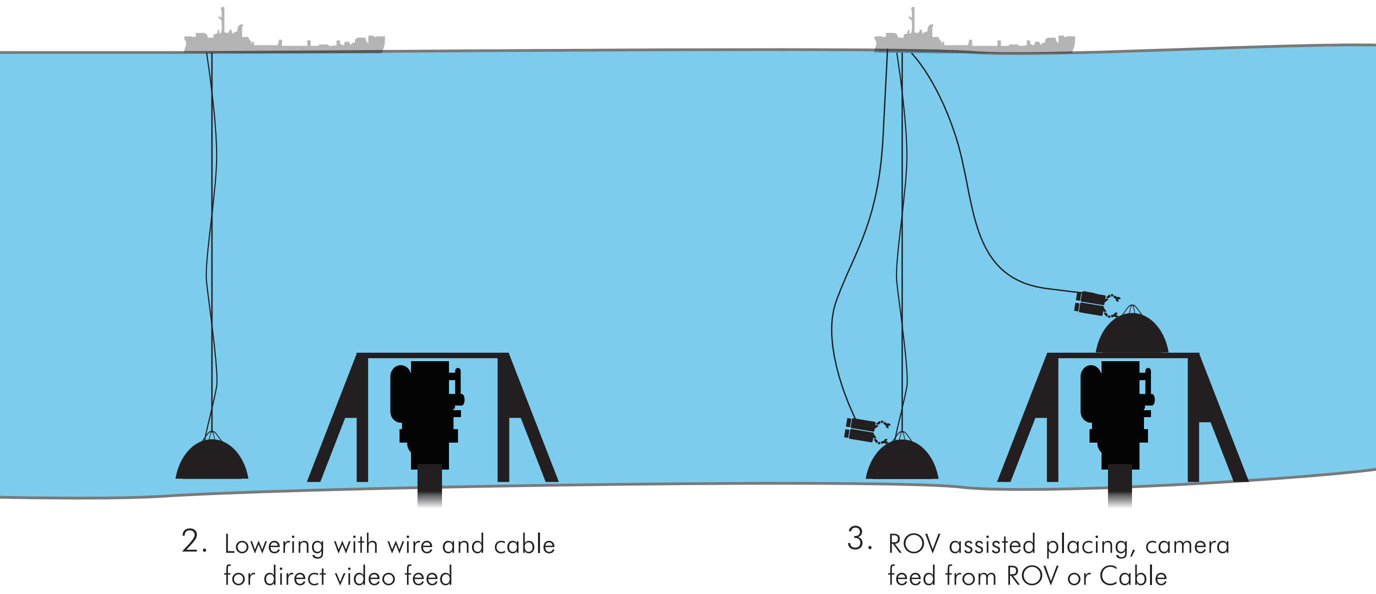


Figure 4: Placing scenario

The placing scenario describes a critical point in the "life" of the unit. After being produced and transported to the deployment site it has to be placed so that it can surveil and monitor the temporarily abandoned oil well (or other object) it is supposed to surveil. There are three alternatives for placing, lowering the unit with wire, lowering the unit with wire and cable and ROV assisted placing. Both cases of lowering with wire are quite straightforward, the only difference is that with cable one will be able to have a live camera feed to aid with positioning and calibration of the camera. The ROV assisted placing is required if one make a unit which has need for high precision in positioning such as if the unit will be anchored to a subsea structure, also placing on very large deeps require ROV.



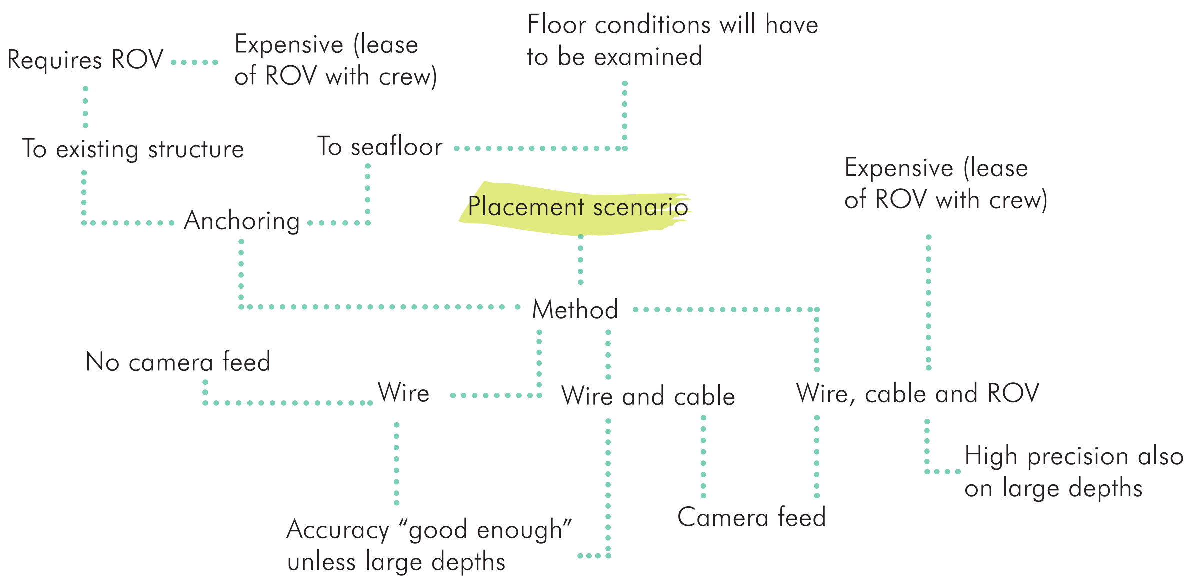


Figure 5: Mind map used in the redevelopment of the placing scenario

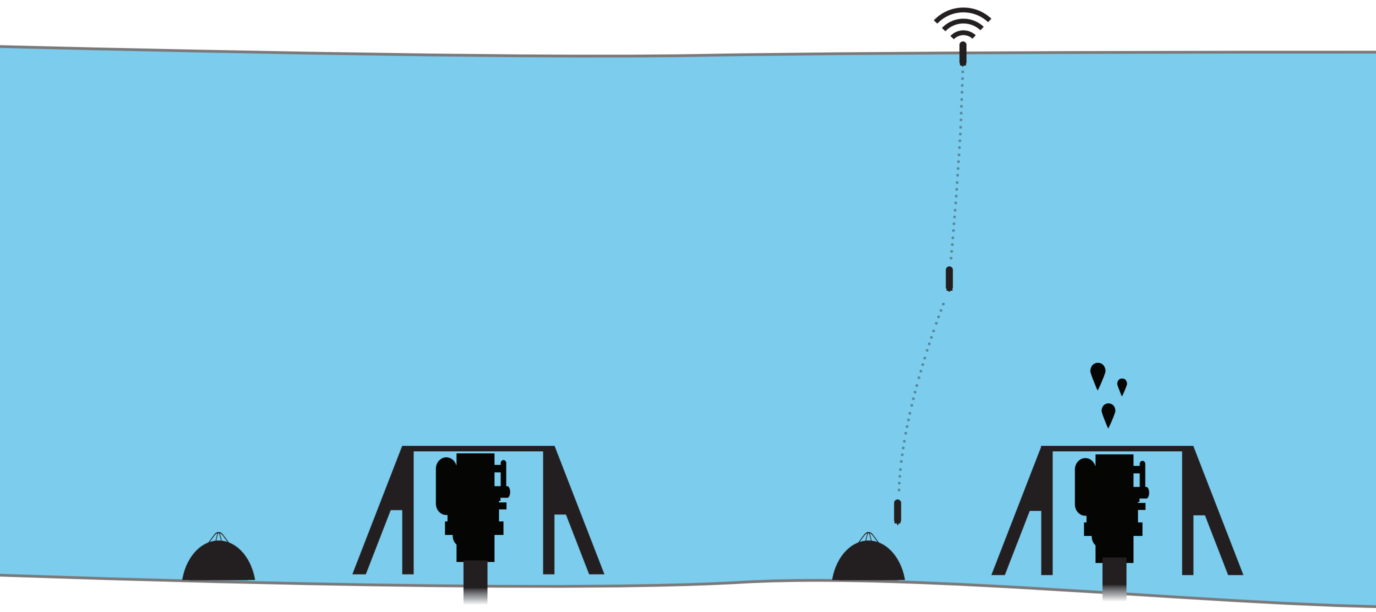
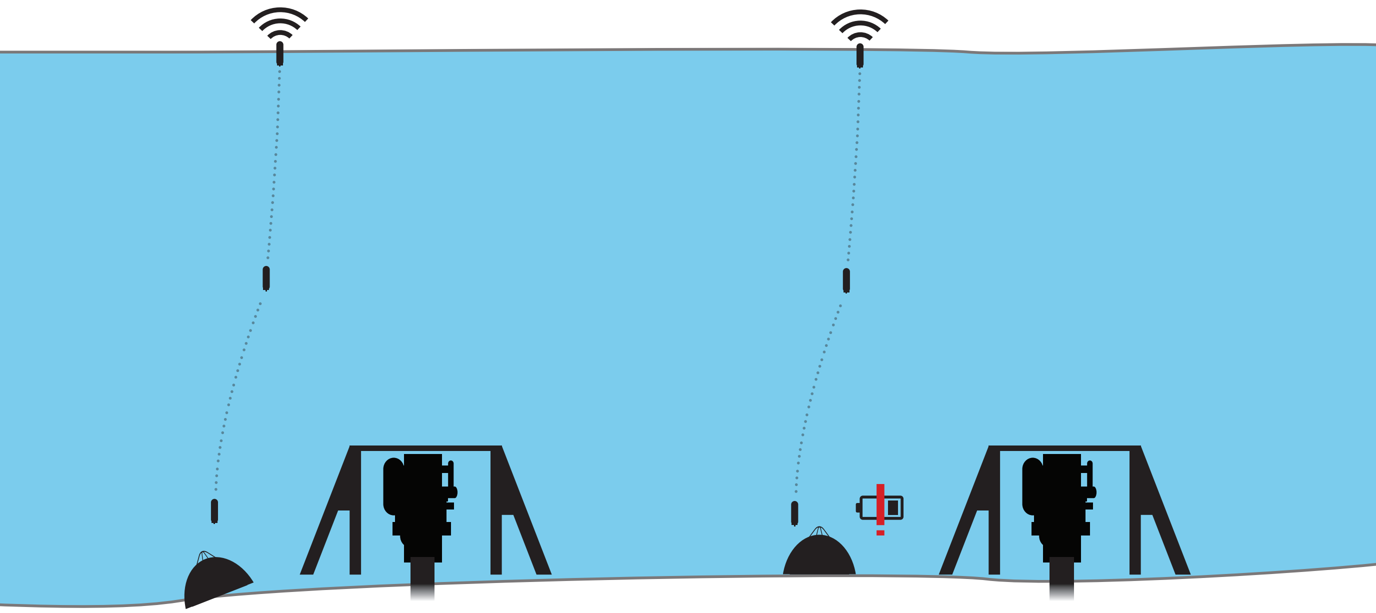


Figure 6: Deployment scenario

The deployment period of the unit is where the unit works autonomously without needed interference. During this period there are some incidents that may happen and that should be handled by the unit. Firstly, when no leak or other cause for alarm is detected there should be no communication from the unit. If, on the other hand, a leak that needs immediate attention is detected, an alarm should be sent. The same goes for any problems that can prevent the unit from working properly such as low battery or change of position/obstruction of camera/sensors etc.



3. External error, i.e. unit loses position, alarm sent

4. System error, i.e. unexpected low battery, alarm sent

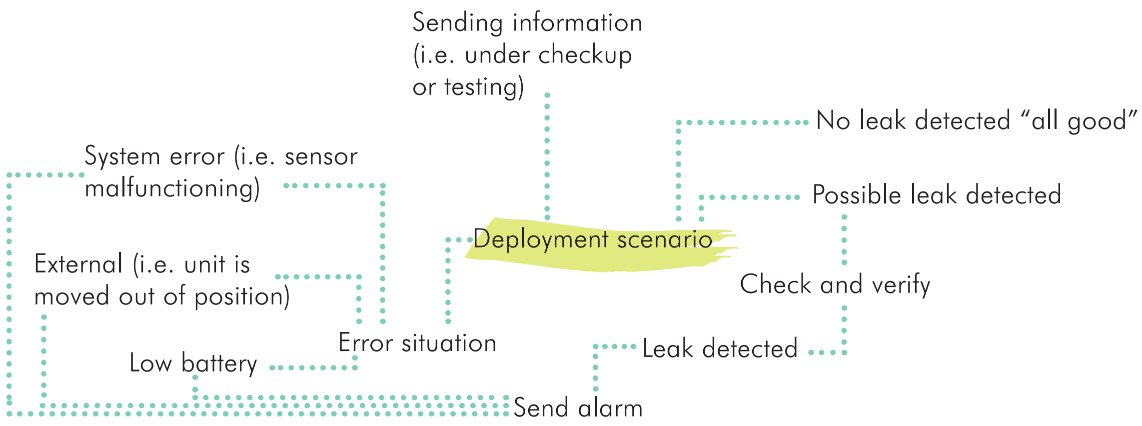


Figure 7: Mind map used in the redevelopment of the deployment scenario

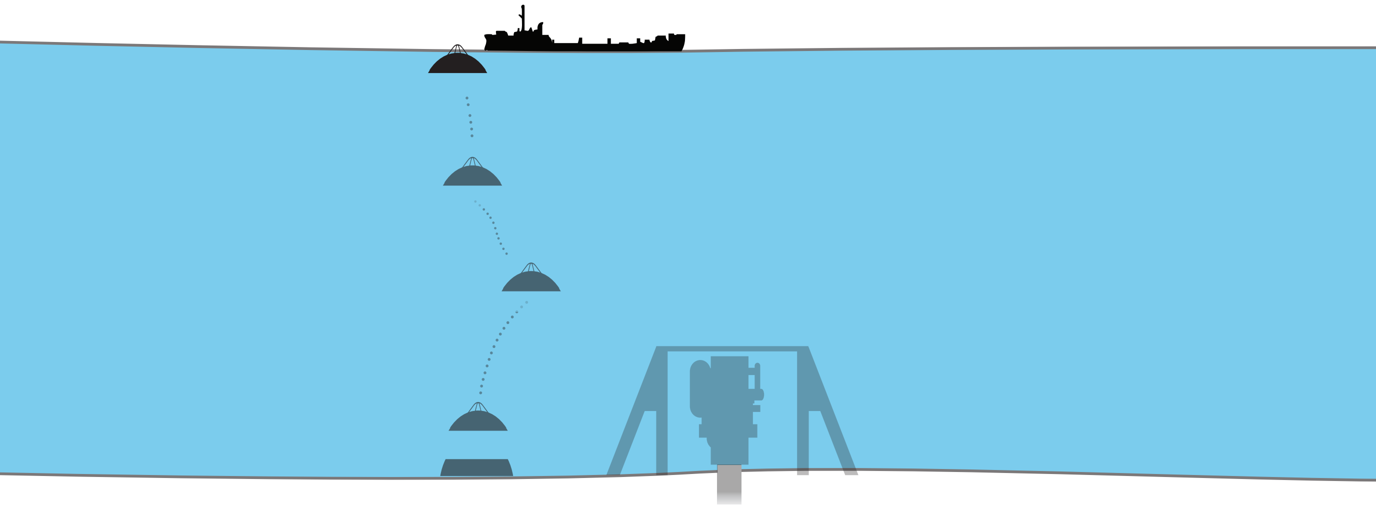
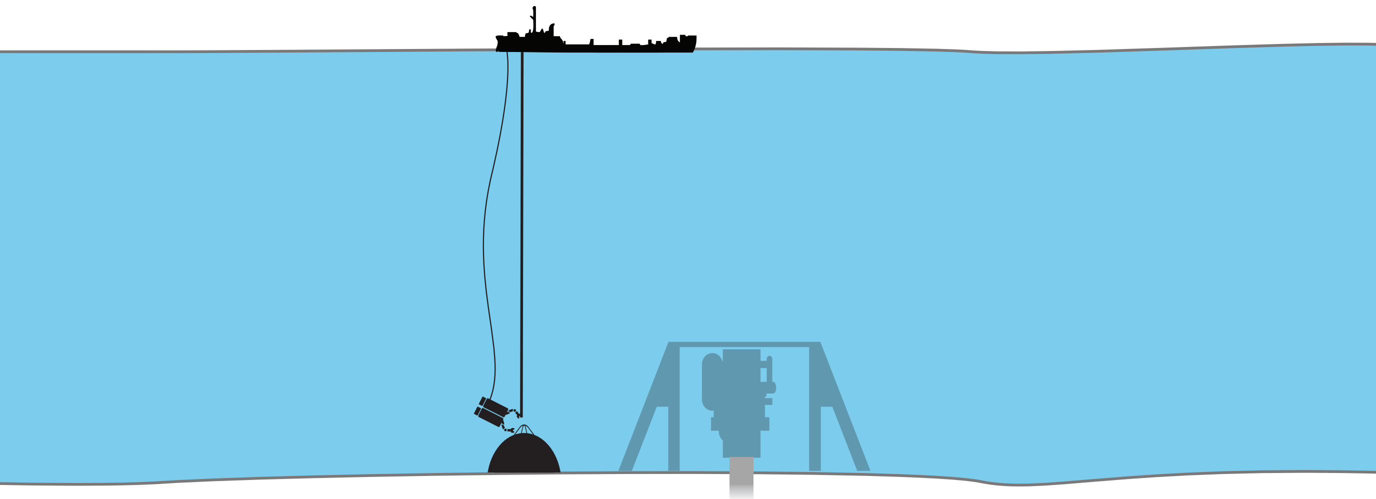


Figure 8: Collection scenario

The collection scenario describes the last critical situation in the life of the surveillance unit before it either undergoes maintenance and is re-deployed or is “retired”. For the collection and recovery of the unit there are two options. If one makes the unit self-recovering one can avoid intervention with ROV. The recovery process will then be to send a signal to the unit from a recovery vessel, a self-recovery protocol will be initiated by the unit, and it will be possible for the vessel to retrieve the unit from the surface. The only other option is ROV assisted recovery where an ROV is used to either collect the unit or secure a wire to the unit so that it can be hoisted to the surface.



2. ROV assisted recovery and on-land maintenance

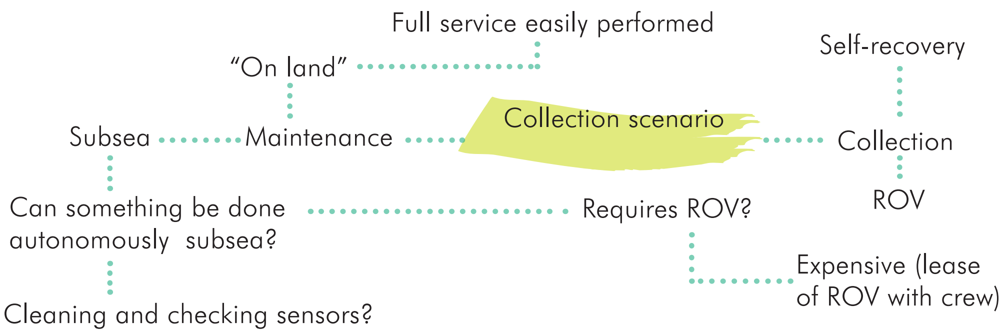
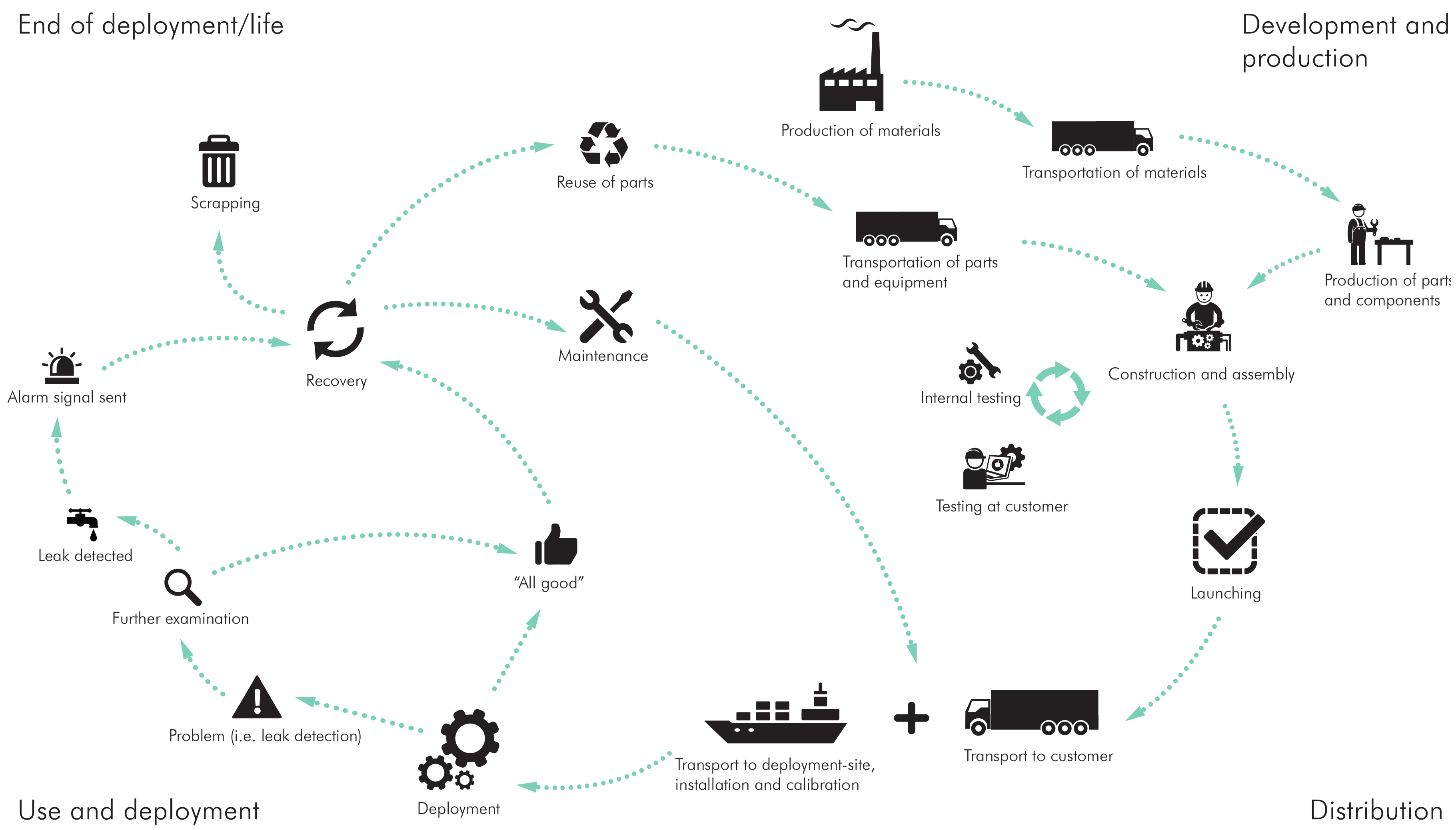


Figure 9: Mind map used in the redevelopment of the collection/maintenance scenario



End of deployment/life
Development and production
Scrapping
Reuse of parts
Production of materials
Transportation of materials
Transportation of parts and equipment
Production of parts and components
Recovery
Maintenance
Alarm signal sent
Construction and assembly
Internal testing
Testing at customer
Leak detected
"All good"
Launching
Further examination
Problem (i.e. leak detection)
Transport to deployment-site, installation and calibration
+
Transport to customer
Deployment
Use and deployment
Distribution

Problems and challenges

Ocean space

Depths from 0 to 3000 meters

Splitting up in different levels i.e 0-200m, 200-1000m etc.?

Challenges from ocean environment:

- Marine growth (biofouling/marine snow)
- Other marine life?
- External natural forces, i.e.underwater currents etc.?
- External human made forces like trawl-fishing etc.?
- Corrosion etc.?

Anchoring

How to anchor the unit?
To existing structure or to seabed?

What anchors exists and which to use?

- Weight-anchor
- Semi fastened-anchor
- Bore and bolted

Trawlsafe/recistance anchoring?

Expenses/necessities?

Conditions on ocean floor?

Other disturbances at anchoring/placing (i.e mudd, streams, pipes etc.)

Trawl-resistantce

Trawlsafe/recistance anchoring

Areas for trawling? Is it a problem?

Design concidерations for trawlsafety?

Placing

Lowering the unit with wire and cable or ROV/AUV and cable?

Where to place unit?

Lifting/lowering point of unit

Interaction unit - ocean floor

What is feasible at which depths (0-3000m)

Expenses/necessities?

Is there standards for placing?

Collecting

Self-raising

Selfraising and trawl resistancy

Is it ok to leave weight?

Can suction anchors be used in an with a self-raising solution?

Objections, agreements/ disagreements?

Petroleum Safety Authority Norway

Norwegian Directorate of Fisheries

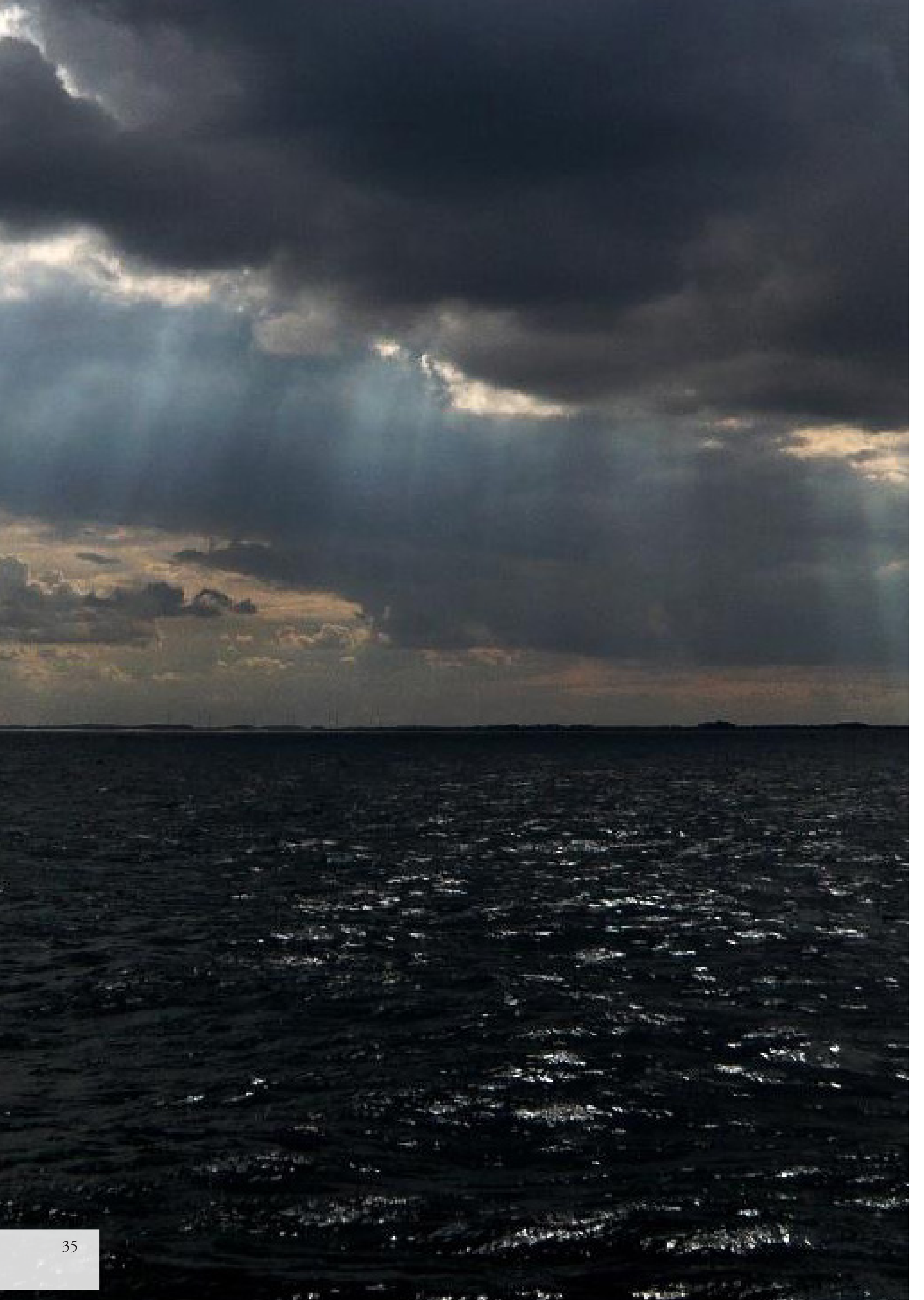
Client/employer

Figure 10: Lifecycle diagram.

This diagram was used during the startup of the project to get an overview over aspects concerning the life of the unit which could be essential to regard during the development process.

Figure 11: Chart over identified challenges and problems.

This chart over challenges and problems regarding the design of the unit was compiled from the results of the evaluation of the pre-project, the lifecycle diagram and the redevelopment of the scenarios. It was used as a basis for questions, i.e. during interviews, in the research phase.



Part 2

Insight

2.1 Research

Gathering information

Interviews and visits to companies

2.2 Results and findings

Gathering information

As mentioned earlier, the research for this thesis has been largely based on information from persons, organizations and companies of interest. Acquisition of information has been through interviews, visits and meetings as well as conversations over phone and email. Furthermore, information has been gathered from literature, found mostly on the internet, such as reports and documents as well as general information from websites.

Where to find knowledge and information?

The first and most obvious source of knowledge and information is the academic environment of NTNU and the research environment connected to the university, primarily SINTEF and MARINTEK (The Norwegian Marine Technology Research Institute). Other potential knowledge sources were found in the professional network of Trollhetta. Kongsberg Maritime is a company with extensive knowledge and experience in the field of subsea appliances and, together with being a possible collaboration partner and developer/supplier of equipment, was seen as a key source of knowledge and information. Fugro OCEANOR (company working with environmental monitoring, ocean observing and forecasting systems) and BOA (company working with subsea installations and offshore construction services) could also be potential collaboration partners. Furthermore, Statoil (the largest operator in the field of oil and gas in Norway), EMGS (Trondheim-based company working with things seabed logging surveys) and Sperre AS (ROV developer) could also be potential sources of knowledge and information.

Offshore regulations and guidelines

For the Norwegian offshore industry there exist a lot of regulations and guidelines in the form of standards and reports. Although they are aimed at the petroleum industry they also provide much knowledge and information about design for subsea in general and even some for leak detection. Worth mentioning are standards and guidelines from DNV GL and NORSOK as these have been used most extensively as references in the research for this project.

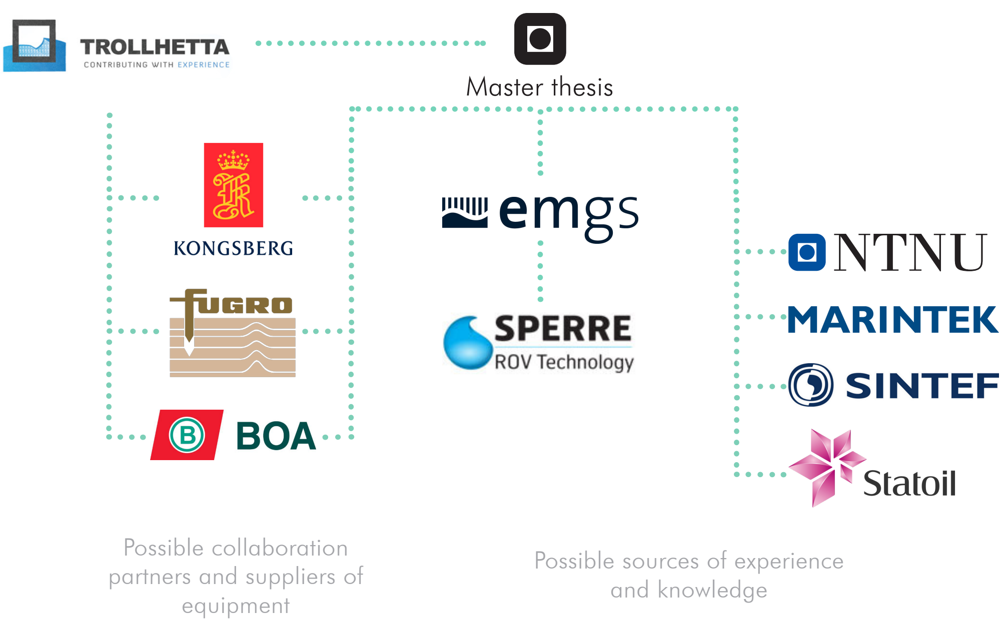
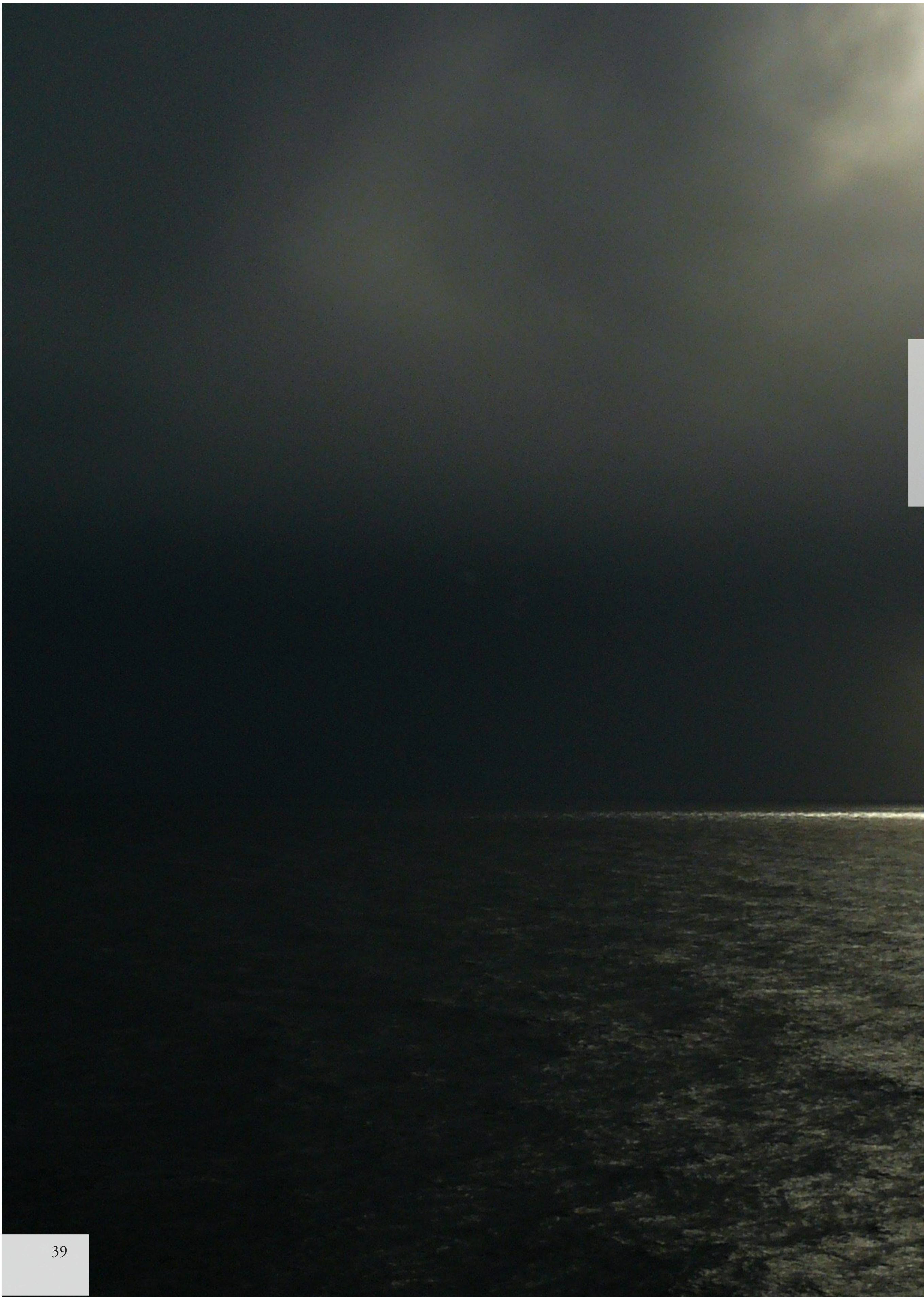


Figure 12: Educational institutions and professional businesses



Interviews and visits to companies

Approach

Depending on both how far the work with the master thesis had advanced and my prerequisite knowledge about the interviewee or company the method of interviewing differed. In the early phase of the project, when I did not exactly know what I needed to know or if the area of knowledge of the interviewee was not clear to me, a more open approach was used to encourage a broader base for discussion and answers. After establishing grounds for further questioning, previously found challenges and problems, i.e. from the evaluation of the pre-project, were brought in and discussed. Later on in the project, or where I was aware of the interviewees field of knowledge, a more direct and timesaving approach could be used. Visits to companies offered, in addition, a deeper insight in how professionals actually work with these types of projects and what challenges and advantages their solutions displays.

Visit at EMGS and interview with Audun Sødal, 8 April.

About EMGS

EMGS (Electromagnetic Geoservices ASA) is a company that is working with geological models based on seismic, petrophysical, and geologic data. With headquarters located in Trondheim they have been supporting oil and gas companies in search for hydrocarbons (offshore) since their star-up in 2002. Their services are based on technology based on electromagnetic energy to detect hydrocarbon reservoirs beneath the seabed. The method uses a grid system of data logging receivers deployed on the seabed and a high-power EM source that is towed over the receivers by a boat.

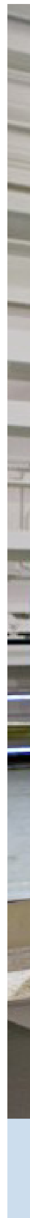
Previous to my involvement in the master project, Trollheta had been in contact with EMGS regarding possible collaboration on development of the alarm buoys for the surveillance unit since the data logging receivers are self-recovering (use of buoyancy and counterweight). The conclusion was to not follow up this thread due mismatch in business area. However, seeing as the EMGS has extensive experience with design of subsea units and equipment including self-recovery solutions it was decided to contact them for advice and guidance.

About Audun Sødal

Audun Sødal is a senior development engineer at EMGS and is active in the development of the data logging receivers. As my contact person in the company he has been contributing notably to this master thesis through both the interview with tour at EMGS and later via email. Following is a summary of the most important findings from the interview and email correspondence, a full overview over this can be found in the appendix (as a mind map).

Summary of interview with Audun Sødal

It is important consider deployment and recovery operations in the splash zone from the surface vessel, since this is a place where large changes in forces occur, for this matter factor of safety is key. Positioning at deployment site can also be challenging and bathymetry data, sea current and local sound velocity profiles can be used to prepare for this, the bathymetry data most likely already exists for the designated location. Depth rating is a cost-concerning issue and it is intelligent to divide the solution in to i.e. 200-1000m and 1000-3000m approved depth ratings, both because the price difference on equipment pressure rated down to 1000 and 3000m is large and because most of the subsea wells in Norway are situated shallower than 1000 meters. This will again support commission based sales which also allows for tailoring of the solution. Syntactic foam as buoyancy material is a good choice, the mechanical properties of the material also makes it suitable to use in the construction of the unit, but it is a brittle material and this has to be considered in the design. Counterweight/anchoring is a problem with self-recovery through buoyancy. Firstly it is important that the release mechanism works as flawlessly as possible, otherwise one have to intervene with ROV for retrieval. Secondly leaving behind the counterweight on the seabed is not a very environmental friendly solution, and it may cause problems for marine activities such as trawl fishing. EMGS has solved this by developing a time controlled water soluble concrete which ensures that the unit eventually floats up if the release mechanism should malfunction, it also leads to less impact on the environment both since the anchors dissolves into pure sand and gravel and because the tethered units are not left at the seabed. Anchors of EMGS concrete could be a viable option (provided a license) for this project if buoyancy-based self-recovery is chosen.



Picture 2: Workers at EMGS assembling a data logging receiver, the water soluble concrete anchor can here be seen.

Visit at Kongsberg Maritime Subsea (Horten) and interview with Arild Brevik, 28 May.

Picture 3: Kongsber Maritmes Simrad Echo in the port outside their offices in Horten

About Kongsberg Maritime

Kongsberg Maritime (part of the Kongsberg Group, established in 1814) delivers a wide range of products and systems to the marine-, offshore- and subsea industries. With 4712 employees in 20 countries and as part of the Kongsberg Group, an international technology corporation, they have extensive experience in their field. Their subsea department is located in Horten, where they design, develop, manufacture and test subsea equipment and sensors mainly based on their core technology competence which is hydroacoustics.

Trollhetta has been in negotiations regarding possible collaboration on delivery of equipment as well as development of the surveillance unit. How this negotiation has, and will, proceed is not known at the moment and this matter is left up to the respective companies. However, seeing as it is likely that Kongsberg Maritime will supply most of the equipment for the unit it was essential for the development process to come in contact with the company both to find out what equipment is needed and to get a closer look at this equipment. In addition, it provided a good opportunity to harvest guidance and advice from very experienced people. The visit to Horten was, unfortunately, not possible to make happen until relatively late in the process. Understandably, a hectic work schedule does not always allow time for helping students. Even though an earlier visit could have been useful for the project it could also have resulted in a more restrained approach, i.e. designing for specific equipment. Getting expert feedback on different ideas and concepts was also both valuable and helpful at that point.

About Arild Brevik

Arild Brevik is the head of business development and sales for subsea monitoring at Kongsberg Maritime Subsea. He is, among other things, working with integrated environmental monitoring subsea solutions and has as my contact at Kongsberg Maritime provided invaluable insight and support for this master thesis. Both the interview and tour at the subsea department in Horten and communication via email have been indispensable towards the development of the final concept. A summary of the most important findings from the interview and email correspondence is provided here and a full overview can be found in the appendix (as a mind map).

Summary of interview with Arild Brevik

Regarding placing and installation an ROV can be avoided unless deployment site is at very large depths or requires very high precision in placing. It is also possible to twist/rotate the unit on installation (if needed) by turning the deployment vessel. The cost of installation without ROV will be from 500 000 NOK and upwards towards 1000 000 NOK. The seabed is most likely quite soft, and the unit might sink down in the grounds a bit (max. ½ m) and this have to be taken into account. However one should not be afraid of size and weight, 5 tons is still lightweight in the subsea-world. Furthermore, a relatively heavy solution will support stability and make forces from ocean currents negligible.

Equipment that potentially can be delivered by Kongsberg Maritime includes camera, flash/floodlight, transponder (cNODE-mini), echo sounder (EK80 WBAT), battery packs and central processing unit. The company does deliver hydrophones, but mostly for military purposes, so it is recommended to use another supplier (i.e. Naxys). If buoyant self-recovery is chosen it is likely that special release mechanism will have to be designed and manufactured for the unit, the cNODE release mechanism can be used but might not be suitable for this application. However, it is not likely that Kongsberg Maritime can deliver this.

Regarding the concepts and solutions, self-recovery is a good choice to reduce retrieving expenses. Furthermore, the shown concept of the concrete-anchor seems like a good option. It will provide a steady and reliable base for the unit and probably good protection against interactions with trawling gear. Using cNODE mini parts for development of the alarm buoy is, in theory, possible. A special floating collar will have to be designed as well as either a new design of release mechanism or a redesign of the existing cNODE release (since it will not fit as is). Data transferring between the buoy and the central processing unit can be done with cable and wet-mateable connector, provided that the buoyant force from the buoy is enough to disconnect the cable. Another option is to integrate the satellite antenna into the cNODE technology, making a cNODE-satellite hybrid, allowing acoustic communication. The suggested surveillance network also seems like a good idea, and again cNODEs can provide acoustic communication between the units allowing avoiding the use of cable.

2.2 Results and findings

Market analysis

About design for subsea

Self-recovery

Sensors and equipment

Conditions at deployment site

Biofouling

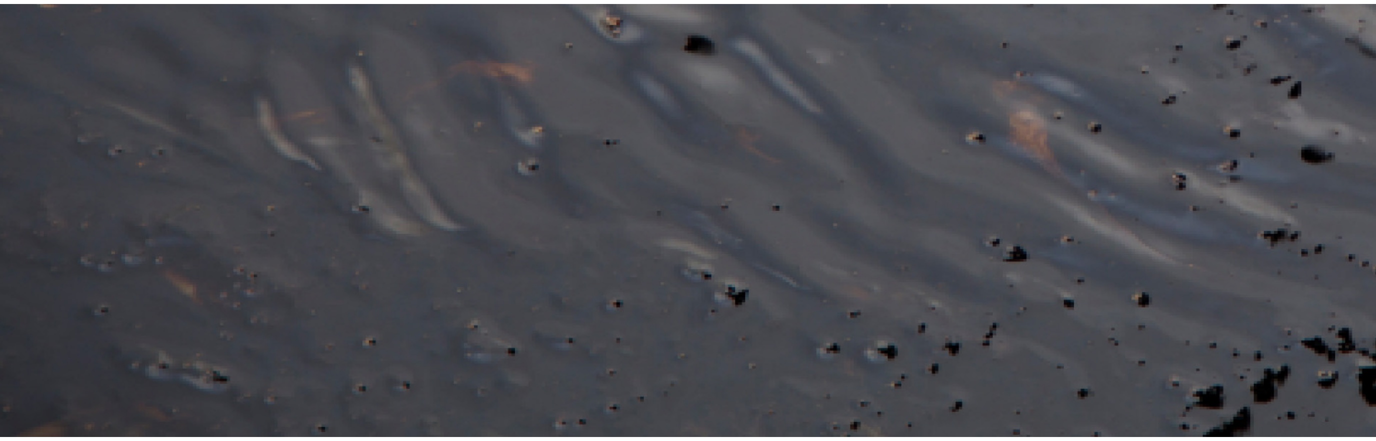
Trawling

Analysis of competitors

Market analysis

A simple study of the market

Gaining an overview over regulations and current trends in activities in the petroleum industry gives a good pointer towards the situation in the market. It can also provide insight and knowledge useful for establishing a development strategy for the surveillance unit. The main focus of this section is the situation in Norway, although other countries are mentioned it is in the Norwegian market Trollhetta plans to first launch their product. Furthermore, seeing as Norway is a leading and trendsetting nation in offshore technology and business, a successful entry in the Norwegian market can potentially help promoting the product worldwide.



Increased focus on leak detection

"The field experience to date with leak detection systems is limited to the Norwegian sector and this field of technology is generally young. The existing experience includes problems with false alarms and consequently disabled sensors as well as fields where one has accomplished solutions that are described as promising." - Cited form DNV's report: Selection and use of subsea leak detection systems, DNV-RP-F302, 2010.[6]

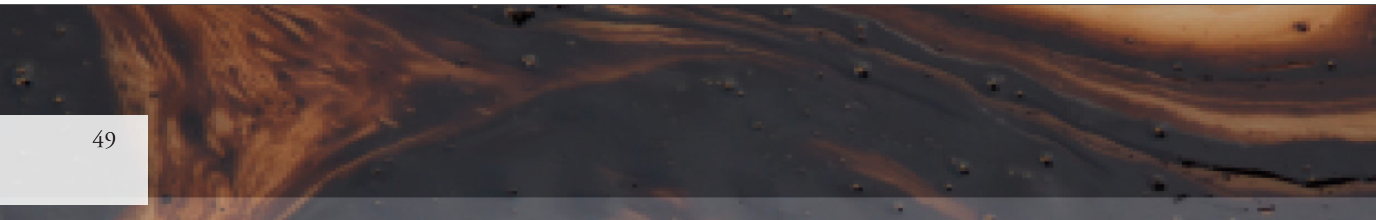
Subsea leak detection is becoming more important in the petroleum industry and during the past decades there has been an increased focus on these activities. In Norway, the Petroleum SafetyAuthority has outlined requirements for measurement of acute pollution, and likewise corresponding authorities in UK, USA andEU describe similar requirements[6]. This shows that it is safe to assume an increase in the general need of leak detection systems as well as a need for innovation regarding the functionality of these systems.

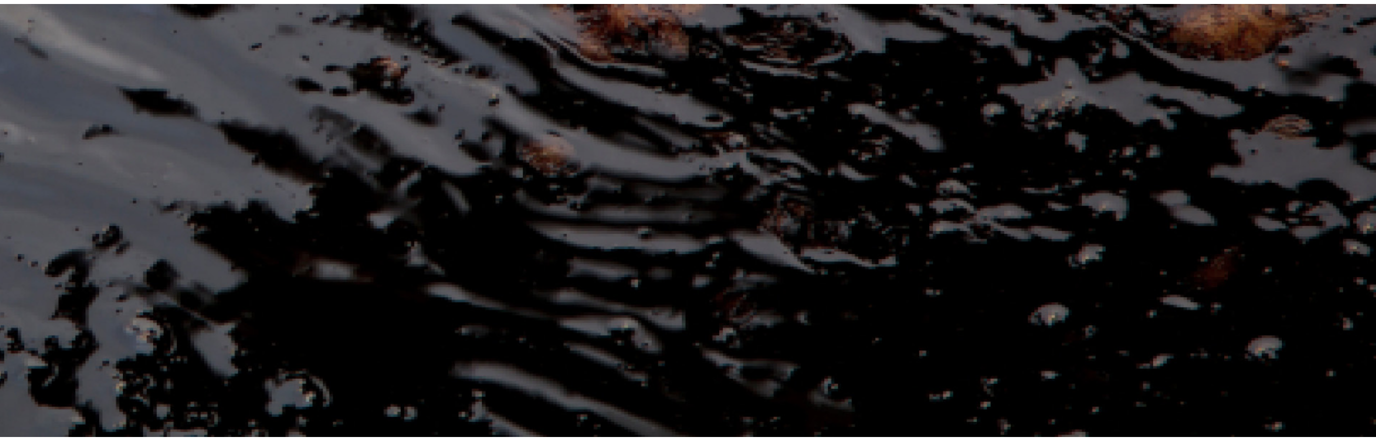
An introduction to temporary abandonment

During the course of oil and gas production it is sometimes necessary to leave a well inactive, i.e. a technical failure has occurred or production has become unprofitable and other areas are prioritized, in which case the well have to be temporary abandoned. Some typical situations where temporary abandonment of the well is chosen[14]:

- During a long shut-down
- When a repair requires safety equipment usually the blow out preventer) to be removed.
- When moving rig to higher priority well work
- While waiting for a work over
- While waiting on field development or re-development
- When converting a well from an exploration- to a development well
- When re-entry at a later stage (to perform sidetrack) is possible

Depending on the reason for abandonment one can imagine that the location and infrastructure around a temporary abandoned well can vary greatly. If, for instance, the reason is a longer shut-down with planned re-entry at a later stage surrounding infrastructure might be removed rendering the location remote and less accessible.





Wells which are left temporarily abandoned year after year represent a safety challenge on the NCS. The regulations are now being tightened up. Exploration wells must be permanently plugged after no more than two years, according to new regulatory requirements which came into force this year. Furthermore, production wells which are not being continuously monitored will now have to be plugged and abandoned within three years – unless monitoringcontinues. – Cited from "Use it or lose it" web article by Thor Gunnar Dahle[15]

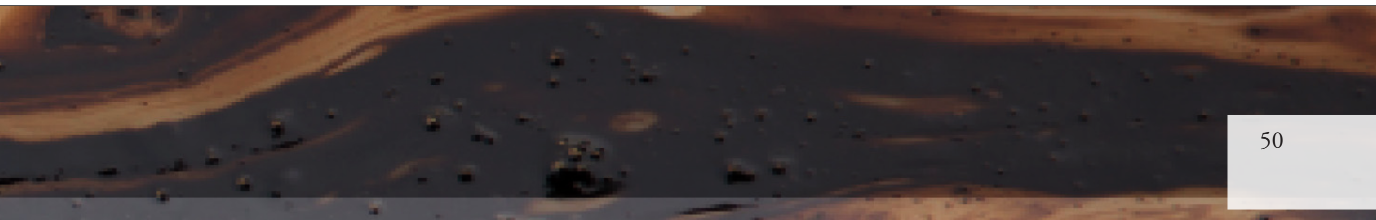
Temporary abandonment is, as the name implies, meant to be temporary and oil and gas wells abandoned in this way may represent a greater environmental threat regarding spill and leakages. A report regarding status of temporary abandoned wells on the NCS (Norwegian Continental Shelf) initiated by PTIL (Petroleum Safety Authority Norway) and conducted by SINTEF (The Foundation for Scientific and Industrial Research) from 2011 evaluated 193 temporary abandoned wells at the NCS. The report reveals that 27 of the wells were temporary abandoned before year 2000 with the oldest being temporary abandoned in the early 70's. Furthermore, it was stated that about one third of all the temporary abandoned wells had some kind of integrity problem[16].

Due to the environmental risks connected to temporary abandoned wells the Norwegian regulations have been newly revised. The NORSOK D-010 standard from June 2013 defines temporary abandonment in the following way:

Temporary abandonment – with monitoring: Well status where the well is abandoned and the primary and secondary well barriers are continuously monitored and routinely tested. If the criteria cannot be fulfilled, the well shall be categorized as a temporary abandoned well without monitoring. There is no maximum abandonment period for wells with monitoring.

Temporary abandonment – without monitoring: Well status, where the well is abandoned and the primary and secondary well barriers are not continuously monitored and not routinely tested. The maximum abandonment period shall be three years.

It is further stated that for temporary abandoned subsea wells without monitoring, a program for visual observation shall be established. These regulations makes it is clear that a solution for monitoring temporary abandoned wells is a welcome contribution to the market.



The situation in petroleum production

The extraction of oil and gas started moving towards the sea as early as 1897 and over 60 years later, in 1961, the first subsea production well was completed. Following advancements in methods and technology an increasing number of new oil and gas wells have been built since then [16]. According to BP's annual statistical review of world energy from June 2014the total world reserves for oil and gas is estimated to last, given the current rate of production, respectively 53.3 and 55.1 years [17]. For these reasons it is not hard to picture that oil companies more often will have to resort to means, such as suspension and later re-entry of wells, to keep production profitable. Another relevant situation is the process of decommissioning and shut down of production fields. Although an inevitable and acknowledged problem, this has during the later years started to get proper attention from the industry. A study conducted in 2008 stated that a total of 4600 wells will have to be abandoned during the next 15 years in the UK sector and in the Gulf of Mexico it was estimated to be approximately 3600 temporarily abandoned wells in 2011[18]. As for Norway, on the NCS (Norwegian Continental Shelf) it has been estimated to be approximately 2000 wells to be abandoned between 2011-2040, it should also be kept in mind that closer to 150 new wells are drilled each year on the NCS [19].

An important aspect of suspension or decommissioning of production bores and field is abandonment of the wells. At this point permanent abandonment of an oil or gas well is an expensive and time-consuming procedure. The cost of permanent plugging a well is, per today, approximately 1 billion NOK, which is a substantial cost. Regarding time one can use the previously mentioned 4600 wells on the UK continental shelf as an example, the abandonment of the, approx. 3700 platform wells and 900 subsea wells, is estimated to equal a total of 123 rig years (respectively 97- and 26)[20]. With permanent abandonment re-entering of the well is, of course, impossible and both due to this and the before mentioned reasons companies often want to delay this action. Temporary abandonment is, as the name implies, temporary and not a viable alternative to permanent plugging. At an approximately cost of 500 million NOK temporary plugging is considerably cheaper and offers benefits such as possibility for re-opening the well and postponing permanent abandonment in anticipation of more effective methods for these procedures.

Comment

As the situation appear today, with regards to both suspension and decommissioning of fields, expecting a future increase in temporary abandoned wells is rather realistic. Taking in to account the increased focus on leak detection together with the tightened regulations regarding temporary abandonment the need for a good leak detection solution which also is capable of monitoring temporary abandoned wells seems very much present.

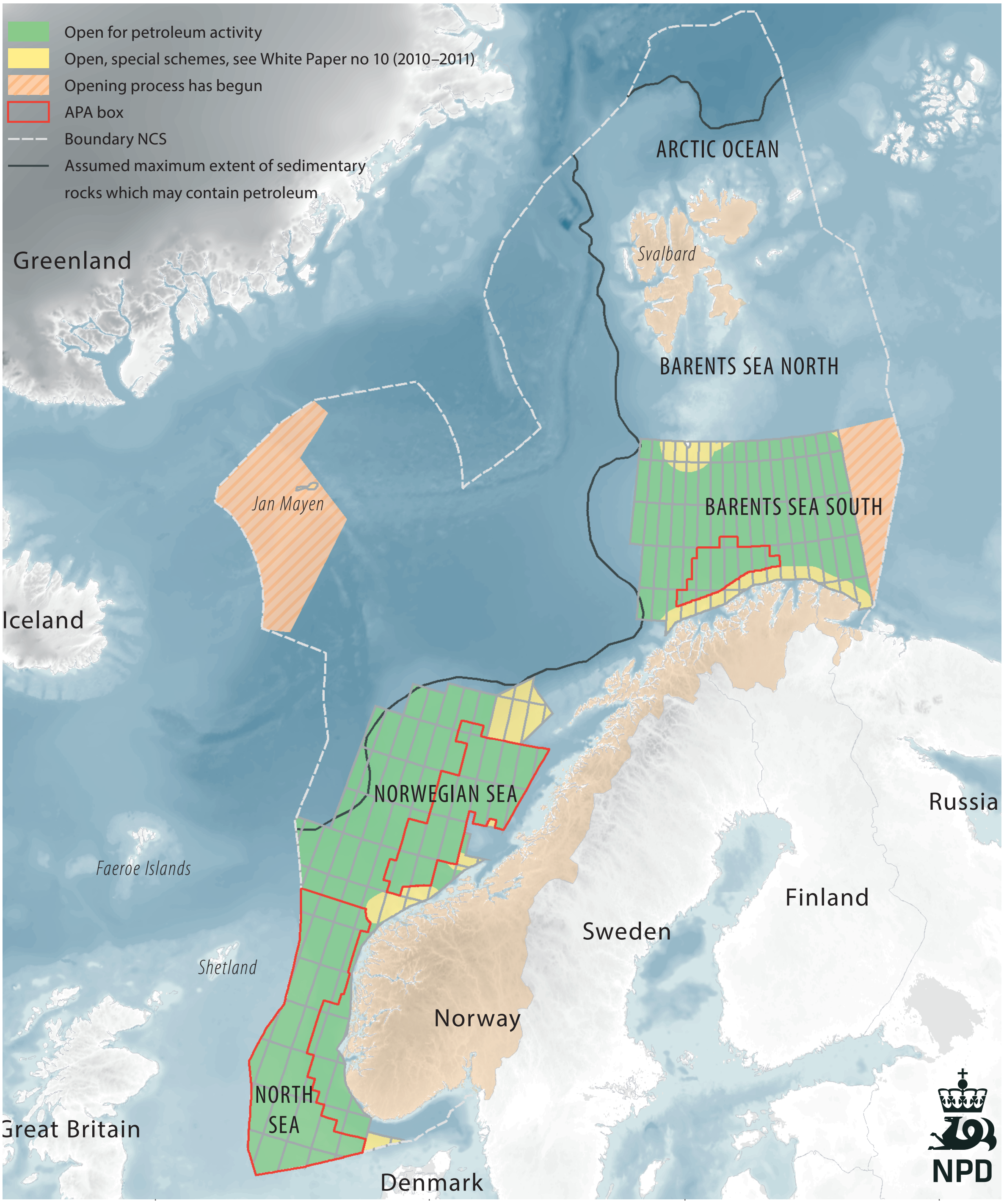
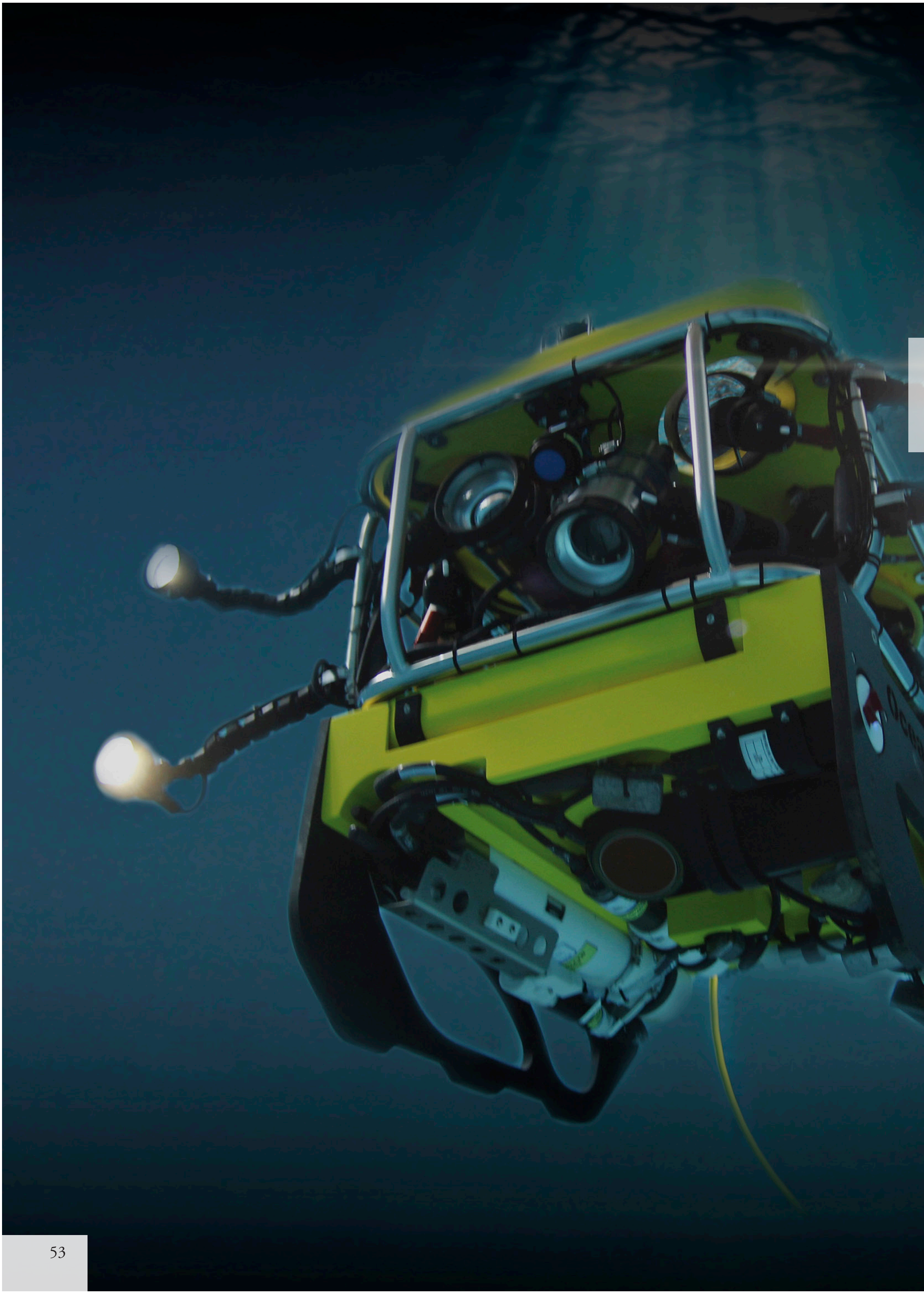
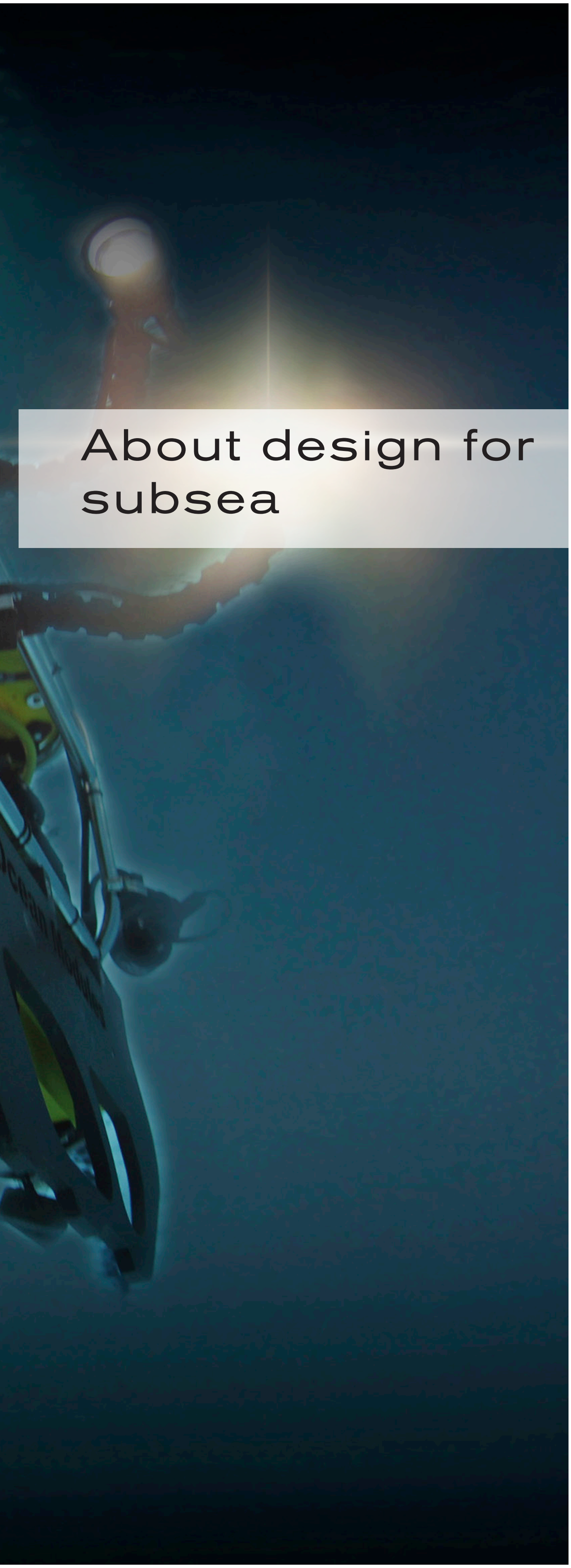


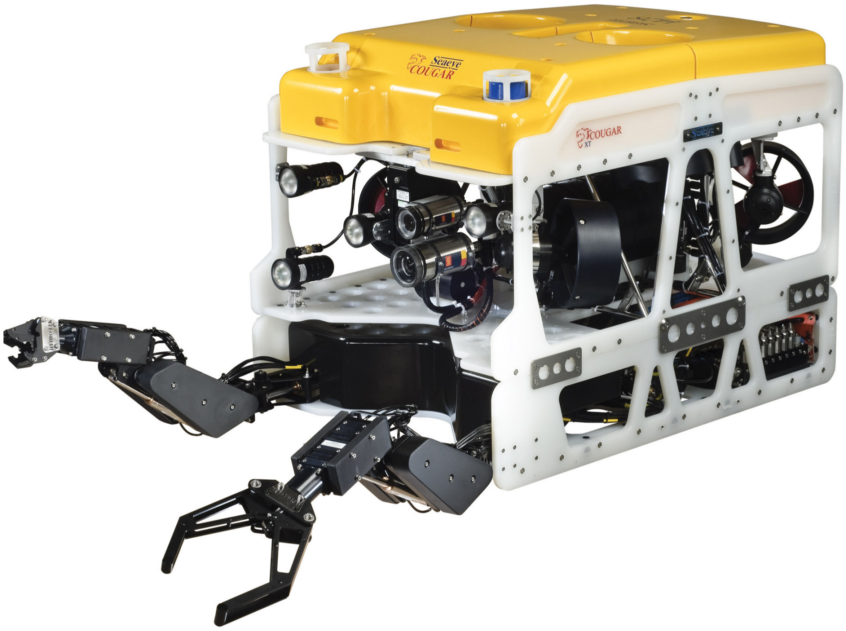
Figure 13: Map showing area status for the Norwegian Continental Shelf March 2012 (NPD Facts 2013)

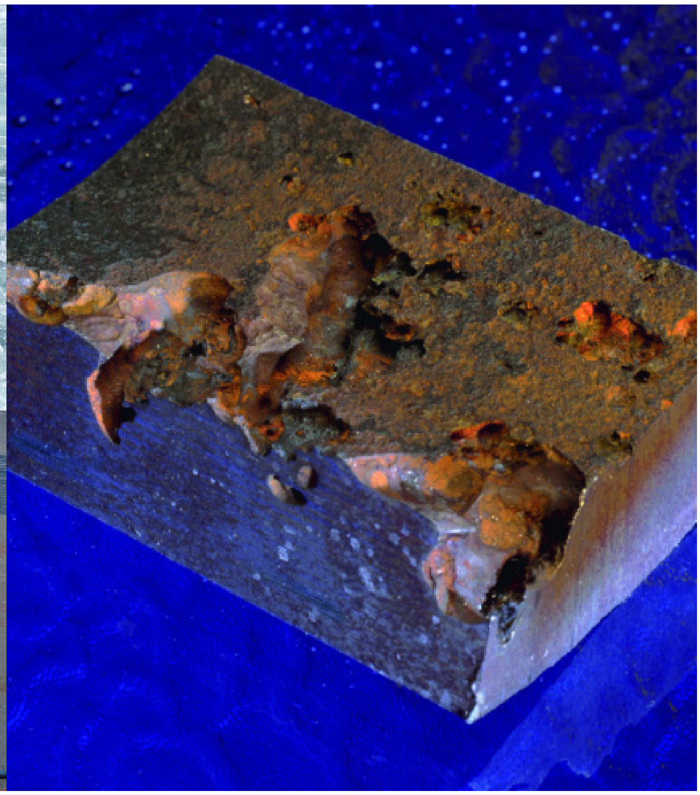


About design for subsea



Designing for subsea require a quite different approach than what it does for above the ocean surface. The rough sea environment is rather cruel to materials and offer challenges such as high pressure and reduced accessibility and in addition everything is covered in water. The next sections will give an overview over common practices for subsea design.





Picture 4 (top): ROVs are typical examples of subsea design
Picture 5 (bottom left): Another example on subsea design
Picture 6 (bottom right): Corrosion on subsea gas pipe

General guidelines for subsea design

For construction and composition of subsea units some general guidelines can be described. Because of the enormous pressure objects are exposed to under water air-volume has to be minimized wherever it is possible. As one see, for instance in ROV designs, this is done by constructing the vehicles so that water flows freely around all parts of the system. All equipment that is sensitive to water is, of course, incorporated in watertight and sufficiently pressure rated containers (usually of a cylindrical shape) and connected with water proof cabling. The components and equipment are contained by a frame which typically is constructed by steel pipes or hard plastics.

Materials

A large range of materials are used in subsea applications. For structural applications where a larger design load is expected, various types of steel (normal, stainless, austenitic, super duplex), aluminum alloys and in some cases also titanium are used. Where design loads does not play a considerable part plastics are widely used due to their excellent resistance against corrosion and relatively light weight, POM and polyethylene are examples of such plastics[4].

Production methods depend on material choices and the final design of the unit and are because of this difficult to outline here.

Depth rating

As mentioned, all objects are exposed enormous pressure under water, and with the pressure increasing approximately 1 atmosphere per 10 meters in depth [3] it is not hard to imagine that there are great differences in requirements for units or gear that is deployed at depths of 500m and 3000m. These increases in requirements lead to increased prices for subsea equipment and materials.

Corrosion and erosion

The sea environment is harsh on most materials and degradation happen both in form of corrosion and erosion. With erosion one talks about physical removal of material due to numerous small impacts i.e. from grains of sand which usually leads to light polishing of surfaces[5]. Corrosion is deterioration of a material caused by a chemical (or electrochemical, often called galvanic corrosion) reaction between the material (metals) and its environment. The rate of corrosion is dependent on a lot of factors such as salinity, temperatures, presences of organic acids etc. [5].

To battle both corrosion and erosion it is common to use coatings that protect both against abrasion and corrosion. Although some metals are more or less resistant to corrosion (i.e. titanium) it is also common practice to use cathodic protection such as sacrificial anodes of zinc or magnesium (especially for steel)[5]. Galvanic corrosion should especially be considered for electrical components. The process is dependent of two different metals being in electrical contact, differences in voltage between the metals then cause carrion in the one metal preferentially to the other which makes electrical components more exposed to this. To avoid galvanic corrosion electrical components should be isolated from other metal components if it is possible.

Placing and anchoring

One can roughly explain the placing process in two steps. Firstly it is lifting the unit off the deployment vessel and lowering it down to the deployment site. The most critical part of this step is when entering the splash zone (where the unit goes from air into water). Here large forces occur due to the change of pressure and in addition, if the weather is rough, also waves slamming into or lifting the unit can be a problem. When the unit is lowered down to the deployment site positioning is the last step. A common method is to use acoustics for positioning, this is done by placing transponders on the seabed which read the surroundings and sends signals to the deployment vessel, this way the unit can be quite accurately positioned. If higher precision or intervention is needed for the anchoring ROV's are used, where an ROV usually provides a live camera feed so one can see what one are doing. To aid in positioning bathymetry charts (underwater maps) are used, these already exists for the deployment area from development or later intervention, but if not they have to be made.

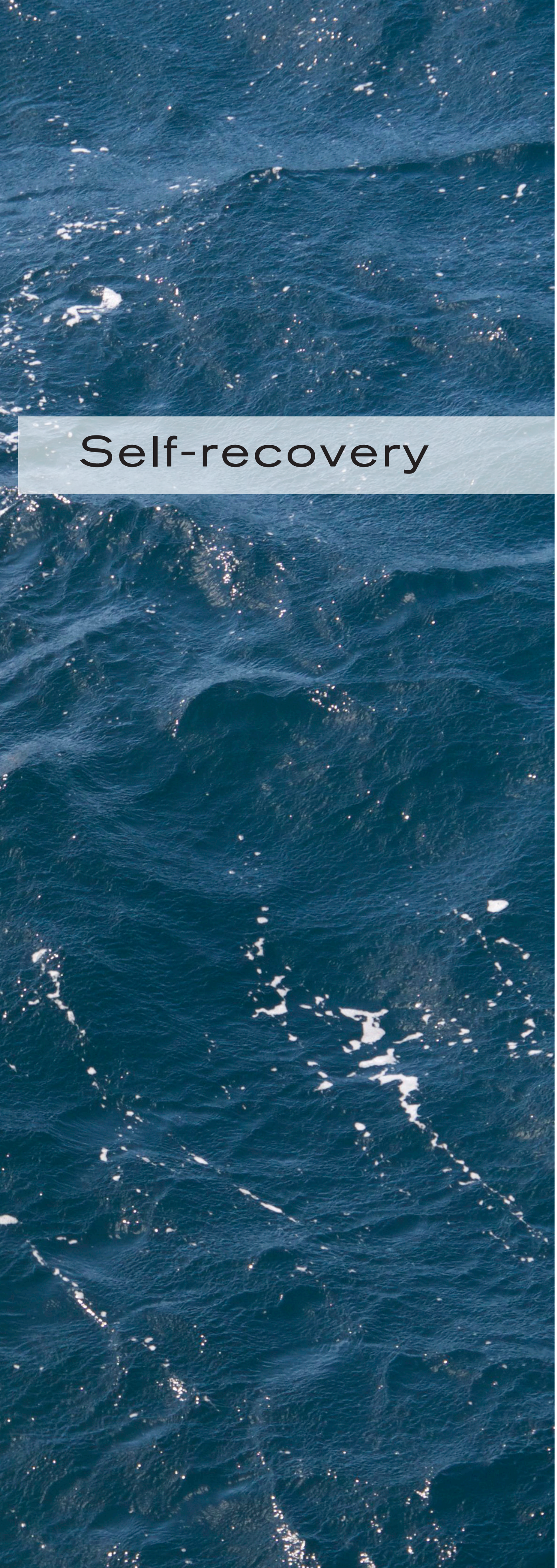
Regarding anchoring there are different solutions to consider, and whether the unit is placed on the seabed or on an existing subsea structure plays a role in this. For placing on the seabed one have the option to just place the unit there without any additional anchoring, for this solution it is the weight of the unit that holds it in place and from the interview with Arild Brevik this will be sufficient if the weight is relatively large. Another option for anchoring on the seabed is to use suction caissons; this is often used for subsea structures in the petroleum industries. A suction caisson is simply a bucket put upside-down. Depending on the size and weight the bucket either sinks down on its own or has to be vacuumed into the seabed, the resulting suction effect provides a reliable anchoring. Options where drilling in the seabed is needed for the anchoring procedure have not been researched since this would drastically increase deployment costs. Anchoring the unit to a subsea structure requires a different approach. The most interesting solutions are to develop a clamping mechanism or to use magnets. A clamping mechanism will, however, be relatively complex and it will have to accommodate for different beam dimensions etc. Magnets on the other hand are quite straight forward and are widely used in subsea and offshore tasks. The only requirement is that there has to be a magnetic structure to fix the magnet on, which should not be a problem since most subsea structures in the offshore industry are made of steel.

Picture 7: Offshore deployment vessel

Comment

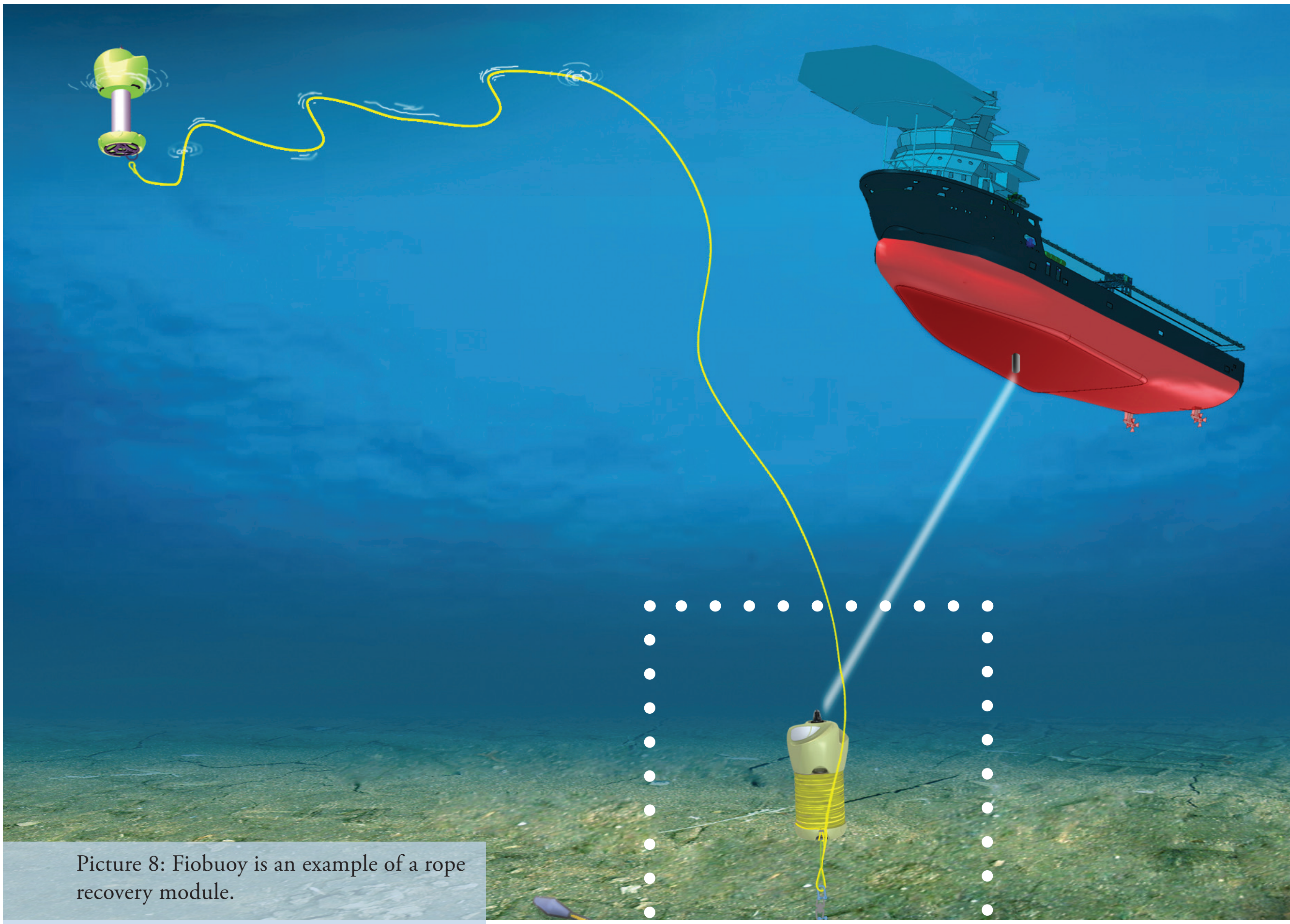
It goes without saying that the design of the unit should follow general principles for subsea design. Material choices will have to be considered during the development process, some type of steel is a likely choice for the frame structure and plastics should be used where design loads allow it.
Where the unit is placed largely decides what anchoring can be used and what criteria with regards to precision in positioning are needed. Since Trollhetta wishes a low-cost product designing the solutions so that placing, positioning and anchoring can be done cheap and easy should therefore be given priority. For this reason placing the unit at the seafloor might be the better option.
Regarding depth rating Trollhetta did in the initial design brief set a requirement that the unit should be able to work at depths down to 3000 meters. This will lead to a more expensive unit due to increased costs of sensors and equipment and, as made clear during the interviews of both Arild Brevik and Audun Sødal, it should be considered if it is necessary for the unit to have such high depth rating. Another point opposing very high depth rating is that most subsea production fields on the NCS are at shallower depths than 1000m, and even the deepest one is only at 1300m.

Short about standards and guidelines: As previously mentioned there exists a large amount of guidelines and standards for offshore and petroleum industries and these should be consulted when and if the development of the unit comes that far. Of interest regarding leak detection units is DNVs guidelines RP-F302 for subsea leak detection systems. This guideline also suggest that a leak detection unit should comply with the European standard ISO 13628-6 – "Petroleum and natural gas industries - design and operation of subsea production systems"[6]. Furthermore for the design of the frame NORSOK standard N-001 –"Structural design for subsea structures" and N-004 –"Design of steel structures" can be of interest as well as DNV standard for certification no. 2.7-3 "Portable offshore units". There also exist standards and guidelines for use of protection coating and cathodic protection, i.e.IOS 12473 –"General principles of chatodic protection in sea water" and NORSOK M-501 – "Surface preparation and protective coating".



Self-recovery

Designing the unit to be self-recovering so one can retrieve the unit without use of ROV will greatly simplify the collection procedure as well as reduce expenses connected to this. This can be done in many different ways, and the most relevant methods for the surveillance unit will be pointed out in this section. All the methods typically rely on an acoustic signal being sent from the collection vessel initiating the self-recovery protocol.



Picture 8: Fiobuoy is an example of a rope recovery module.

Rope recovery

The first approach involves incorporating a rope recovery module in unit. In essence a rope recover module is a buoy with an integrated rope. An acoustic signal sent from the retrieval vessel allows the unit to release the buoy and it floats to the surface with the rope still connected to the unit. The retrieval vessel can this way, after picking up the buoy, hoist up the unit. The limitations for this recovery method are rope length (currents in the deployment area also affect recovery depth) and rope strength.

There exists some different options regarding rope-recovery modules, but from the visit at Kongsberg Maritime it was found that it could be an option to use their solution.

Making the unit buoyant

Another approach is to make the unit buoyant itself. It will then need to be anchored to the bottom, usually with a counterweight, and when releasing the unit from the anchor it will float to the surface where it can be collected by a boat. One limiting factor regarding buoyancy will be the weight of the unit.

Buoyancy foam

Buoyancy foams exist in a lot of different qualities and variations, however, syntactic buoyancy foams comprises the group which probably is best suited for this project.

Picture 9: Syntactic foam is widely used for buoyancy in offshore applications.

Syntactic foams are composite materials consisting of a polymer binder and hollow microspheres (usually glass, ceramics or metal) forming a matrix system. This gives these materials optimal properties such as low weight (which gives good buoyancy), good mechanical strengths (especially compression strength) and low degree of water absorption. Although syntactic foams generally have good fatigue and impact resistance and can handle compression good the materials are rather brittlein terms of handling tensile stress [1]. The density (and uplift) of the foam varies with depth rating, and generally higher depth rating gives a higher density. Typical densities for syntactic foams are 350 - 600 kg/m^3 with depth ratings down to 500 - 6000 m. [Supplier as source]

Regarding production syntactic foams are very malleable and parts are either machined from ready-made blocksor molded. One can leave the task of manufacturing the parts to the supplier (if the parts are to be molded this will have to be done) or one can choose to do the machining oneself. Finishing treatment of the parts is usually to apply abrasive coating or a fiberglass skin for extra protection. Prices also vary greatly depending on the quality of the foam and if the manufacturer will deliver a finished par, costs can vary as much as 30 000 – 180 000 NOK per m^3. [Supplier as source]

Other options for buoyancy

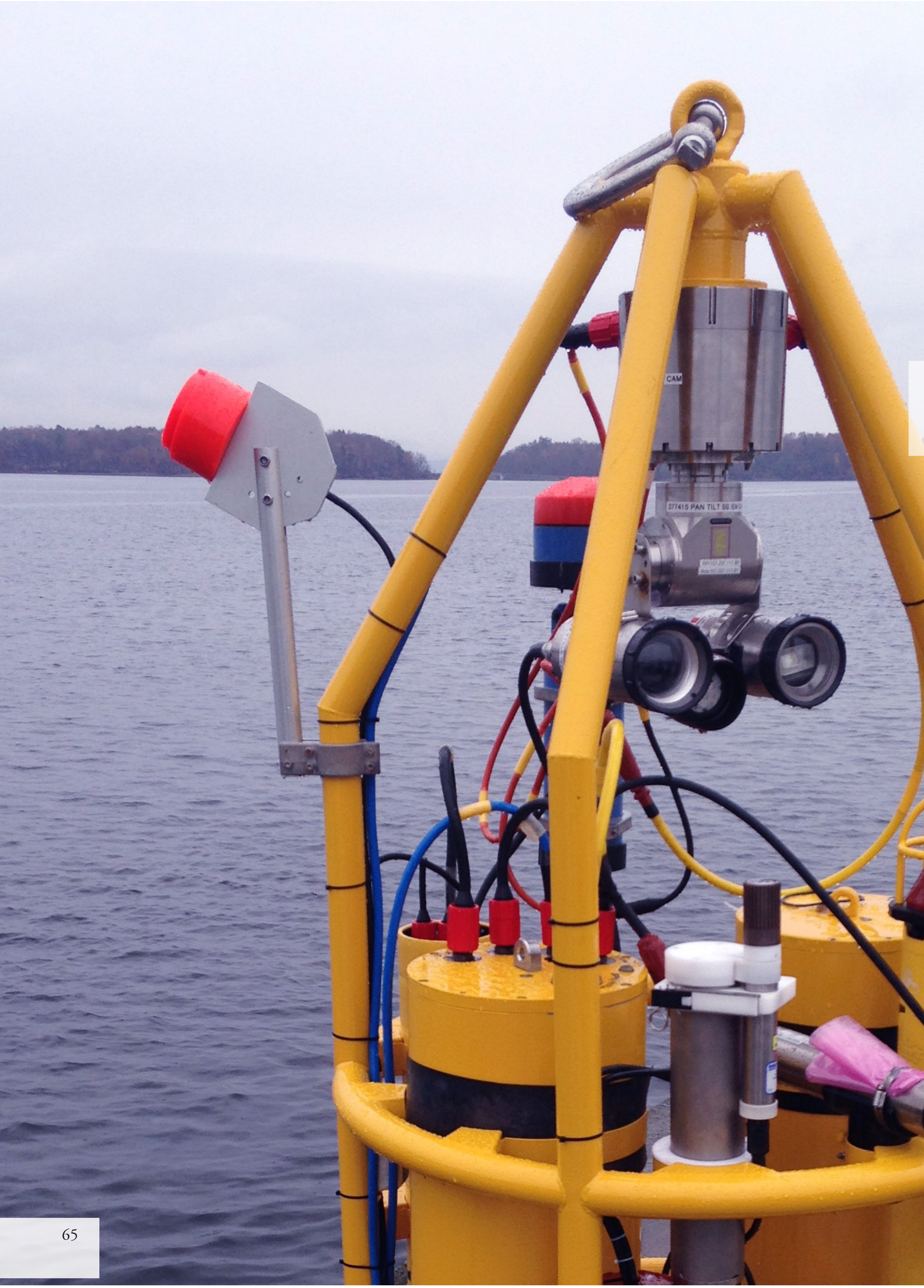
Buoyancy floats which are not made of foam are usually made of larger steel, plastic or glass spheres with a plastic skin for protection (sphere diameter approx. 10 - 100 cm [2]). Depending on the material these floats provide relatively good uplift and depth rating (glass spheres have been used down to at least 6000 m [2]). However, this solution is less malleable given the relatively large spheres.

As far as this research concluded inflatable "balloons" filled with either air or gas is not a possible option because the pressure at the likely working depths of the unit will be too high for such a solution. Another option could be to use a ballast tank, as seen both in normal boats and submarines. This would most likely require use of electrical pumps which are power consuming and not very compatible with autonomous units relying on battery as power source.

Comment

In essence the two methods presented here are both feasible for the unit. Integrating a rope recovery module is a quick and easy way to make the unit self-recovering. The biggest challenge with a rope-recovery module will be to elegantly integrate it in the unit. Advantages include less concerns regarding weight of the unit and low-cost (no price estimate was procured but it should be safe to assume that it can be relatively cheap). There are more options for making the unit buoyant itself, the most interesting will be to use either syntactic foam or spheres floats. Advantages with syntactic foam are good malleability and good material properties which make it suitable for using also as a construction material for the unit, however, costs can be an issue. Sphere floats offer some of the same qualities as syntactic foam, but are noticeable less adaptable, this may make them less tempting to use. The research did not procure any price estimates for sphere floats either, but it is assumed that they may be cheaper than syntactic foam.

Picture 10: Flotation buoys, here glass spheres in plastic molds.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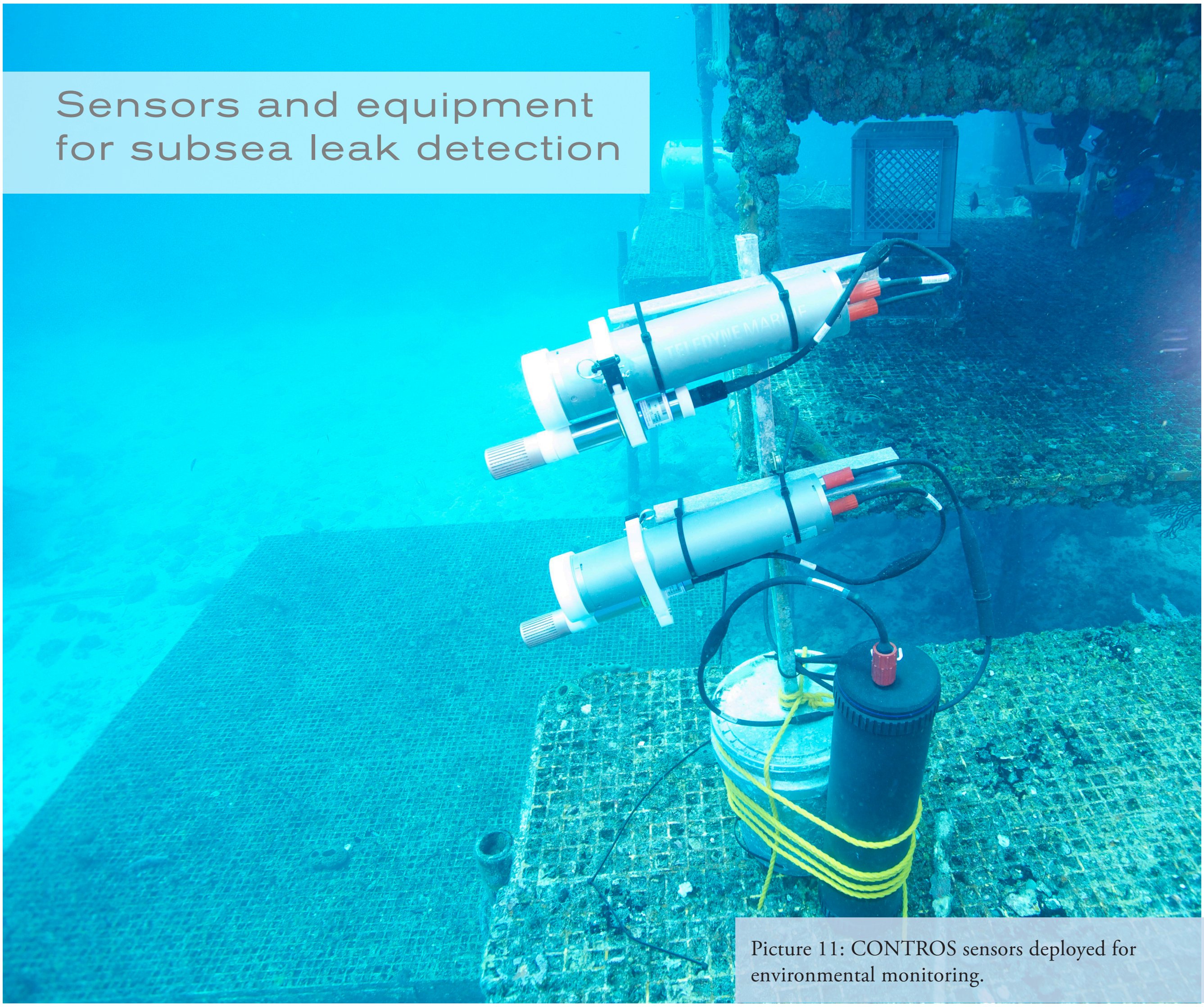
Sensors and equipment

From the pre-project it was made clear that a great part of the surveillance unit would be sensors and equipment bought “off the shelf” from a supplier. Getting acquainted with this gear, how it looks, works and should be used, was crucial step to be able to approach layout and design of the unit in a sensible manner. Although some of the equipment already had been specified by Trollhetta, i.e. central processing unit, camera, hydrophone, potential other sensors and equipment were not specified and it was left up to the student to research this. In the next sections sensors and equipment for leak detection and other needed equipment is described.

Sensors and equipment for subsea leak detection



Picture 11: CONTROS sensors deployed for environmental monitoring.

The waste progress in development of complex solutions for offshore and subsea industries together with the rapid development of existing and new production fields have not always transpired without unfortunate incidents. For this reason, the use of leak detection systems is becoming a more common practice. The systems are put to use primarily to discover and expose small to medium sized leaks so they can be dealt with in an appropriate way or kept under surveillance.

Currently the most common leak detection methods are based on one, or a combination, of the following technologies: active acoustics, bio sensors, capacitance sensors, fiber-optics, fluoresce detectors, methane sniffers, optical cameras, passive acoustics and pressure sensors (called mass balance methods) [6] The above technologies which are most relevant to incorporate in Trollhetta's solution will be briefly presented together with a short remark of some relevant assistive sensors.

OE14-376/377 Compact Color Camera
Diameter: 45 mm
Length: 96 mm (excl. connector)
Weight in air 0.37 kg, in water 0.21 kg

OE14-502 Underwater HD Camera
Diameter: 95 mm
Length: 222.5 mm (excl. connector)
Weight in air 3.2 kg, in water 1.6 kg

Picture 12 and 13: Kongsberg Maritime cameras OE14-376/377 and OE14-502 are both viable options for the surveillance unit.

Optical cameras

Methods based on optical cameras use analysis of video/images to detect leaks in the form of oil or gas bubbles in the water. The method provides spatialcoverage and determination of direction (from the camera to the leak) can be possible. Limitations include biofouling (possibly solved with maintenance and/or surface coatings), limited detection range (due to light and visibility conditions subsea, approx. 10 m), need for contrast background and sensitivity to water turbidity. Lenscleaning and checkup of moving parts every 2 years is typical recommendations from suppliers[6].

icListen HF Titanium
Diameter: 45 mm
Length: 96 mm (incl. connector)
Weight in air 0.958 kg, in water ca 0.6 kg

Picture 14: icListen smart hydrophone from OceanSonics is a hydrophone with correct frequency for leak detection tasks is a likely choice for the unit.

Passive acoustics

Passive acoustic sensors usually consist of hydrophones which essentially are under water microphones. Sound generated for instance by leaks are picked up by these microphones and this way the leak is detected. Both spot and wide area covering variations exist, and for the wide area variations positioning is possible by use of three or more hydrophones, detection ranges. Limitations are the fact that the sound has to reach the sensor, so both magnitude of the sound (pressure) wave and shadowing disruption/shadowing of acoustic signal can be a problem. No requirements of inspection or maintenance[6].

EK80 WBAT
Diameter: 144 mm
Length: 922,5 mm (excl. connector)
Weight in air 25 kg, in water 12 kg

Picture 15: Kongsberg Maritime echo sounder EK80 WBAT are a probable choice.

Active acoustics

Active acoustic sensors are sonar detectors that work by sending out sound waves and listening to the reflected "echoes". The difference in density between water and bubbles of gas or oil causes the sound to reflect back and this way leaks can be detected together with point of origin. Area coverage is very good but depends onleak size and media, detection range is up to 150m for small gas leaks and 50m for fluids. Limitations include disruption/shadowing of acoustic signal caused by subsea structures and relatively high power consumption. Typical recommendations for maintenance/inspection are usually every 3-8 years[6].

Diameter: 49 mm
Length: 200 mm (excl. connector)
Weight in air: 0.8 kg, in water: 0.5 kg

Picture 16: Franatech Mets methane sensor is a typical lightweight methane sniffer.

Methane sniffers

Methane sniffers are point sensors which detect methane dissolved in water. Although very small concentrations of methane can be detected the method is dependent on the distance to the leak and the drift of the leaking medium (currents may lead the gas or oil away from the sensor). Limitations are positioning of the leakages (which is not possible) and evaluation of volume and size of the leak. Typical recommendations for inspection and maintenance are between 1-2 years depending on sensor technology[6].

SEGUARD CTD
Diameter: 140 mm
Length: 352 mm
Weight in air: 12.2 kg, in water: 7.4 kg

SEAGUARD Recording Current Meter (ACDP)
Diameter: 140 mm
Length: 352 mm
Weight in air: 11.5 kg, in water: 5.2 kg

Picture 17 and 18: CTD and ADCP from Aanderaa, a Norwegian supplier of oceanographic instruments.

Assistive sensors

Only two sensors will be mentioned here: ADCP and CTD. ADCP or Acoustic Doppler Current Profiler is an advanced current meter which uses acoustics to measure water current velocities. This can be helpful for calculating or predicting spread of leak plume as well as origin of the leak. CTD stands for conductivity, temperature and depth, and the instrument is used for environmental impact assessments such as measuring of anomalies (i.e. connected to detection of leaks)[6].

Comment

The general implications from Trollhetta have been that optical camera and hydrophone will be the core technology for the solution they want to deliver. However, it was expressed a wish that the final concept should leave room for incorporation of other sensory technology and equipment and this should be considered during the development process. Especially the limitations regarding optical camera should be noted given the aforementioned implications from Trollhetta.

Other equipment

The other equipment is necessary for the functionality not directly connected to monitoring and sensing. As it is likely that Kongsberg Maritime also will supply this equipment it is their products that are presented here, of course other products and solutions exist on the market.

cNODE mini
Diameter: 85 mm
Length: 598 mm
Weight in air: 6.7 kg, in water: 3.4 kg

cNODE – transponder

A transponder is an acoustic datalink used for subsea positioning and communication (wireless transmission of data). The cNODE transponders are some of the flagship products from Kongsberg Maritime. They are delivered in three different sizes (maxi, midi and mini) which all are built with a modular design, to allow different components such as electronics, battery pack and optional add-ons can be replaced as per customer's choice. Two different depth ratings are offered, 4000 m and 7000 m. During the visit at Kongsberg Maritime it was decided that the cNODE mini would be a suitable choice for the surveillance unit.

cNODE transponders are compatible with the HiPAP (High Precision Acoustic Positioning) protocol which is widely used on maritime vessels both in Norway and all over the world. Also compatibility with the Cymbal acoustic protocol is possible, which provides high data speed (8000 bits/second) and accuracy in positioning (0,01 m accuracy even on longer distances).

Picture 19: The cNODE transponder family, from the left maxi, midi and mini.

IEM hub/Quad Pack battery
Diameter: 304 mm
Length: 947.5 mm
Weight in air: 165 kg, in water: 145 kg

IEM hub (Central processing unit) and battery packs

Both the central processing unit and the battery packs are not standard products that can be bought off the shelf from Kongsberg Maritime. They do have the solutions needed for Trollhettas unit, however, if they can be provided or not is a matter left up to the respective companies to figure out.

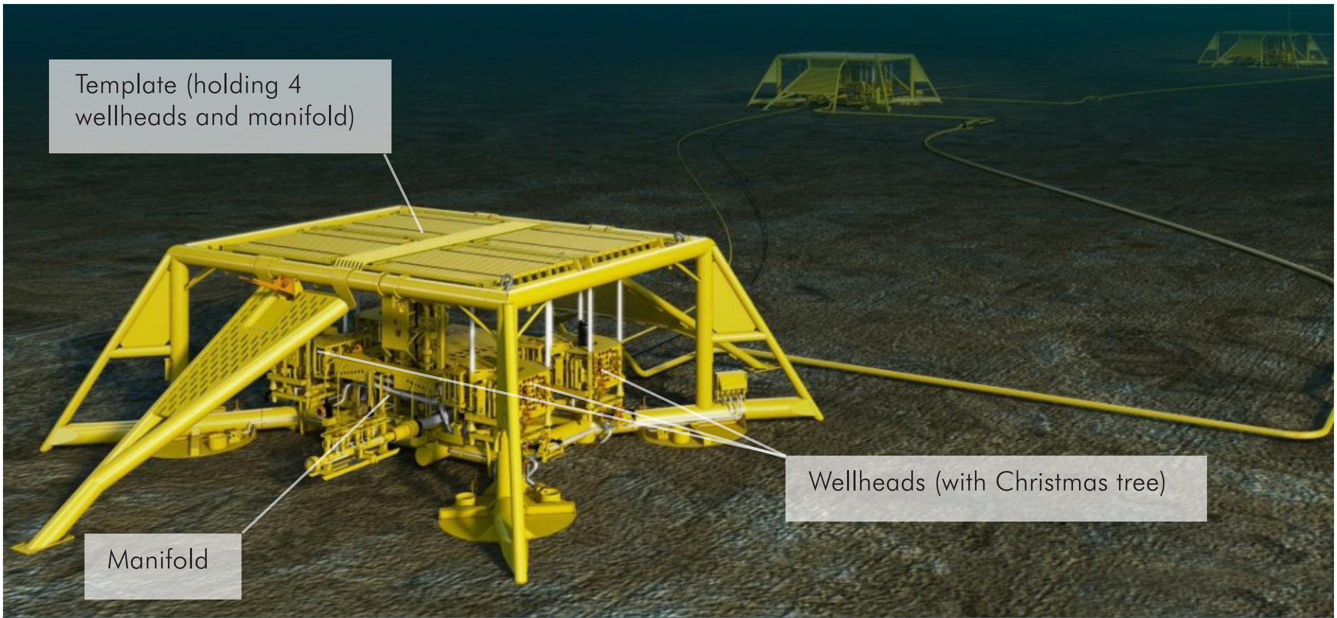
The possible solution offered by Kongsberg for a central processing unit is their IEM hub, which in essence is a computer placed in a pressure rated housing.

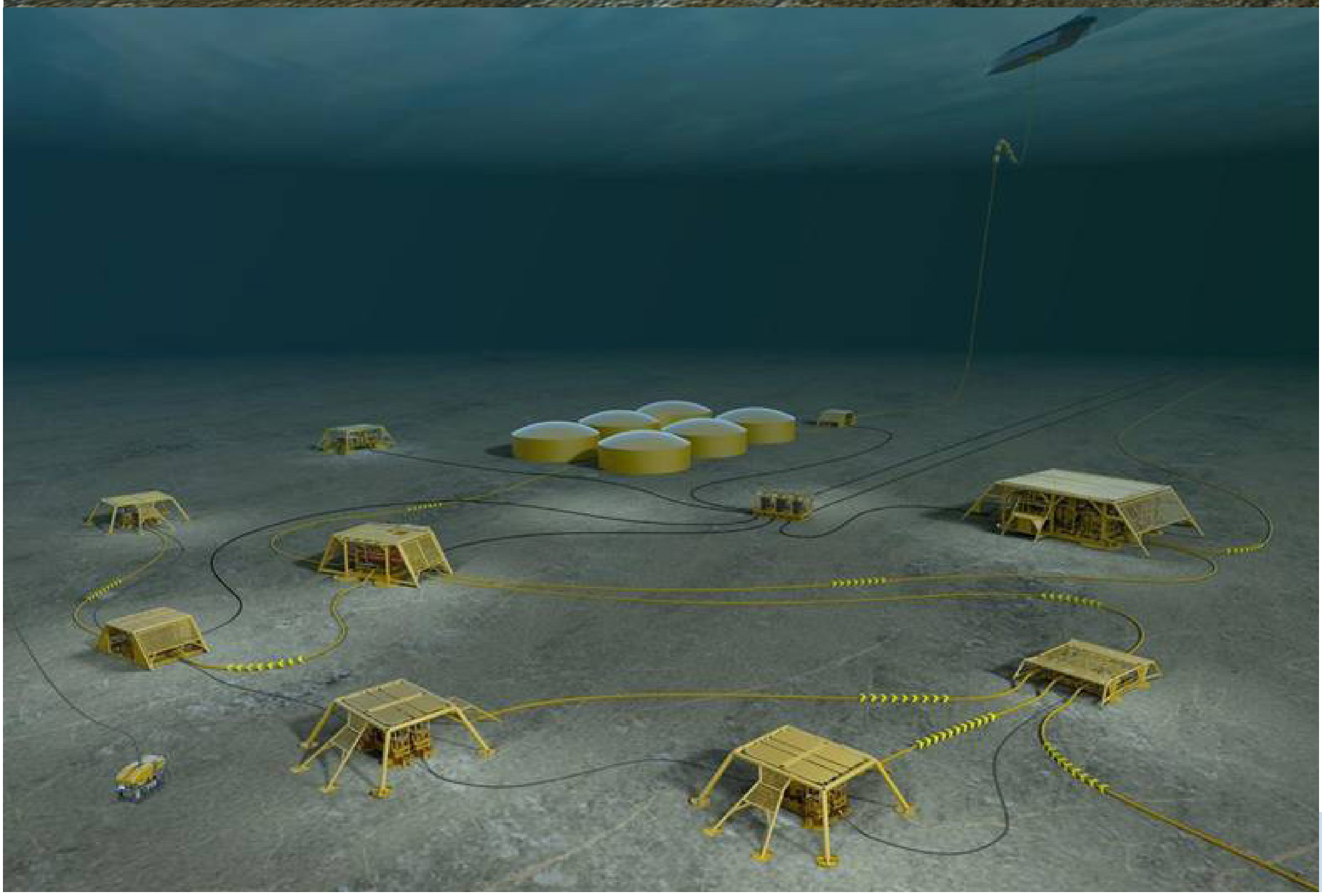
Picture 20: The large yellow cylinder in the picture is a Quad Pack battery, the IEM hub from Kongsberg Maritime comes in the same pressure housing, to the left in the picture is a cNODE maxi transponder.

Regarding the battery packs, Kongsberg offer two solutions. One solution, named Quad pack battery, consists of four cNODE batteries placed in a similar housing to that of the central processing unit. This is a very heavy and robust solution, weighing approx. 165kg in air, and can be considered if weight is not a limiting factor for the solution. The other option for battery packs are the cNODE-battery packs currently used on Kongsbergs K-Lander sensor carrier. This is a more lightweight solution, weighing approx. 34kg in air, but more battery-packs will be needed since in only contains one cNODE battery per pack.

Conditions at deployment site

To develop a good design one has to know what to design for.For this reason it was important to get a picture of how it looks and what the conditions are at a typical deployment site. The next section describes this for petroleum industry on the NCS (Norwegian Continental Shelf).


Template (holding 4
wellheads and manifold)
Wellheads (with Christmas tree)
Manifold



Subsea well systems

A subsea well system consists of one or more wellheads, a manifold, a template, outgoing pipeline and umbilical for power supply. The template is a steel structure which acts as a base on the seabed holding and protecting the wellhead and manifold from damage caused by e.g. falling objects or trawling gear. The template often varies in size since it is made to the particular operation and needs to accommodate for the planned number of well systems[7]. The wellhead assembly typically rises 5m over the seabed and consists of a casing head, a tubing head and a "Christmas tree". Simply put the Christmas tree controls the flow of oil or gas and the casing and tubing heads from a safe connection between the well and the Christmas tree[8]. A production field may contain several templates/ subsea well systems in addition to satellite wells and piping and cabling. On temporary abandonment it is common practice to leave Christmas tree and template in place for protection of the subsea well[9].

Depth

Although the depths vary some on the NCS most subsea wells are on relatively shallow depths, between 200-500 meters. Currently the deepest subsea development is at 1300m at the Aasta Hansteen field on the coast of Northern Norway[10].

Ocean floor

It is feasible to assume the deployment site will be flat. Even though it does vary some, a continental shelf is called a "shelf" because it is a more or less flat underwater landmass. Furthermore, critical subsea field operations, such as borehole drilling, requires relatively good bottom conditions to be carried out and, if needed, these areas are prepared during field development. One can expect the ground to consist of sand and mud in addition to slag and rock cuttings (from borehole drilling). Of course the composition of the foundation will vary some from location to location, being either muddier or more sandy, but it can still be regarded as rather soft.

Picture 21 (top): Typical subsea template on the NCS
Picture 22 (bottom left): Example of subsea field development

Comment

It is the wellhead assembly, or parts of this assembly, which will be the primary target for the surveillance unit to monitor. This means that the unit must be designed so it is possible to place and position it within appropriate range of the wellhead for the chosen sensors to detect leakages. Possible opportunities can be to place and anchor the unit either on top of the template or on the seafloor close by. If it is decided that the unit will be anchored at the seafloor one should consider that the unit may sink down in the ground a bit (according to Brevik maximum ½ m). Anchoring the unit to subsea structure may limit the unit's area of application some, especially in terms of use in other countries.

In depth research on how subsea well systems look in other regions than on the NCS have not been done. Since different regulations apply to these systems they may vary from the presented systems in design and appearance, i.e. in the Gulf of Mexico subsea production systems are not required to be overtrawlable and one will find wells with Christmas trees stand alone on the seabed[7].

Picture 23: This picture gives a good impression on how massive subsea structures can be

Biofouling

Biofouling is a well-known problem in the world of offshore and subsea industries. It is caused by plants, animals and bacteria living in the sea and can be a major problem to deal with. The main concern for the surveillance unit regarding marine growth is obstruction of vision for the camera and possible other sensory equipment (mainly optical). Other effects related to biofouling is accelerated corrosion, however, good methods for preventing this problem exists and will not be a topic here.


Picture 24: Example of biofouling, barnacles and other growths has settled on this spherical camera housing.

Short about biofouling

The intensity of biofouling is related to various factors such as location, temperature, access to nutrition and light, time of year etc. and will vary greatly. Depending on these factors one can talk about everything between matters of weeks to several months before the problem manifests. Given this high variation in the intensity of biofouling only general implications can be given towards its occurrence. It is feasible to assume that the rate of marine growth will decrease with depth. Sufficient light for photosynthesis is only able to penetrate approximately 200m down in the sea[11], rendering the part of the sea where one finds organisms dependent of photosynthesis, i.e. plants and algae, limited. Furthermore, decreasing temperature and less access to nutrients due to increasing depth will additionally contribute to lower biofouling intensity the further down one gets. However, one still finds marine creatures, bacteria and other oceanic organisms which are capable of affecting the unit and its equipmentat greater depths.

Project status at beginning

Today mainly three methods for battling biofouling are found on the market[12]:

- Purely mechanical devices such as wipers, scrapers or shutters.
- “Uncontrolled” biocide generation systems, usually coatings based oncopper or TBT (tributyltin, a strong biocide), i.e. applied on shutter mechanisms and housings.
- “Controlled” biocide generation systems, usually either a dosing pump that sprays out acid or a localized seawater electro-chlorination system.

Shutters and other mechanical devices needs to be adapted and integrated in the sensor at the design stage, and is therefore not an option if it is not already on the sensor. Controlled biocide systems are low cost and rather easy to adapt to existing sensors, and as such a good choice [12]. Protection systems based on coatings applicable to glass faces are not yet commercially available (as far as this research has found).

Picture 25: Algae has taken a liking to this RCM 11 current meter from Aanderaa.

Promising technology

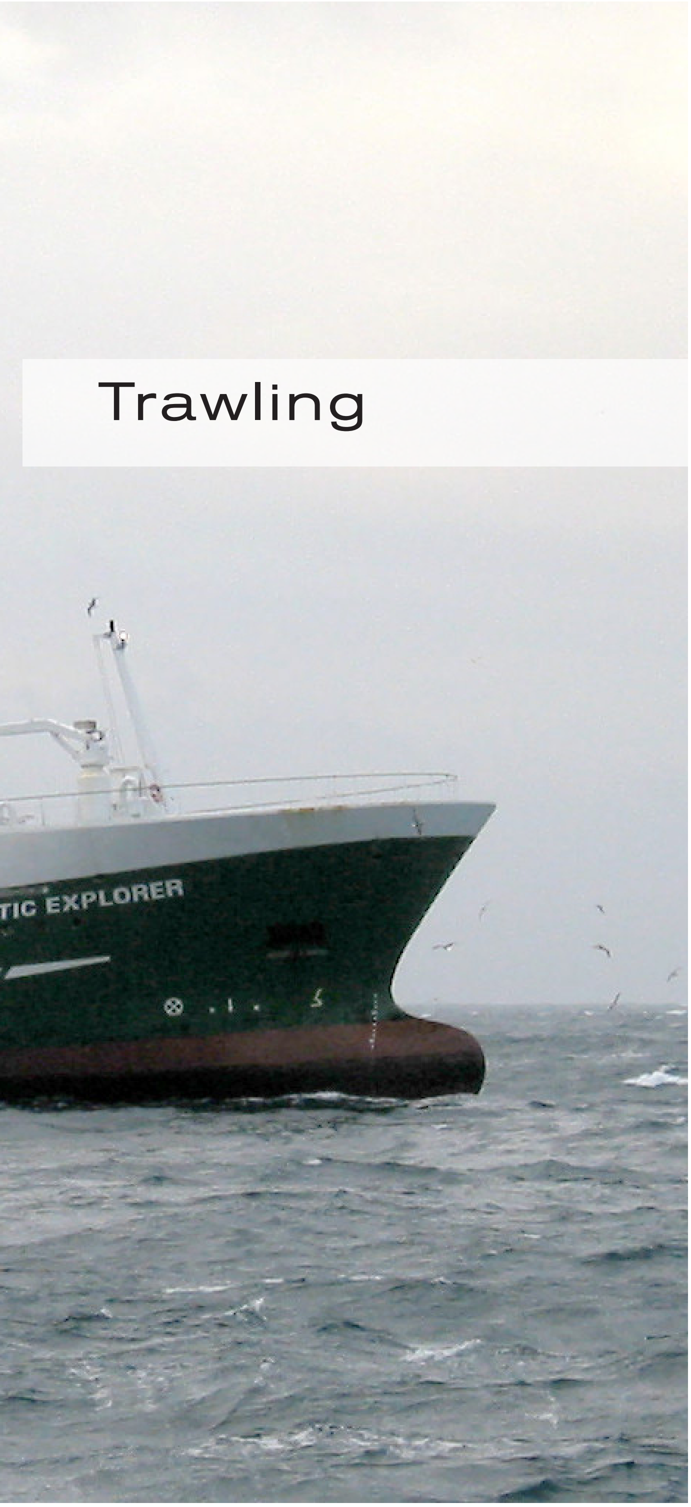
A promising technology for dealing with the problem of biofouling is hydrophobic coatings. Trollhetta have been in contact with InNano, a company which work on hydrophobic coatings. A hydrophobic coating is based on silica-organic hybrid materials, and some of these coatings are transparent. Since the coated surface does not get wet it prevents growth of marine species. Challenges with these coatings are to make them sufficiently adhesive and abrasion resistant.

Comment

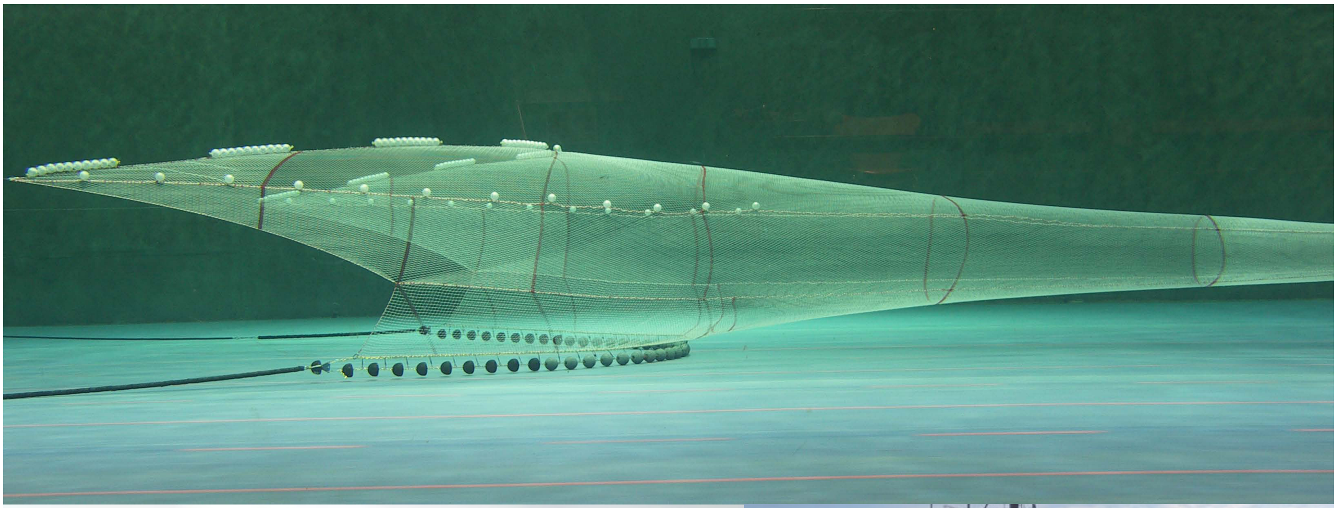
From the interview with Arild Brevik it was found that Kongsberg Maritime does not take prevention of biofouling into account for their sensors. Biofouling may be a problem for the camera (and potential other optical sensors) on the unit, although it is hard to say to what degree. There are not that many good options for preventing this but hydrophobic coatings looks to be a promising solution.


CELTIC

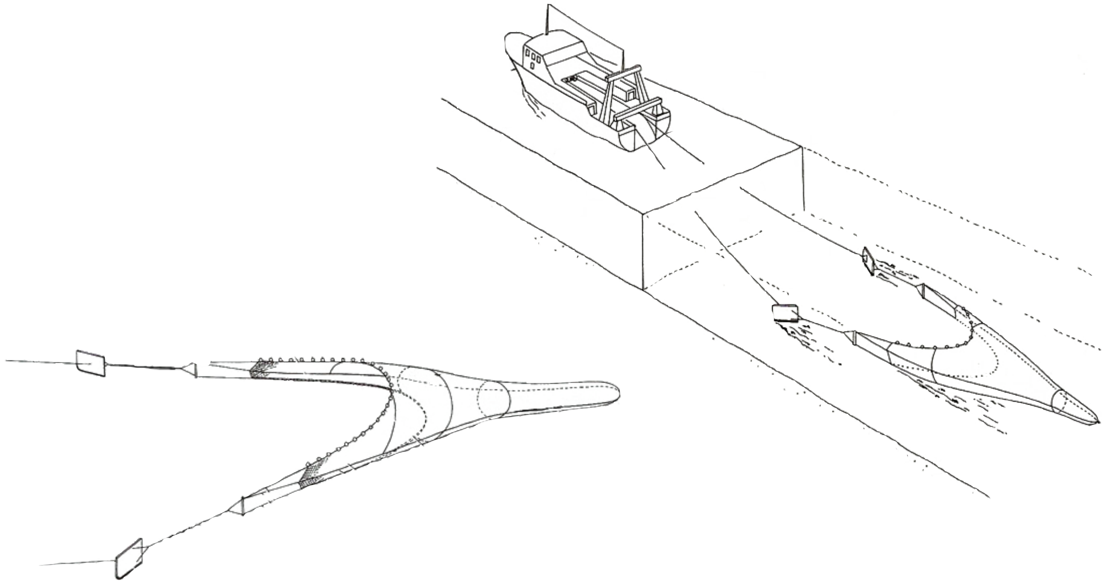
Trawling



Trawling and bottom trawling is a common method of fishing all over the world and given the nature of this fishing activity it is important to consider this when designing the surveillance unit. From the pre-project it was also decided to further investigate regulations and recommendations regarding design of subsea leak detection units and trawl-safety.



Picture 26 (top): Bottom trawl net with bobbins
Picture 27 (bottom left): Bottom trawl doors.
Picture 28 (bottom right): The same bottom trawl doors on a trawler, as one can see the doors are large.



Picture 29: Set up of the trawl gear, the gear is towed after the trawler, the heavy trawl doors move along the sea bed spreading out the net. Floaters along the top side and bobbins or rockhoppers along the bottom side of the net keep the net open.

Short about bottom trawl fishing

Bottom trawling is a fishing method where a boat tows a fishing-net along the sea floor. Trawling can be done at depths down to ca. 1000 m, but it is most commonly done along the continental shelf on depths down to 300-500 m. There exists a large variety in gear designs, sizes, rigging and operational methods for bottom trawling. A very common method is called bottom otter trawling and this gear usually consists of a trawl net with floaters, bottom gear and two trawl doors for guiding the net along the seabed.The bottom gear is weights spaced out along the bottom line of the trawl-net holding the net to the ocean floor, and the most common types are "bobbins" or "rockhoppers". Bobbins are heavy steel balls and rockhoppers are heavy rubber discs (as the name impliesrockhoppers are designed to jump over rocks and rough ground). Typical dimensions for trawl doors are weights between 3-4 tons and 10-12 square meters, and typical towing speeds for a trawl-boat is 3-5 knot.

Picture 30 and 31: Typical overtrawlable designs

Trawl-safe designs and overtrawlable installations

When talking about overtrawlable one are mostly talking about a collision with the trawl door, the installation needs to be able to withstand this collision and there should be no places where the trawl-door or other gear can snag on to the structure (the outer surface must be as smooth as possibleand diameter of holes/distances of slits and gaps should not exceed 150 mm). A “flat and wide” structure with sides at a slant angle further encourages easy passing of trawl gear and is often seen in overtrawlable designs.

Collisions with trawl-doors or snagging of wire-line (the heavy trawl doors usually sinks some centimeters down into the seabed, the wire between the door and the net follows and can this way get caught “under” the installation) are what one can call worst case scenarios. There are a great deal of forces involved in both cases and even though trawl-safe and overtrawlable designs mostly prevent trawl gear from getting caught one cannot truly call them trawl proof unless they are either sufficiently anchored to the seabed or extremely heavy.

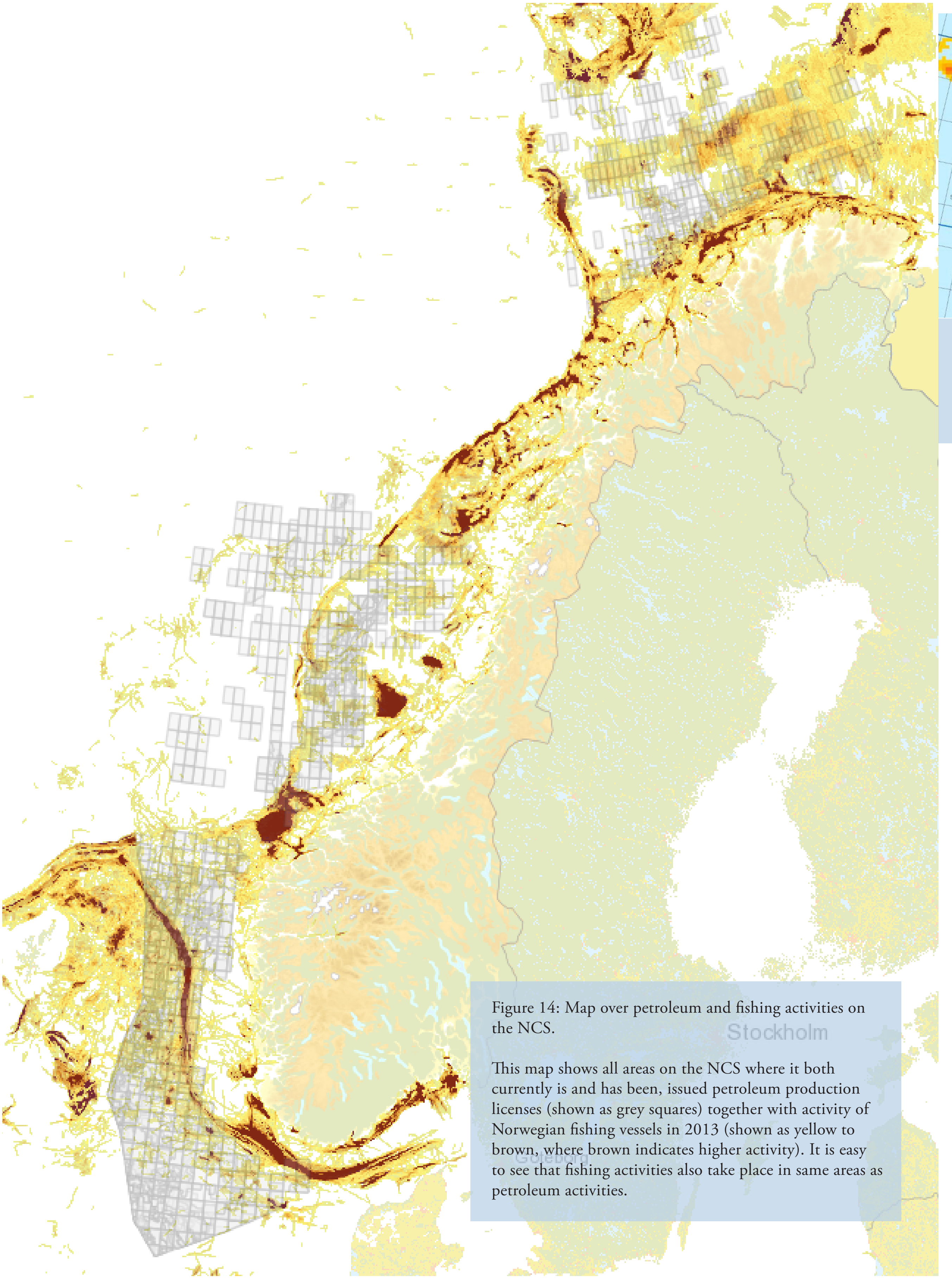


Figure 14: Map over petroleum and fishing activities on the NCS.

This map shows all areas on the NCS where it both currently is and has been, issued petroleum production licenses (shown as grey squares) together with activity of Norwegian fishing vessels in 2013 (shown as yellow to brown, where brown indicates higher activity). It is easy to see that fishing activities also take place in same areas as petroleum activities.

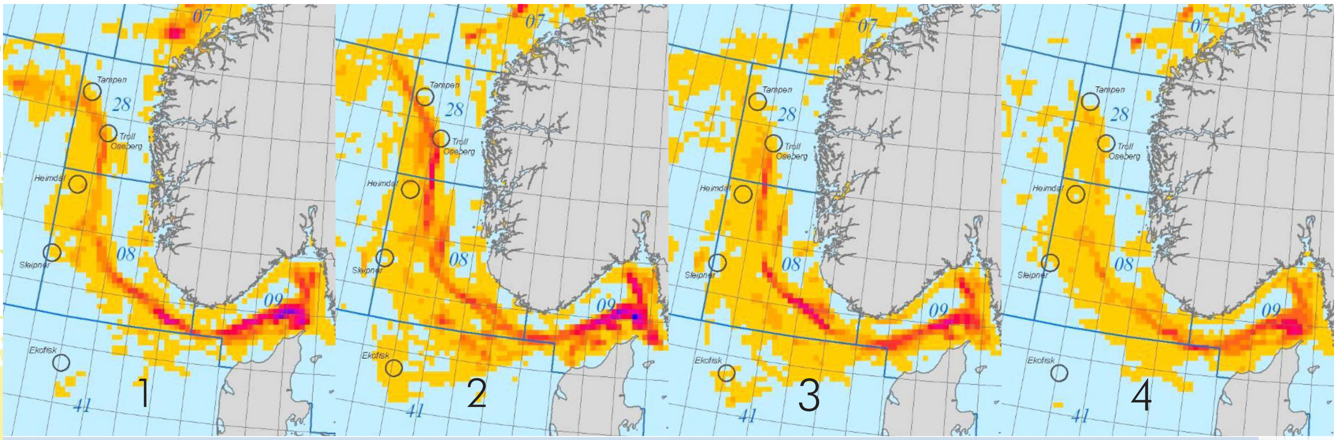


Figure 15 Maps over trawl fishing activities in the North Sea.

The maps above show the activities of both Norwegian and foreign trawling vessels in the Northern Sea for each quarter of 2010. Yellow areas indicate 50 or less vessels and red indicates higher activity, black circles can be seen where petroleum fields are situated. One can clearly see that trawlers avoid petroleum fields.

Caught by a trawl: a design concern?

During the research for this master thesis it has not been found any regulations regarding design of subsea leak detection units and trawl safety or resistance, the general recommendation is that petroleum regulations should be followed. Since it is not strictly required it is necessary to consider whether to handle the case of the surveillance unit caught by a trawl as something which is accounted for in the design of the unit or not.

Norwegian regulations regarding petroleum activities state that subsea installations should not be an excessive hindrance for fishing activities and therefore these installations have no safety zone (special exceptions can be granted). Offshore facilities have a safety zone (usually 500 meters horizontal) preventing unauthorized vessels, like fishing boats, from coming to close[13]. However, cases of accidents have taken into account and subsea installations connected to offshore facilities are often trawl-safe. For the petroleum industry this means that almost all subsea installations are designed so that they are overtrawlable.

In 2013 a series of reports regarding management of the North Sea and Skagerrak was released. Findings in these reports point towards fishermen fishing with trawl (mainly bottom trawls) avoiding areas with subsea installations because of fear of losing or destroying their fishing gear[13]. Data showing the concentration of trawling activity in the area of interest further supports these findings (see figure 15). This point towards that trawling activity may not pose as big a concern as one could think.

Comment

As stated earlier making the surveillance unit completely trawl-safe and overtrawlable requires it to have a sturdy construction as well as to be thoroughly anchored to the seabed. This in turn will add expenses both with the construction of the unit as well as possibly adding a comprehensive placing process for the unit. Fishing activity (and bottom trawling) happens in areas where deployment of the surveillance unit and the risk of interaction with trawl gear can be deemed rather low in light of the above findings. Still recommendations suggest that requirements from petroleum regulations should lay a basis for the construction of the unit and for this reason it is sensible to design a unit which is trawl-resistant. Regulations and situation regarding trawling outside of Norway have not been researched.


TROLLHETTA
CONTRIBUTING WITH EXPERIENCE
NAXYS
METAS
STINGER
Biota Guard
KONGSBERG

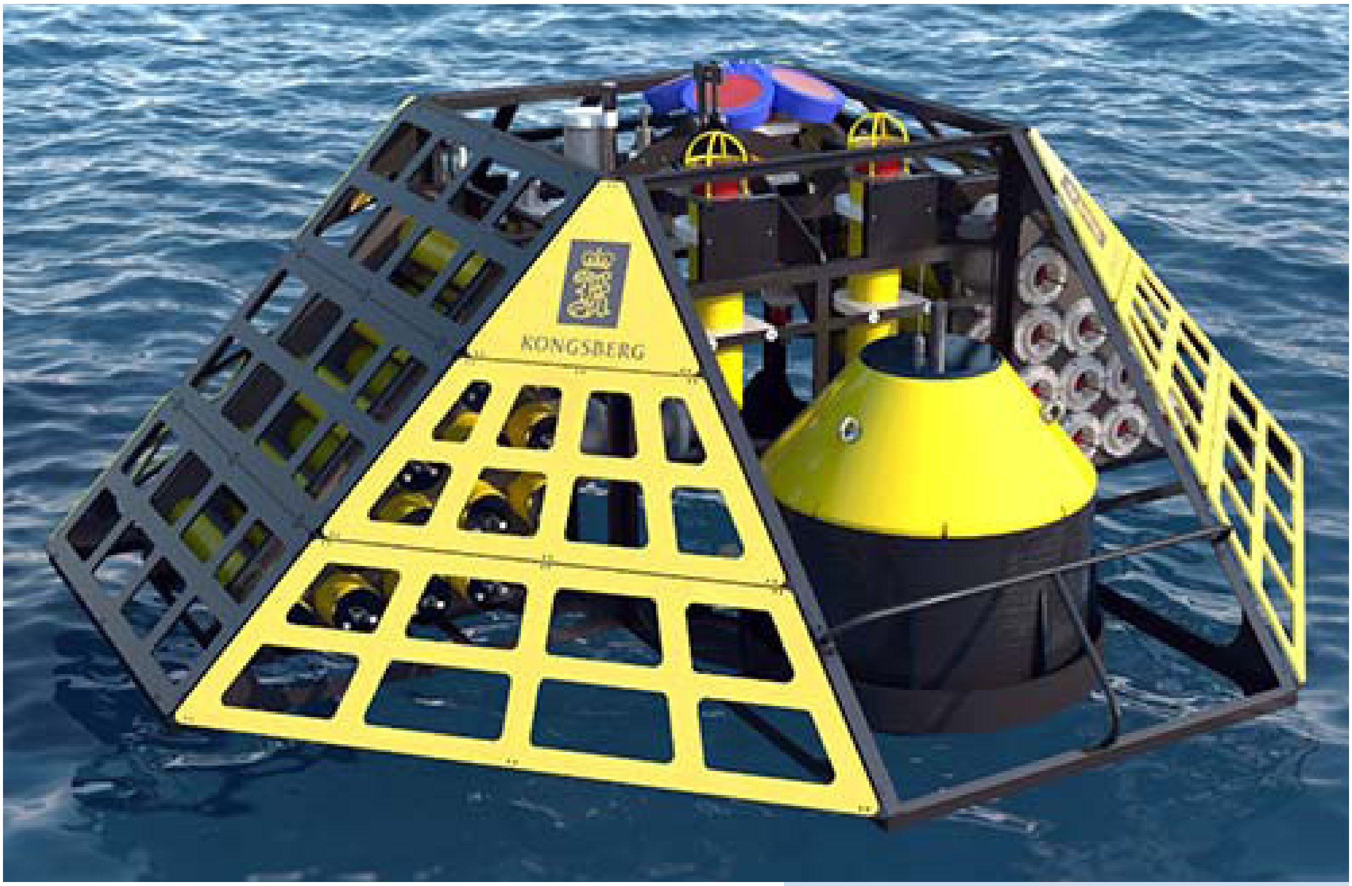
Analysis of competitors

Competitors in the Norwegian market

As with analyzing of market, analyzing of competitors can provide useful information for creating a development strategy for the surveillance unit. Firstly one gets an overview over what solutions already exists on the market and what they offer. Furthermore, one can see how competitors have solved problems one face when developing a product like this and partly see what works and what has potential for improvement. Analyzing competitors can also give new ideas and inspiration for the development process. However, it is also important to note that becoming aware of existing solutions may cause one to think less "out of the box" and become more narrow-minded in the design-process. For the purpose of this project it was still considered useful to perform a simple analysis.

The five leak detection solutions reviewed in this section are all developed and produced by Norwegian companies. The main reason for this is, again, that Trollhetta plans on first entering the Norwegian market which makes these solutions more interesting. Another reason is that leak detection solutions developed in other countries often are based on operation assistance from ROV or other subsea vehicles and following is of less interest for this project.

KONGSBERG



Picture 32: Kongsberg K-Lander

KONGSBERG MARITIME

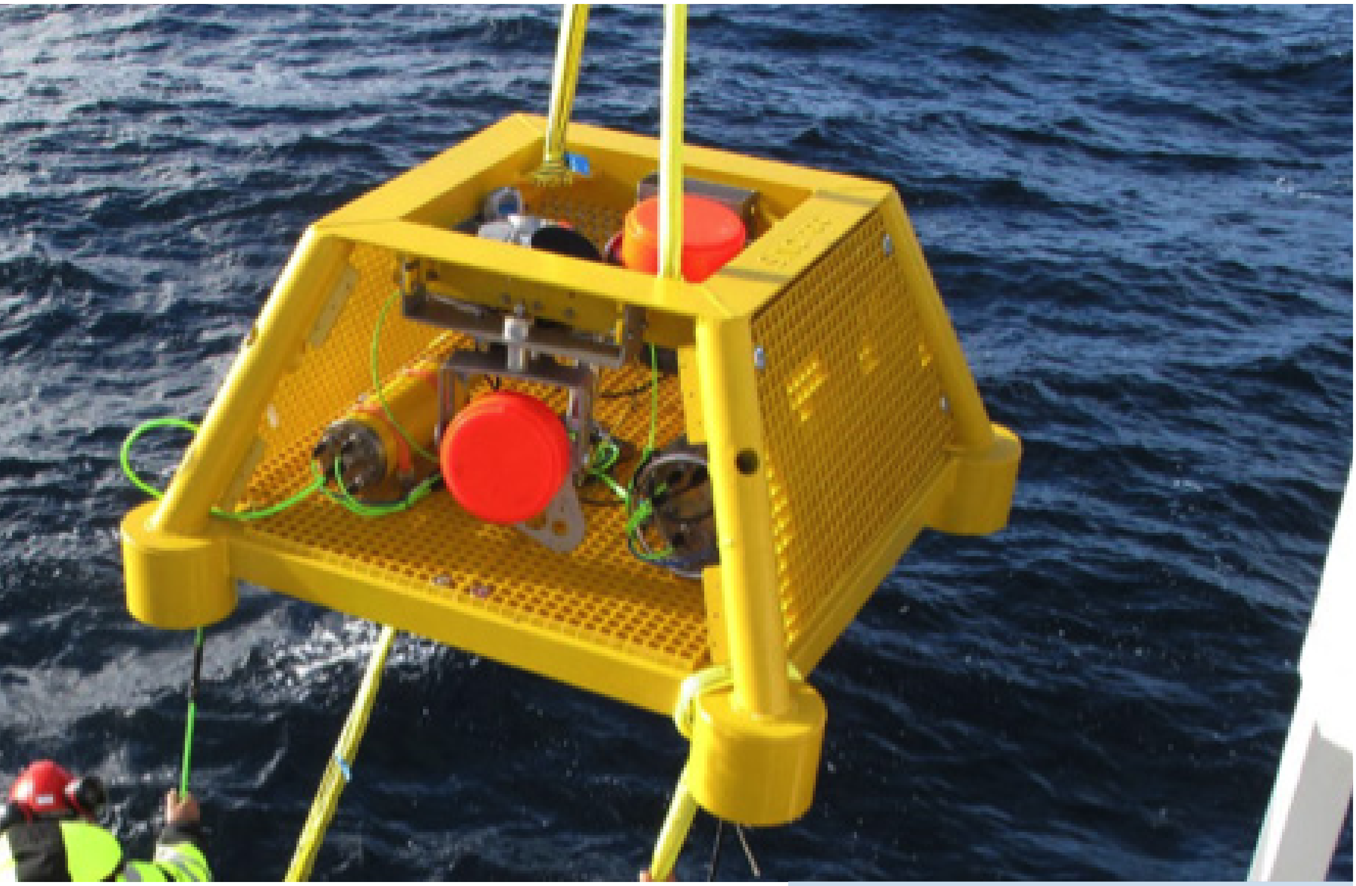
As stated earlier, Kongsberg Maritime delivers a wide range of products and systems to the marine-, offshore- and subsea industries. They have newly launched a modular subsea monitoring unit, K-LANDER autonomous scalable sensor carrier for environmental monitoring including leak detection.

Features

- 2000m standard operational depth, other depths available
- Installation: free, resting on seabed (lowering with wire)
- Communication: acoustic or with umbilical
- Power supply: 4 battery packs (each 128 A) standard, up to 30 possible
- Dimensions: 3.6 m x 3.6 m x 1.6 m, weight approx. 1-2 tons depending on configuration
- Frame material: stainless steel
- Dower management unit, standard equipment
- Data processing unit, standard equipment
- Sensors:
    - cNODE transponder, acoustic communication, standard equipment
    - Conductivity, temperature and pressure (CTD) sensor, standard equipment
    - Sensor suite may be configured to customer needs
- Self-recovery system: rope-recovery
- Trawl-resistant

K-Lander autonomous scalable sensor carrier

The K-Lander is not a pure leak detection system but a modular sensor carrier designed for environmental monitoring. The system works relatively straight forward, depending on selected sensor package, the unit is able to detect and monitor leakages in a variety of ways. It is installed free standing on the seabed by lowering with wire from deployment vessel. If high precision in positioning is needed ROV is required at large depths. Topside communication takes place through acoustic link or umbilical for direct contact. This means that the unit requires either surrounding infrastructure or intervention to be able to notify detected leaks etc.   In terms of dimensions it is the largest of all the solutions with a lot of space for sensors, equipment, and battery. The solution has a self-recovery system in the form of a rope recovery module, which is in essence a buoy with a rope. With an acoustic signal, sent from the retrieval vessel, the buoy is released and floats to the surface with the rope still connected to the unit. The retrieval vessel can then pick up the buoy and hoist up the lander. Limitations for this recovery method are rope length (currents in the deployment area also affect recovery depth) and strength. Although the robust steel frame is designed with trawl-resistance in mind interaction with a trawl may still be problematic or critical (i.e. points where snagging of bottom gear is possible and concerns regarding collision with trawl-door).



Picture 33: Metas x-frame

METAS

Metas, Marine Ecosystem Technologies AS (located in Bergen, Norway), was founded in 2009 and has since then developed systems for environmental monitoring. In 2014 Metas introduced their active acoustic leak detection (AALD) system, x-frame, for detection of oil and gas leakages.

Features

- 1500m standard operational depth, 3000m available
- Installation: free, resting on seabed, lowering with wire
- Power supply: battery or cable
- Communication: not specified, most likely acoustic or with umbilical
- Dimensions: 1.8 m x 1.8 m x 0.9 m, weight x-frame 400 with 2.6 tons payload capacity.
- Frame material: carbon steel
- Data processing unit, standard equipment
- Sensors:
    - Sonar: Simrad EK80 Scientific echo sounder standard equipment
    - Transducer, standard equipment
    - Acoustic Doppler current profiler (Nortek), standard equipment
    - Camera (Metas), standard equipment
    - CTD sensor (conductivity, temperature, and depth), standard equipment
    - Hydrophone, standard equipment
    - Other environmental sensors
    - Sensor suite may be configured to customer needs
- Recovery: with ROV
- Partly trawl-resistant

Active acoustic leak detection (AALD)

Similar to the K-lander, this is also more or less a sensor carrier system. The standard sensor package is more specified towards leak detection with sensors for both long and short range detection (sonar and camera). As the K-Lander, it is installed free standing on the seabed (lowering with wire) and ROV is needed for high-precision positioning at large depths. Again topside communication takes place thorough umbilical or acoustic link, which means the unit requires either surrounding infrastructure or intervention to be able to notify detected leaks etc. The solid carbon steel frame appears trawl resistant, but this is not verified and there are points where snagging of bottom gear is possible. Lastly retrieval requires ROV which adds to expanses.

Picture 34: Naxys ALD

NAXYS

Naxys (located in Bergen, Norway) and was established in 1999. Their area of focus has been high-tech leak detection & condition monitoring systems for subsea installations related to the oil & gas industry. Currently Naxys offer two systems for leak detection; wide area coverage acoustic leak detection (ALD) and hotspot/limited area single acoustic leak detector (not analyzed).

Features

- 2500 operational depth
- Installation: on well-template, use of ROV
- Power supply: cable (or battery)
- Communication: umbilical
- Dimensions; diameter 1m, height 1.75 m, weight 200-250 kg in air
- Frame material: titanium
- Sensors:
    - Array of hydrophones
- 500 m detection range
- 2500 operational depth
- Recovery: with ROV
- 25 year design life
- Recommended testing of functionality every 2 year

Acoustic leak detector (ALD) - for wide area coverage

Naxys ALD relies solely on hydrophones as sensors which gives good detection range (up to 500 m) together with long deployment-life and low maintenance. Compared to the K-Lander and the x-frame it is a lightweight unit and it is meant to be installed on top of the well-template rather than on the seabed. For this reason, and because it is rather lightweight, trawl resistance is most likely not the highest. Both installation and recovery requires ROV which adds to the total expenses. It can connect to the subsea control module and topside communication (and power) goes through umbilical which again means that the unit needs surrounding infrastructure.

Picture 35: The ALD mounted on site

STINGER

Picture 36: Stinger LeakNodes

Stinger

Stinger (located in Stavanger, Norway), was founded in 2003. The company is working with solutions regarding asset integrity and safety monitoring in offshore operations. Their LeakNode grid unit system is among the first in Norway to have been in use on site for a longer period of time (approx. 2 years).

Features

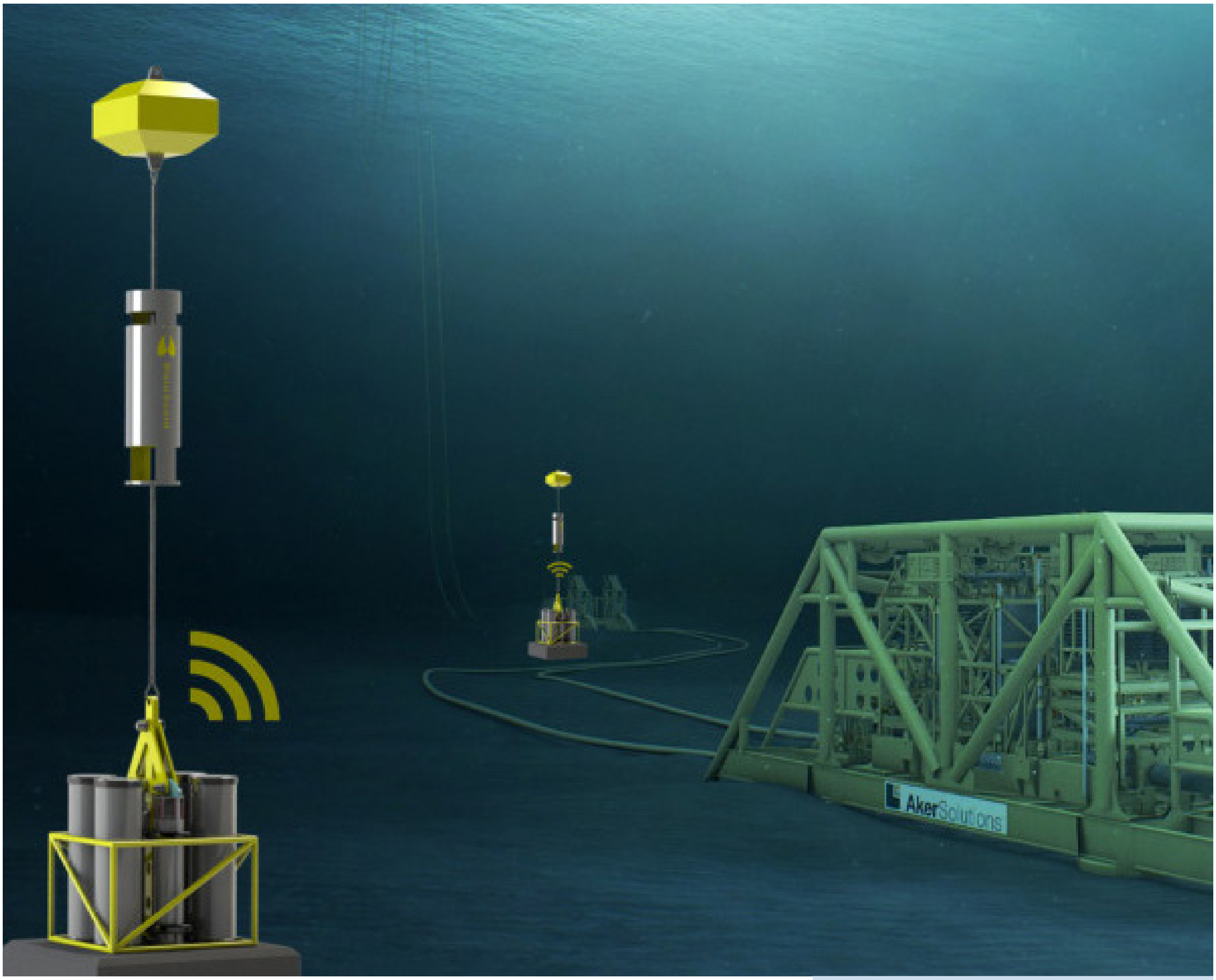
- Opertional depth not specified
- Power supply: cable
- Installation: on preinstalled frame (not pictured), with use of ROV
- Frame material: stainless steel and various other materials.
- Communication: umbilical
- Dimensions: not specified
- Sensors:
    - Sonar, standard equipment
    - Current meter, standard equipment
    - Hydrocarbon sniffers, standard equipment
    - Sensor suite may be configured to customer needs
- Recovery: with ROV

LeakNode grid unit

The LeakNode soltion is a grid based system that utilizes strategic positioning of the units to cover monitoring of the whole work site. In addition, the dispersed positioning helps the system to pinpoint the origin of the leakage. The nodes are connected to each other as well as the topside though umbilical which provides both communication and power. ROV installation and recovery of both mounting-frames and the nodes themselves drives expenses up. The system is clearly intended for deployment at sites where infrastructure is in place and the design of both unit and mounting frames does not consider trawl-resistance.

Picture 37: LeakNode with mounting frame

Biota Guard



Picture 38:Biota Guard leak detector

Biota Guard

Biota Guard (located in Stavanger, Norway), was founded in 2005. With technology that uses instrumental mussels for measuring and monitoring water quality the company offers solutions for leak detection and water monitoring within several markets. They have also developed a subsea leak detection system.

Features

- Dimensions: N/A, weight: approx. 80 kg
- Frame material: stainless steel and various other materials.
- Communication: acoustic to buoy/installation at surface
- Power supply: battery or cable
- Installation: free resting on seabed, lowering with wire
- Sensors:
    - Biosensors, standard equipment
    - Optical sensors, standard equipment
    - Acoustic sensors, standard equipment
    - Sensor suite may be configured to customer needs
- Self-recovery system: buoyant device

Leak detector

The standard sensor package for Biota Guard's solution offers a mix of short and long range detection. It is again a lightweight solution but this time with simple installation (lowering to seabed with wire). It is also the second system with self-recovery, here solved with a buoyant device which means that the unit also has a counterweight/anchor that eventually will have to be left at the deployment site. Communication happens through acoustics with a buoy or installation at the surface and power supply is either battery or cable. The outlines for this solution makes it potentially suitable for more remote locations, provided that a buoy at the surface can be situated in range and support further notification on leakage detection. However, the physical design of the unit does not take into consideration trawl-resistance leaving the system vulnerable to this kind of activities.

Comment

The methods for leak detection, with the exception of the biosensor, build more or less on similar technology for all the competitors and gives good recommendations for what sensory equipment Trollhetta should use. Regarding installation and recovery, systems requiring use of ROV for these operations will be more expensive, due to lease of ROV with crew, and one should consider avoiding this if possible. Most of the solutions requires infrastructure for topside communication (notification of detected leaks) and some of the units also rely on umbilical for power supply. This point towards that development of a standalone solution, also suitable for remote locations, can be desirable. Furthermore, trawl-resistance is taken into account in a varyingly degree and, even though some of the products satisfy requirements for this, improvement may be possible.

Part 3

Outcome

3.1 Specification of requirements

Introduction

Statement of requirements

3.2 Exploring solutions

3.3 Final Concept

Introduction

The work with development of a specification of requirements started with clarifying what would be most reasonable regarding where to place the unit and method of self-recovery since these are two points that affect the design requirements to a large degree.

Self-recovery

The decision to develop a solution which would be self-recovering was made quite early in the project. This was something that was seen as an advantage since it would simplify the process of collection of the unit and as seen from the insight part of this thesis there exist some good solutions for self-recovery of subsea devices per today. By comparing opportunities for the different recovery methods (see mind map) it was decided to look more closely into the use of either a rope-recovery device or syntactic foam.

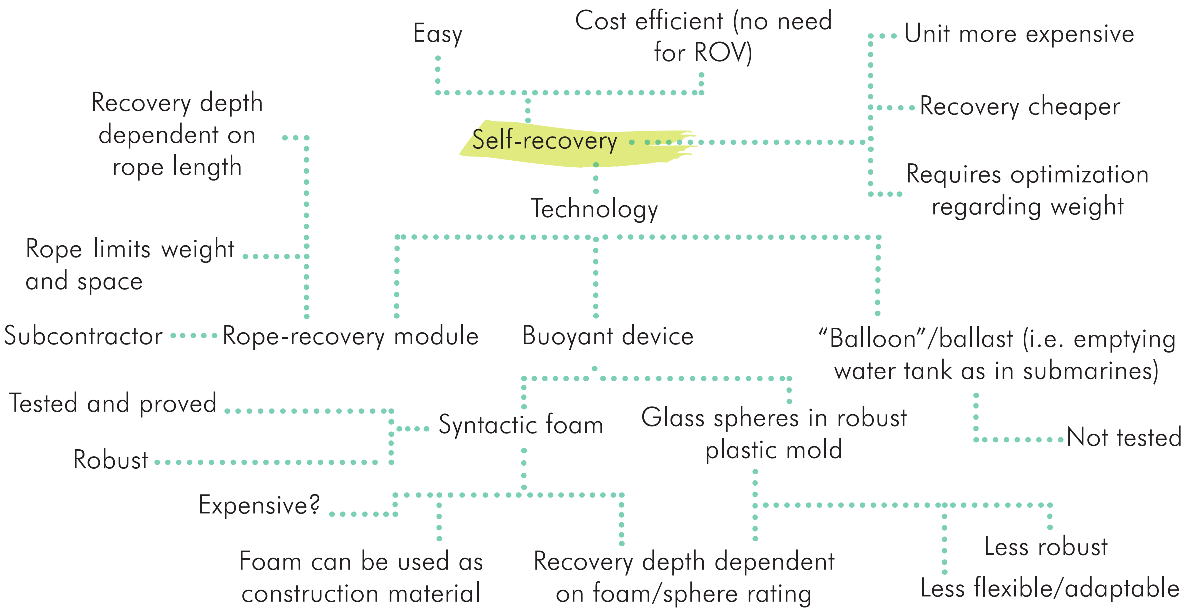


Figure 16: Mind map over self-recovery used to get an overview over the different methods and what they offer.

Where to place the unit

Deciding on where to place and install the unit was a crucial step in the development process. Whether the unit is placed on the ocean floor or on a subsea structure requires very different solutions for anchoring as well as precision in positioning.

As seen from the table there are advantages and weaknesses with both of the options, but since Trollhetta seek a product which has a low TCO (total cost of ownership) it was decided to go for placing the unit on the ocean floor. This also provides the least constrains for the unit it terms of market, since it can be used in places where there are no preexisting subsea structures.

	On Seabed	On Structure
+	"Cheap": ROV can be avoided unless very large depths or difficult conditions at deployment site. Lower requirements for precision in positioning. Opens up for use in areas where there is no subsea structures, also usable outside petroleum sector. Overtrawlability can be managed in easier.	Close to inspection object. Good for methane sniffers and other point or close range sensors.
–	Proximity to inspection object may be "worse" (should still be sufficient for leak detection with optical camera). Methane sniffers and other point or close range sensors may be less effective.	Expensive: Requires ROV or very sophisticated electronics/mechanics for installation, also due to high requirements in positioning Overtrawlability is a problem. Use restricted to sites where suitable subsea structures exist.

Figure 17: Table used in the decision process showing advantages and disadvantages for placing on the seabed and on subsea structure.

Statement of Requirements

This statement of requirements takes grounds is in the results of analyses and research done during in the preceding chapters. Together with serving as part of a basis for development of concepts and solutions for the surveillance unit the specification of requirements summarizes the most important findings from the insight phase that affect the design of the unit.

The statement of requirements is divided into the following parts: equipment, frame, anchoring, placing and installation, collection and maintenance. The requirements presented in all the part consider one or more of the following areas: functionality/use, equipment/components, economy and technology.

Each part is given an own table where the belonging requirements are presented, furthermore the requirements are weighted with mandatory, recommended and optional. Mandatory requirements needs to be included in the final concept, the recommended requirements should be included and the optional requirements can be included if possible.

- Mandatory
- Recommended
- Optional

Equipment

Requirement	Comment	
Battery		Mandatory
Central processing unit		Mandatory
Transponder		Mandatory
Camera		Mandatory
Flash/floodlight		Mandatory
Hydrophone		Recommended
Alarm buoy		Mandatory
Interface for connection to umbilical		Mandatory
Interface for connection to existing sensors		Recommended
Echo sounder/sonar		Optional
CTD		Optional
ADPC		Optional
GPS		Recommended
Possible to adapt sensor package to customer needs		Recommended
Depth rating	500-600m	Mandatory
	1000m¨	Recommended
	3000m	Optional
	Should be adjusted to deployment site	Recommended

Frame

Requirement	Comment
Accommodate for camera view (and other sensors that require sight)	Tilting 90° vertical Pan and tilt 360° x 180°
Accommodate for additional sensors and equipment	Avoid use of ROV or other costly and complicated equipment/procedures.
Trawl resistant/overtrawlable	"Low and wide" Slant sides Openings max 150mm Smooth surface, no place where trawl gear can be caught
Comply with standards and regulations	Standards: ISO, DNV, NORSOK etc.

Anchoring

Requirement	Comment
Keep unit in place (i.e. withstand sea currents and overtrawling)	Either sufficient weight or fixed to the seabed (i.e. with suction caisson) Minimize vibrations and other movement that can affect/disturb data acquisition
Accommodate for easy and cheap installation	Avoid use of ROV or other costly and complicated equipment/procedures.
Accommodate for sinking into the seabed	Maximum 0.5m

Placing and installation

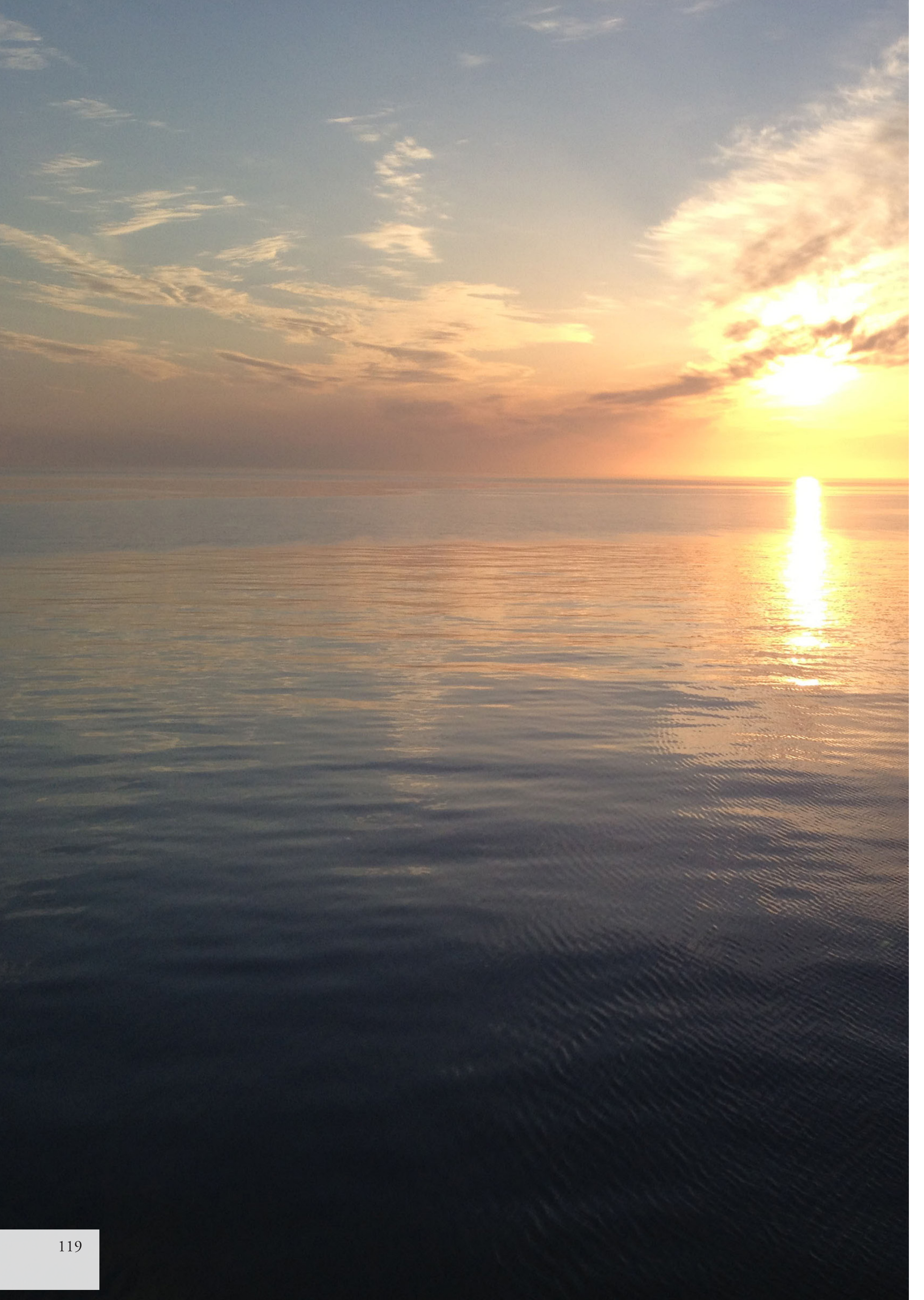
Requirement	Comment
Possible to place the unit in good monitoring range	Depends on sensor choice, for optical camera detection distance is up to 10m.
Cheap	Avoid ROV as far as possible Should not require too large deployment vessel Avoid intervention at installation
Easy to lift and release	1 lifting point is optimal, especially for acoustic releases
Safe to lift	
Acoustic positioning	Transponder (cNODE)
Live camera feed during installation	Needed for adjustment and calibration of lights and camera

Maintenance

Requirement	Comment
Biofouling protection	Normal/as required by standards (coating etc.) On camera lens/other optical sensors Other sensors/equipment
Corrosion and erosion protection	Complying with standards and guidelines Shielding of equipment/sensors
Maintenance interval	On collection
Easy to access equipment	
Easy to replace equipment	

Collection		
Requirement		**Comment**
Rope recovery	Incorporation of rope recovery module in unit	
Syntactic foam	Weight optimization	
	Counter weight	Should be a part of the anchor
		Environmental friendly
		Reuse
		Remove
	Release mechanism	

Figure 18-23: Tables of requirements for the surveillance unit.



3.2 Exploring solutions

Methods

Ideation and conceptualization

Methods

The specification of requirements, together with findings from analyses and research, laid a basis for the development of the final concept. However, the work with exploring solutions started early in the project and was carried out continuously until the final concept was formed. Both general design of the unit and more detailed solutions for various problems have been explored, and as the work with research and analyses proceeded it became possible to reject less viable options and keep working with more promising ones. This made the development process more dynamic and one could to some degree avoid too much unnecessary work.

Inspiration collages

During the development process inspiration has been gathered from different places, both with regards to technical solutions and shape/design. Some of this was gathered in collages.

Mind maps

As one can see from the other parts of the report mind maps have been used frequently throughout the whole project. Also during idea generation and conceptualization this was used as a means to sum up different thoughts, problems, advantages etc.

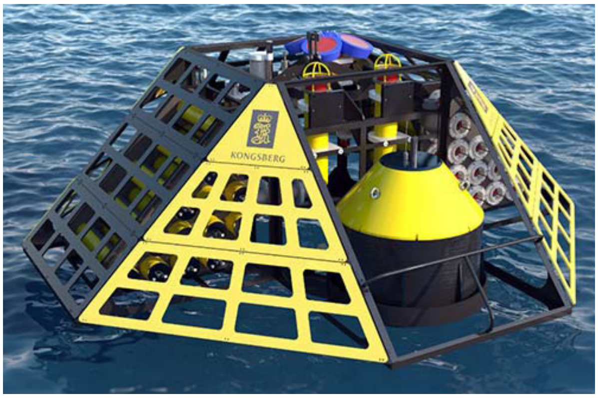
Sketching

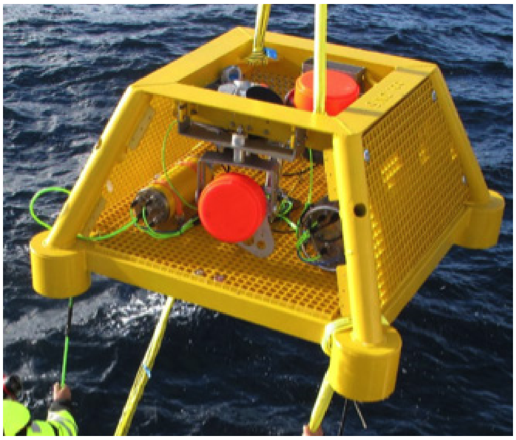
Sketching by hand is often a quick way to visualize and make ideas more tangible. For this project it has mainly been used in the early stages of idea-exploration.

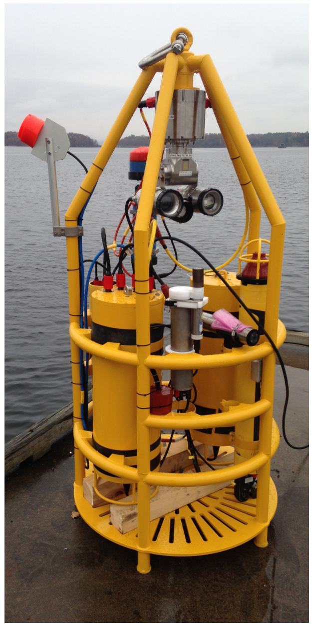
3D Sketching and CAD

CAD and 3D modeling has been a useful tool in the development of concepts and solutions for the surveillance unit. Visualizing volumes and proportions is often easier and quicker with CAD programs than by hand and quick mockups have been made of sensors and equipment as well as components and parts of the unit itself. Furthermore, CAD has been extensively used in the development and visualization of the final concept. Also volume and weight calculations have been necessary since this plays a crucial part of the final solution. Some easy analyses of mechanics and forces have also been done to make sure realization of the concept is more or less feasible.

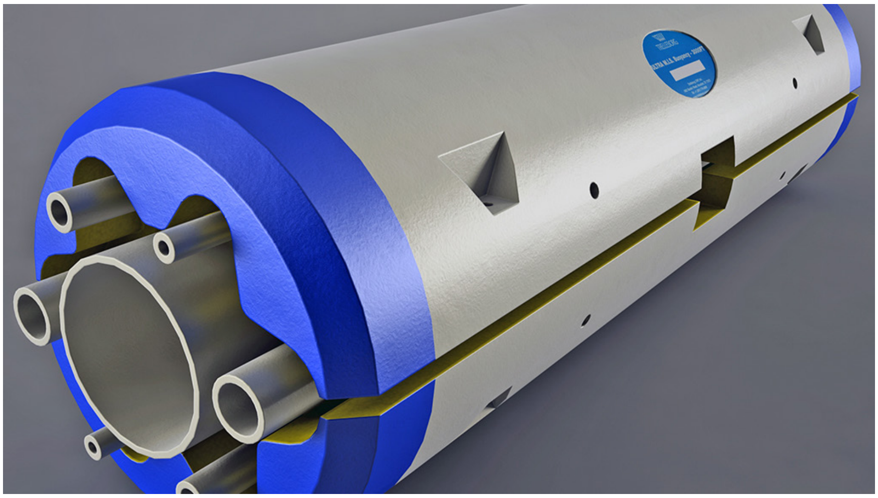
Inspiration





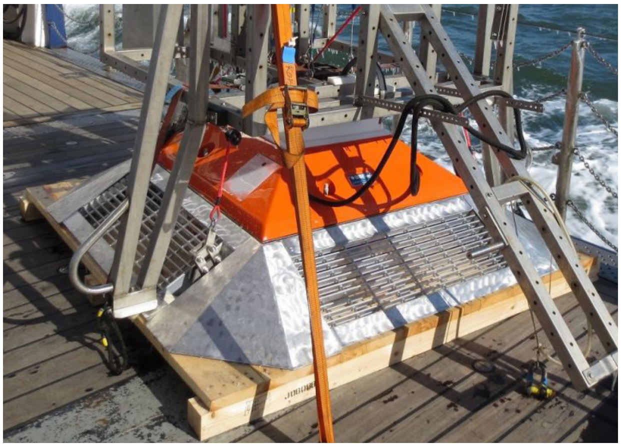


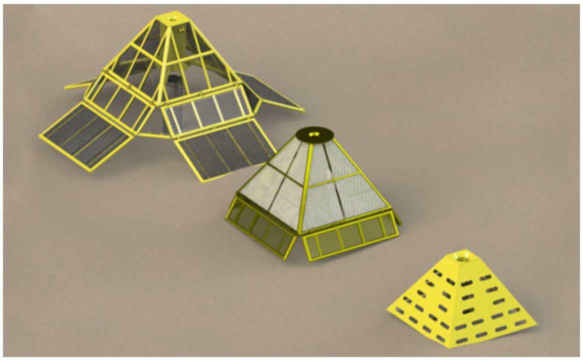
Competitors and other existing leak detection units were of course also used as inspiration both in terms of layout/form and function.



ROVs provide good example for both lightweight and heavy duty subsea design. The seabed receiver from EMGS and the cable riser are good examples on design with syntactic foam.

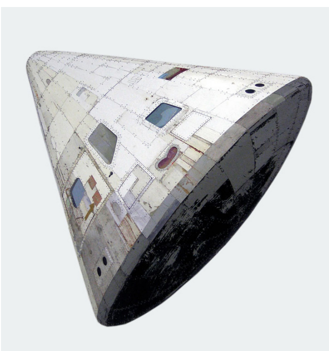
Inspiration



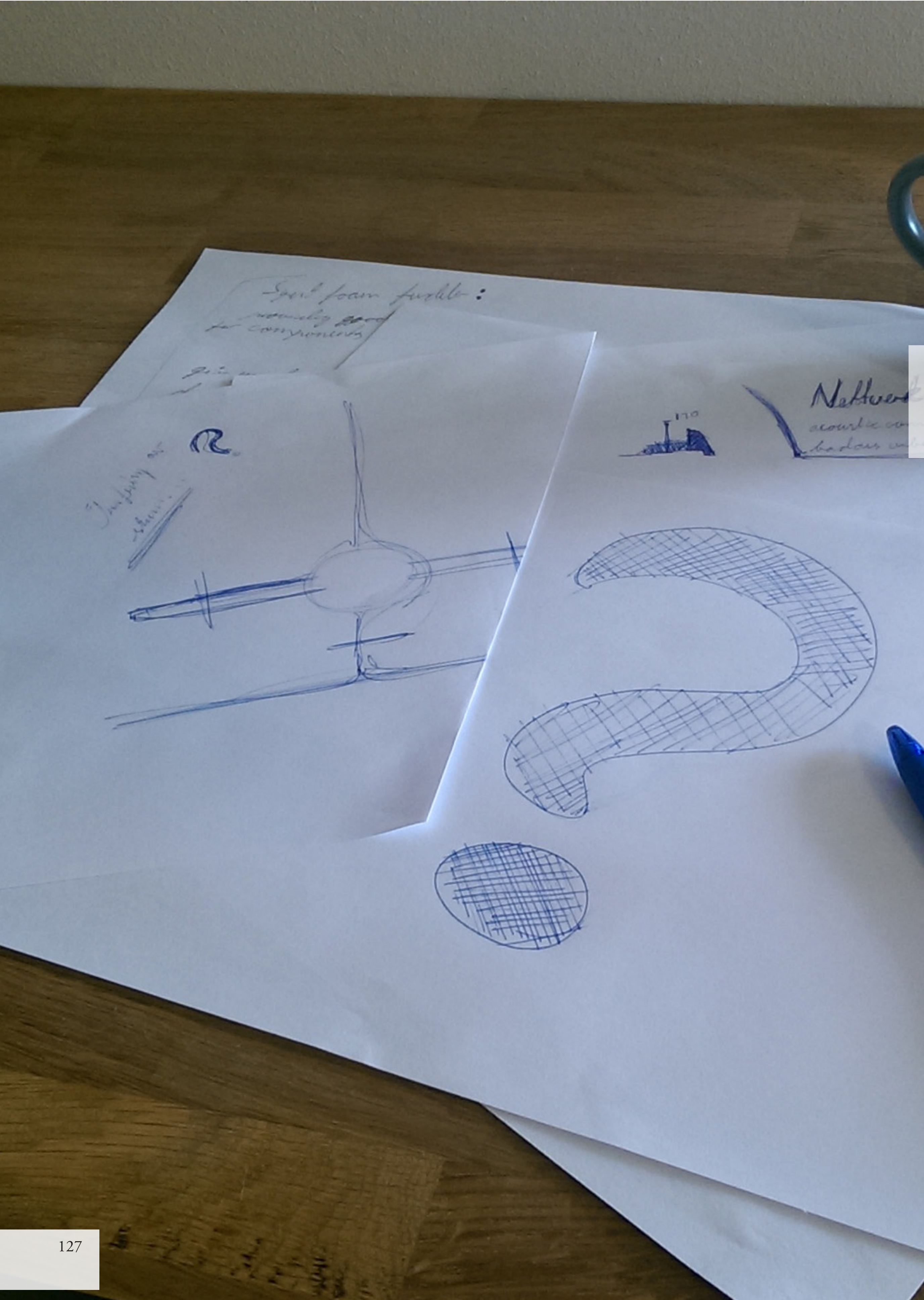


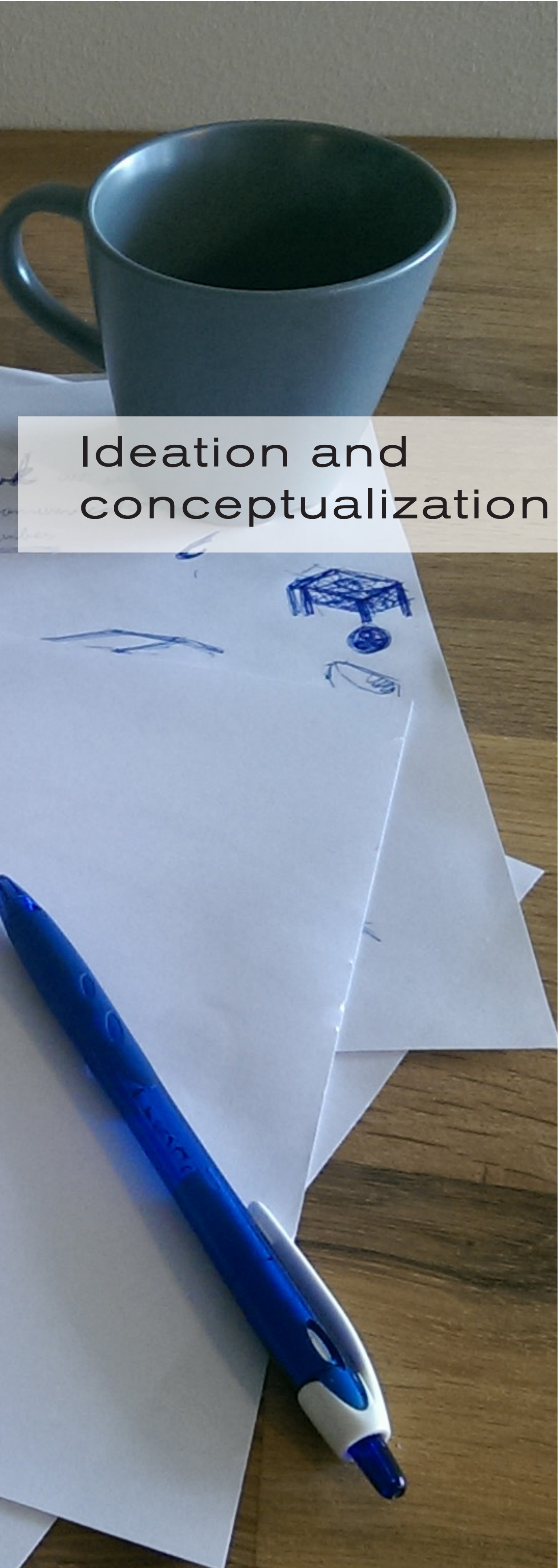
Overtrawlable structures and units give a good impression on the typical criteria for trawl-resistant designs.

Inspiration



Inspiration was also gathered from various other places, here nature and outer space.

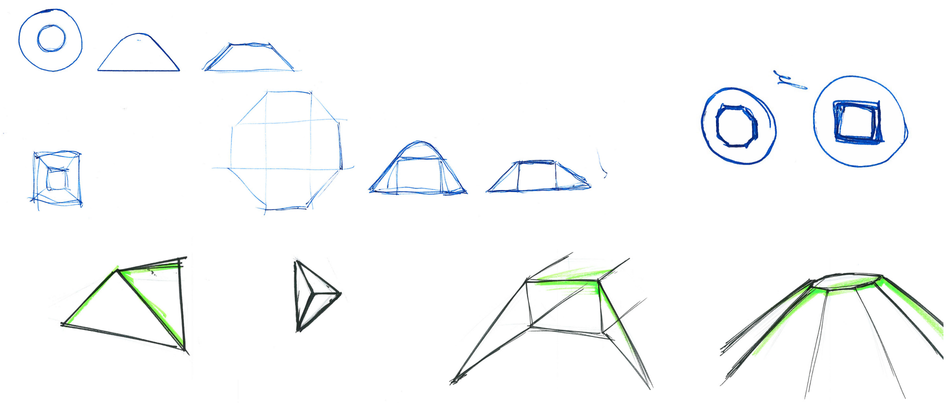




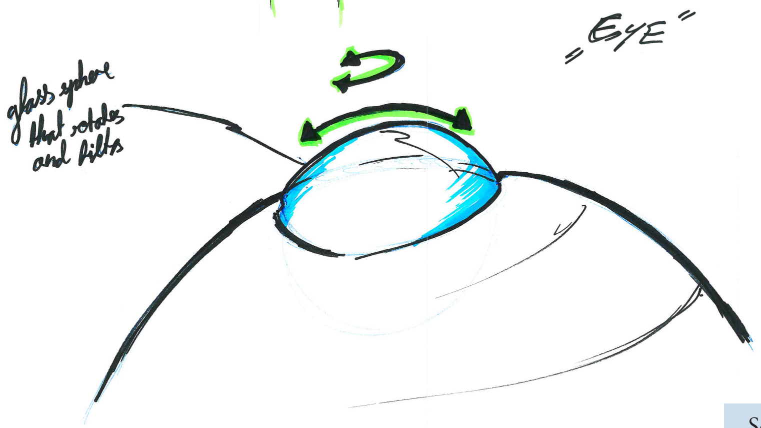
Ideation and conceptualization

This next section will present some of the work and results from the process leading to the development of a final concept.

Early phase



Simple form studies were used to explore possible shapes for the unit

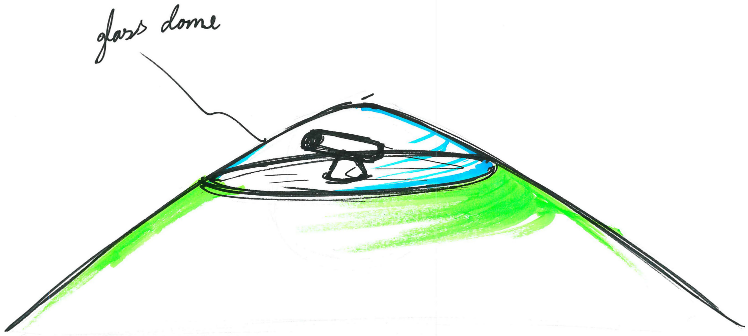


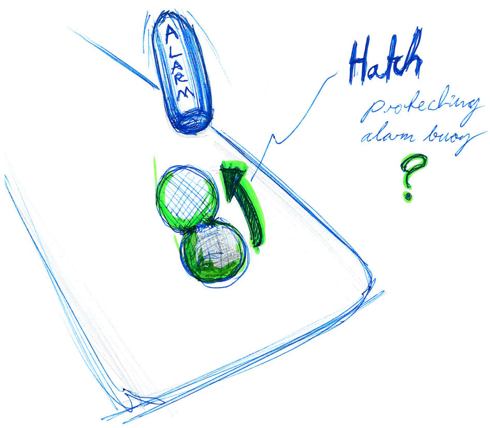
Some experimental ideas were also formed during this stage

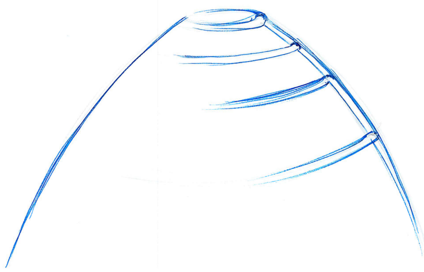
The first part of the idea-generation was mainly concerning the general shape of the surveillance unit, although some solutions for functionality were also explored. Trawl-resistance was considered from the very beginning and consequently influenced the shape and form of the unit. This phase was also somewhat more open since it was not constrained by findings in research.

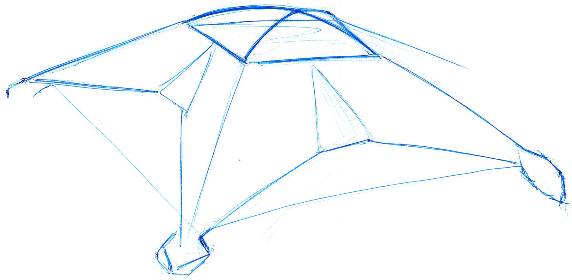

Rope for
recovering
anchor


lifting point
TROLL

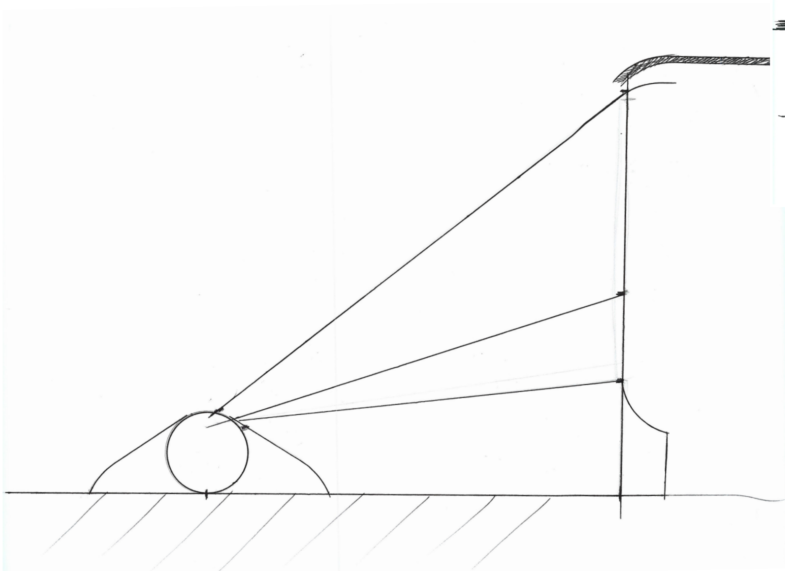

glass dome

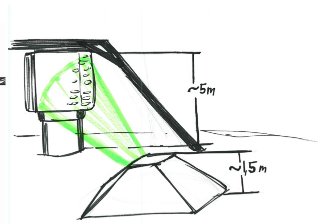

ALARM
Hatch
protecting
alarm buoy
?





Main shape and layout





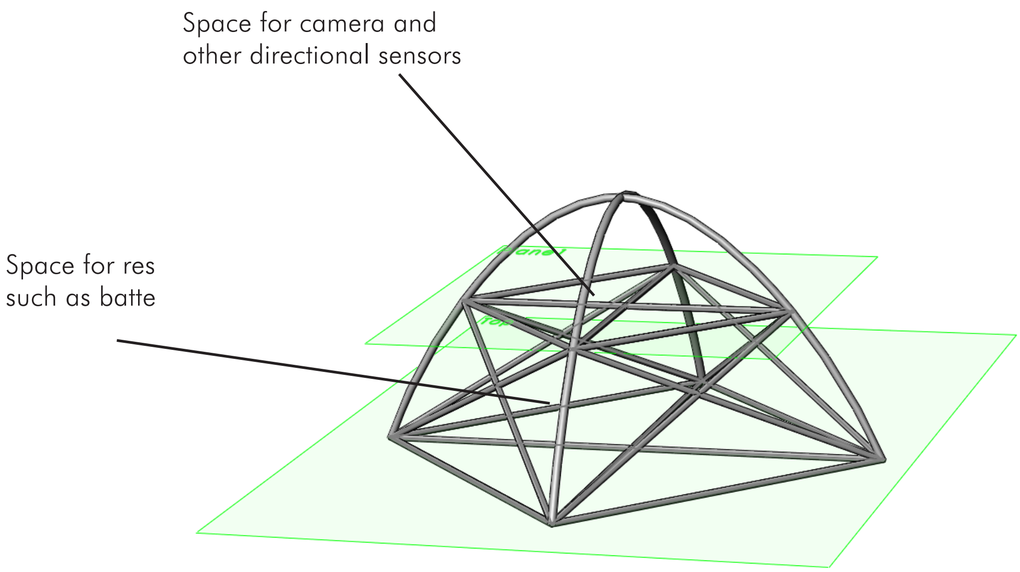
Rough sketches of field of vision for the unit

During the course of the ideation and development process the general shape and layout of the surveillance unit started to take form. The requirements for trawl safety together with positioning and field of view for camera/other directional equipment naturally restricted the opportunities in the design.

A low and wide shape of the unit will in general support overtrawlability. Larger contact surface with the ground and lowered point of mass can further help in handling trawl doors or other gear colliding with the unit, especially if the unit only will be anchored with weight.

Since the unit most likely will have a camera and possibly other directional sensors that need a clear field of view it is important that the design of the unit accommodates for this. Given the low shape of the unit and sight requirements from sensors such camera a pyramidal layout is logical for the unit:

- Camera and other directional sensors can be placed at the "top" allowing for a clear field of view (directing can be done i.e. with a pan/tilt unit) for monitoring and detection.
- Other equipment that does not need a clear field of view such as transponders, echo sounders and alarm buoys can be placed out of the way of the directional sensors.
- Respective components such as battery packs and central processing can be placed at the bottom conveniently away from the other equipment.



Since the unit most likely will have a camera and possibly other directional sensors that need a clear field of view it is important that the design of the unit accommodates for this. Given the low shape of the unit and sight requirements from sensors such as cameras a pyramidal layout is logical for the unit:

Regarding the size of the unit it was decided that it should be in the range of approx. 1.5 meter high and 3-5 meter wide. This should allow:

- Room for necessary sensors and equipment.
- Placing the unit within monitoring and detection range for camera (approx. 10m) and other sensors.
- Comply with requirements regarding overtrawlability.
- Accommodate for the unit sinking into the seabed (max 0.5m).
- Keeping the unit "lightweight" (in terms of offshore appliances) which in turn can help reduce costs with placing and installation.

Selection of self-recovery solution

With the general shape and layout of the unit in place, deciding on which of the two self-recovery methods that were being considered, rope-recovery and syntactic foam, to use became the next necessary step in the development process.

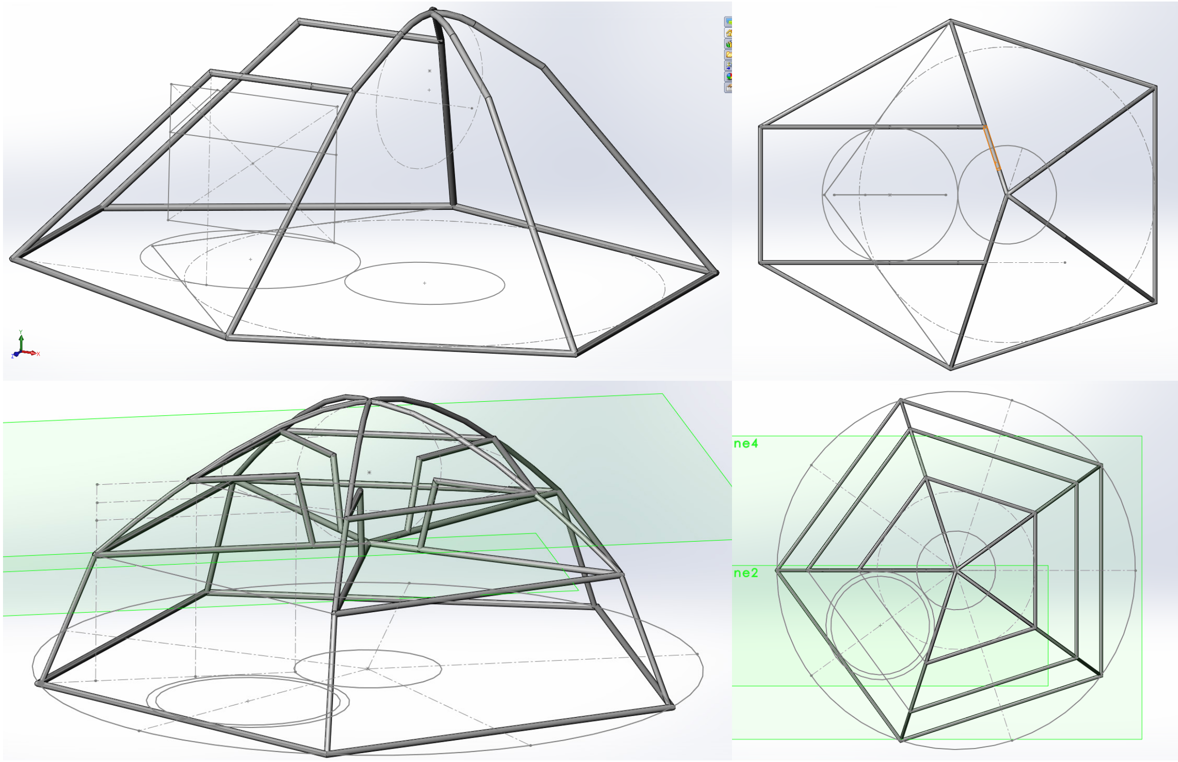
Rope-recovery

With the rope recovery it was incorporating the module itself in the unit which altered shape and design the most. Since placement of camera and other directional sensors should be as centered as possible in the top section of the unit, to avoid problems with positioning the unit, an asymmetric shape or skewed weight distribution is almost impossible to avoid with this solution. Layout and integration of respective components, such as battery packs and central processing unit, could be done very straight forward since there are lots of space for this.

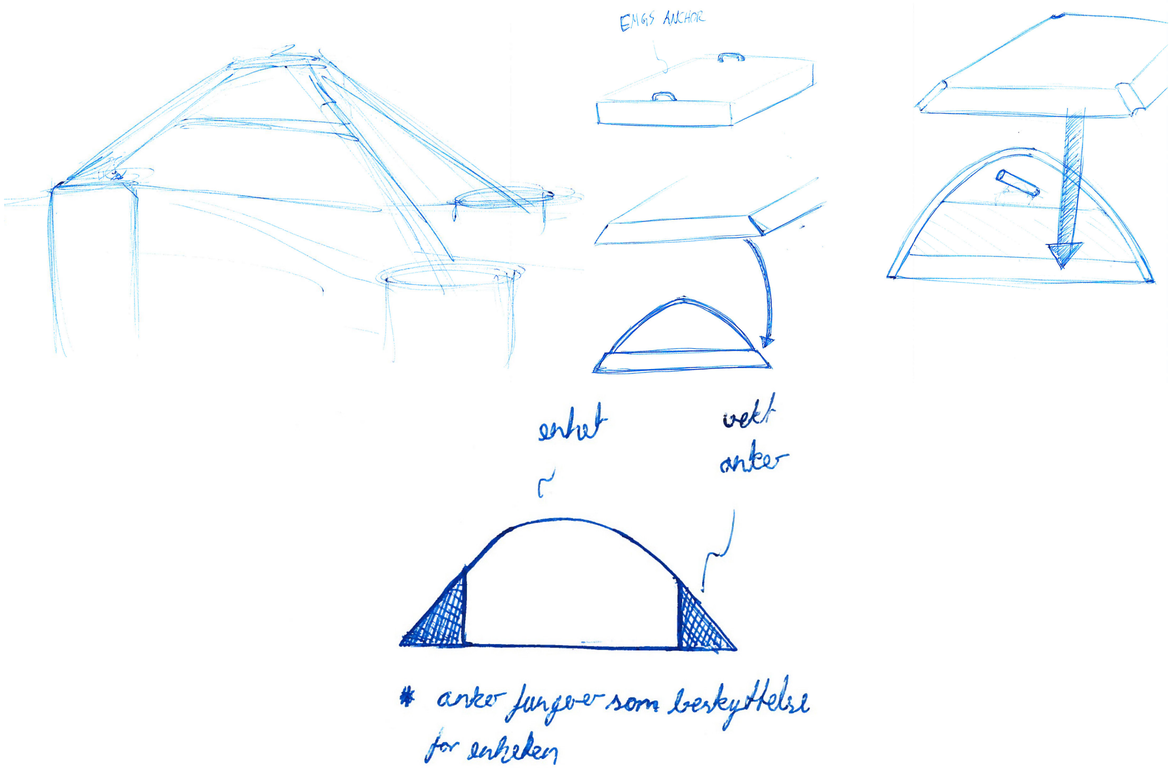
For this solution the rope-recovery module from Kongsberg Maritime was used as basis for visualization and sketching, the module measures approx. 900mm in diameter and 1000mm height.

Syntactic foam

For a solution with syntactic foam the incorporation of the foam in the unit did not stand out as a big issue. It was seen as unproblematic to place the foam in such a way that directional sensors can be centered in the top section of the unit with a free field of view, and respective sensors and equipment can for example be contained in the foam. Counterweight, anchoring and release mechanism were seen as the main challenges for this solution, however, the opportunity of leaving the anchor at the seabed also opens up for other possibilities than just anchoring with weight (i.e. use of suction caissons.)



CAD models exploring incorporation of a rope recovery module



Sketches of anchoring for syntactic foam

Selection of self-recovery solution

Choice

The process with exploration and evaluation of the two recovery methods went over some time and, although syntactic foam already had been discussed during the pre-project and was in many ways the students preferred solution, both options were given a lot of thought. Being a favored solution does not necessarily mean being the best solution and possibilities, advantages and disadvantages had to be discovered and assessed.

The evaluation takes into account potential for further development for the final concept together with possibilities regarding layout of the needed components and equipment of the surveillance unit.

The choice of self-recovery method came relatively easy, although both solutions offer advantages and disadvantages it was decided to proceed with syntactic foam. This solution provides good flexibility and development potential with regards to layout and arrangement of components as well as opening up for use of different methods for anchoring. Even though one was aware of the challenges connected to counterweight and release it was seen as a solution with a lot of potential. Another contributing factor to the choice was also that Kongsberg Maritimes K-Lander does already provide a good option for a leak detection solution with rope-recovery and it was therefore seen as beneficial to take the final concept for Trollhettas solution in a different direction from the K-Lander.

	Rope-recovery	Syntactic foam
+	Cheaper solution compared to syntactic foam Weight of the unit is less limited	Good flexibility regarding design: can be used as building material for the unit holding sensors and equipment Recovery depth only limited by depth rating of the foam Allows for more solutions for anchoring, i.e. suction caisson Syntactic foam is dielectric which is good for holding electrical components
−	Rope length and currents limits recovery depth Rope recovery module must be integrated in the design. Only weight can be used as anchoring	Requires weight optimization More expensive than rope-recovery Requires counter weight Requires release mechanism

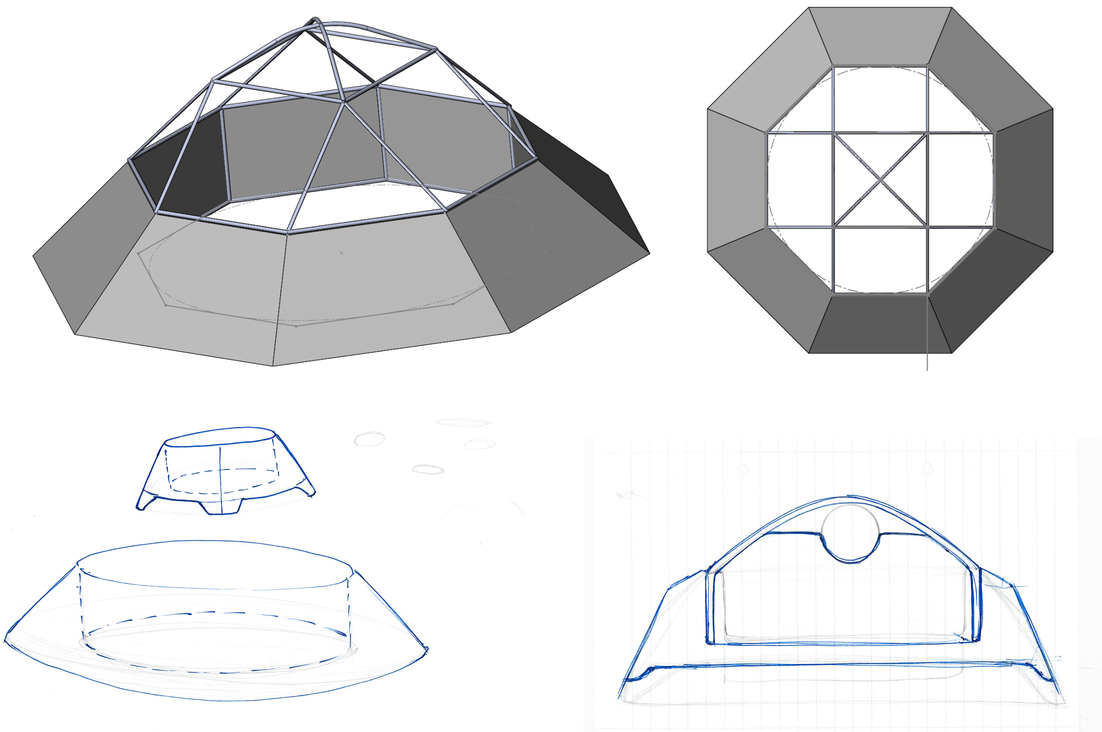
Figure 24: Table displaying advantages and disadvantages for the two self-recovery methods.

Conceptualization

With the choice of syntactic foam for self-recovery the unit would consist of the following components: frame, syntactic foam, release mechanism, anchor, counterweight and alarm buoy together with the remaining sensors/equipment.

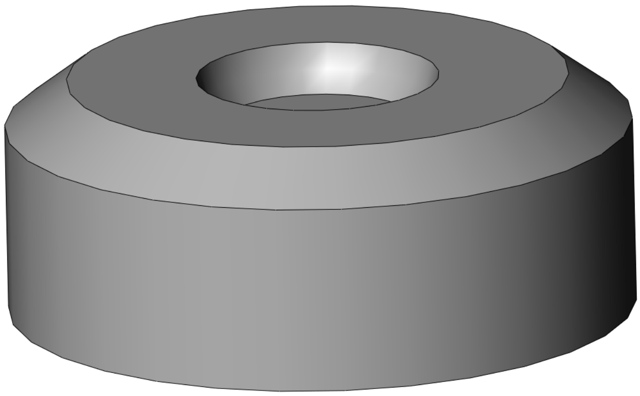
The process with development of a final concept concentrated therefore on combining and uniting these components seamlessly to create a flexible, practical and good solution. Areas which were given particular attention include: modularity and tailorability (both regarding equipment and components of the unit itself), simple use (i.e. construction, installation, deployment and collection) and good abilities of the unit (i.e. good layout for sensors and equipment, overtrawlability and sturdy anchoring).

Placing the anchor/counterweight around the unit



Various sketches/3D models

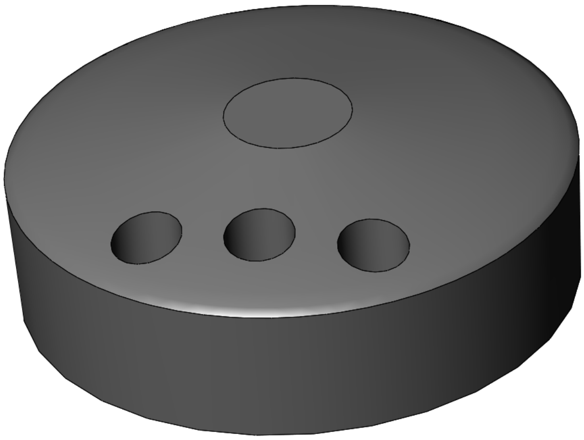
The process which led to the decision of placing the anchor/counterweight around the unit was very intertwined and intricate. In short there was a lot back and forth between different ideas and thoughts and the steps that eventually led to the idea of placing anchor and counterweight around the unit is not possible to arrange in a clear order. Among the main areas that were worked with were calculating the amount of foam needed (to achieve sufficient buoyancy so the unit would float up to the surface) and counterweight/anchoring as well as integration of these components within the previously indicated shape and size of the unit.



3D model used to visualize
the amount of foam needed

Calculating amount of syntactic foam

It was already known that choosing syntactic foam would require weight optimization of the unit. With the buoyancy of syntactic foam being approximately 0.5 kg (this depends on depth rating and quality of the foam) per liter it was clear that one would end up needing a relatively large amount of foam to achieve sufficient buoyancy for the unit to float up to the surface. This could affect the size of the unit to some degree, although, the indicated size if the unit (see main shape and layout) should be able to accommodate for a relatively large amount of foam.



3D model used to visualize the amount of foam needed, here with holes for alarm buoys

Initial estimations

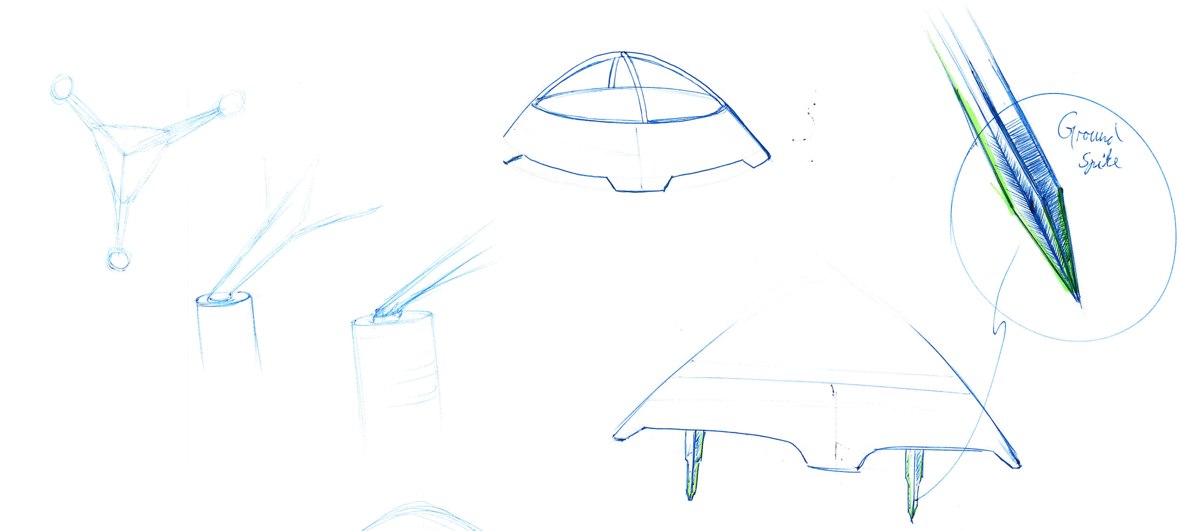
The initial estimations where very rough and mostly based on own assumptions. Exceptions were the weight of the battery pack, which was discussed during one of the interviews with Martin Ludvigsen, and some information about sensors and equipment which was found on the internet.

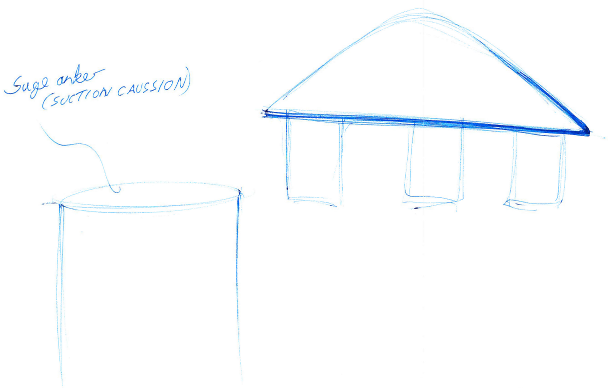
Early weight estimation	
Component	Weight in water
Other components/equipmet	100 Kg
Battery pack	300 Kg
Frame	150 Kg
Total	550 Kg

Figure 25: Initial weight calculations.

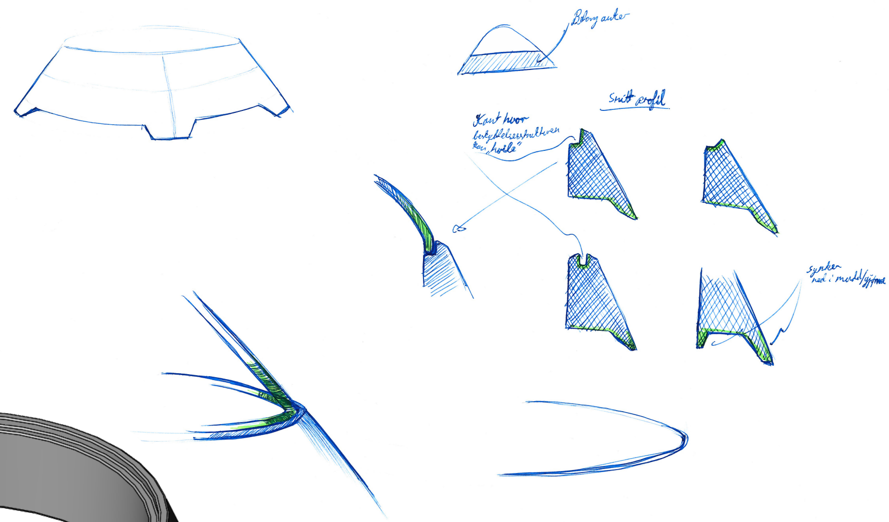
As seen from the table it was estimated that the unit would weigh around 550kg, this equals approximately 1,1 m^3 (1100 liters) of syntactic foam to make the unit neutrally buoyant in water. To ensure that the unit will float to the surface more buoyancy is needed and it was therefore decided to continue using 1,5 m^3 as a temporary estimation of syntactic foam needed. This was the volume of foam needed for making the unit self-raising, however, if components such as battery packs and central processing unit were to be contained inside the foam this would further add to the size of the foam modules.

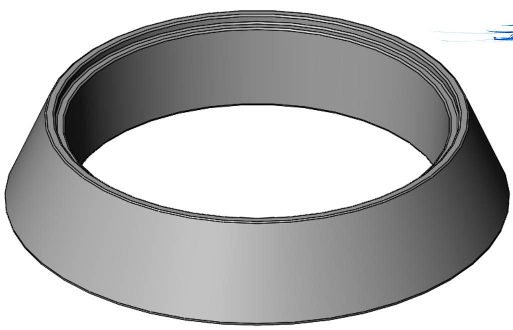
As the project proceeded and more was made clear, especially after the visit in Horten, it became possible to refine the estimations of weight, volume of components and needed volume of foam.





Different solutions regarding anchoring were thought of, here suction caissons and ground spikes





Exploration of cross section of anchor.

Anchoring

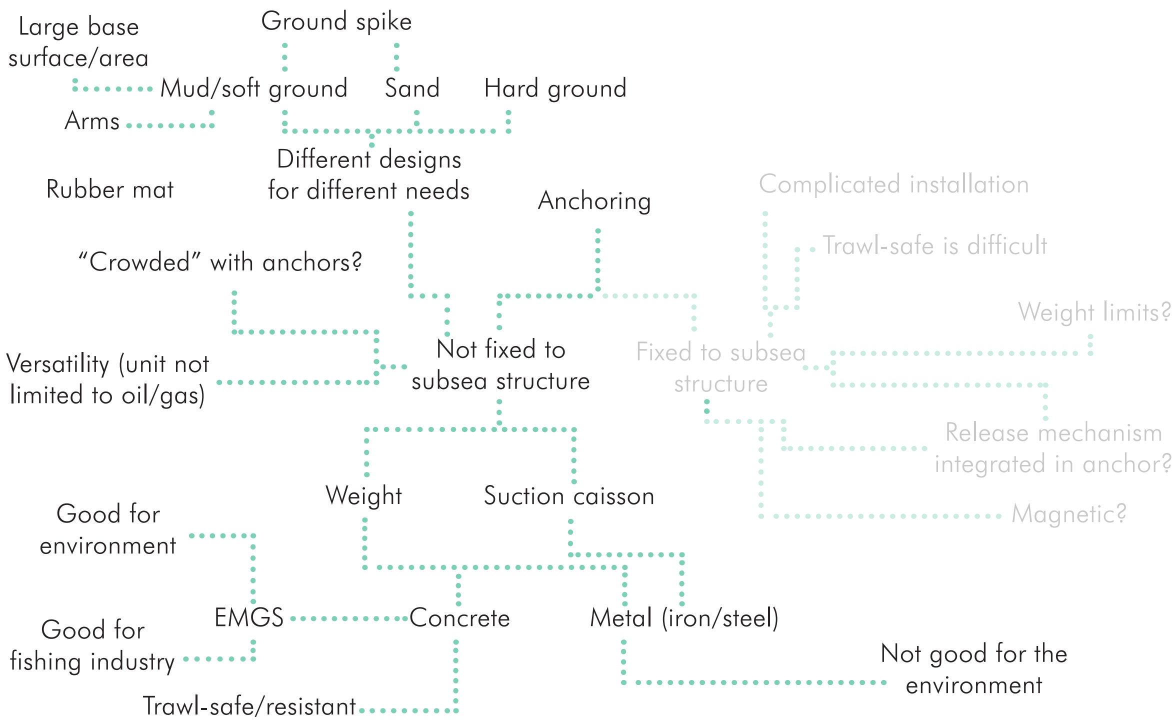


Figure 26: Mind map used to get an overview over different points concerning anchoring.

Sufficient anchoring of the unit to the seabed is essential to ensure good operational properties for the surveillance unit. Any movement or displacement of the unit may disrupt or prevent the sensors from gathering valuable and critical information and must be avoided as far as possible. Concerns regarding anchoring have especially been related to movement due to underwater currents and sinking down in the soft seabed. Also the question of if it is okay to leave something at the seafloor was taken up, both from an ethical point of view and for the reason that it may be impractical or not even permitted by the oil company to leave something behind at the deployment site.

Picture 39: The concrete anchors EMGS use for their seabed receivers are more or less just square slabs of concrete.

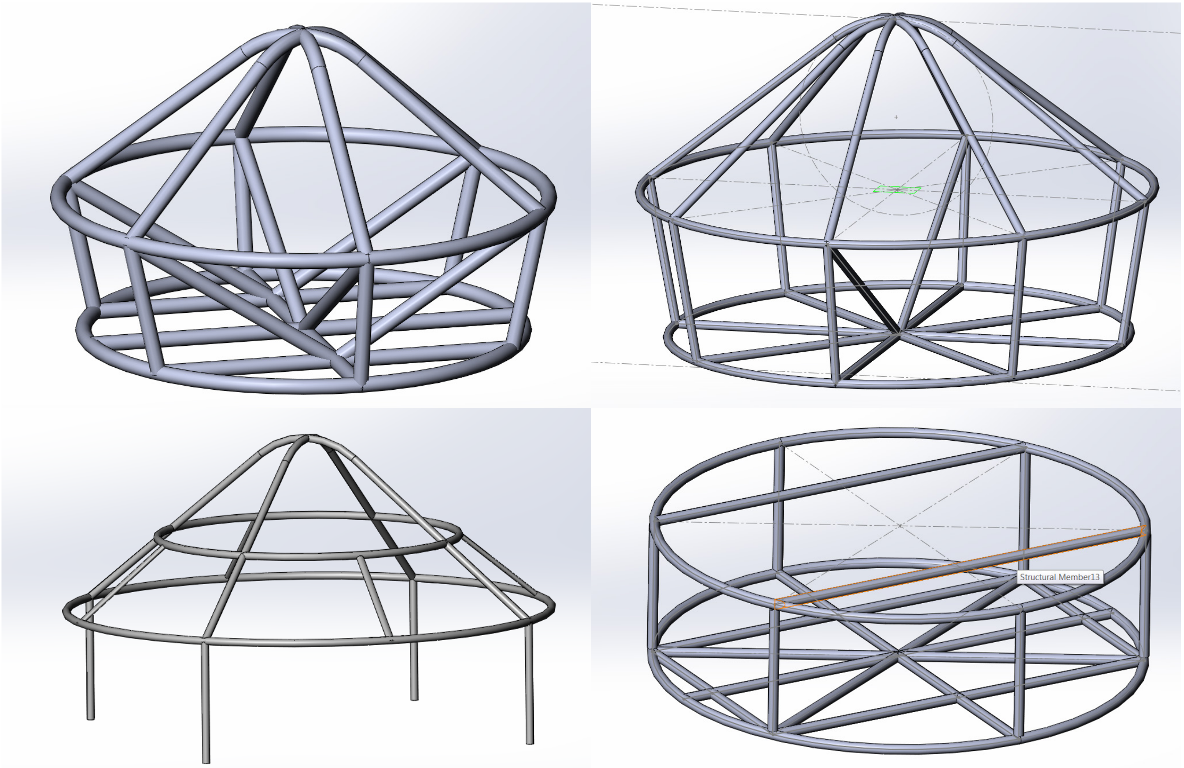
Concrete for anchoring

The meeting with Audun Sødal at EMGS inspired to further investigate concrete as a material for the anchoring and counterweight. Concrete is very suitable for these tasks since it is a very malleable material which in addition is strong, dense and inexpensive. The possibility to use the concrete from EMGS will also contribute to leaving a smaller imprint on the environment as well as offering a fail-safe option for retrieving the unit, i.e. if the release mechanism should fail.

The decision to place the anchor/counterweight around the unit was motivated by the following reasons:

- This would allow maximizing of the vertical space of the unit, i.e. to accommodate for components that need to be vertically oriented in the unit such as the transponder and the alarm buoys.
- It allows the counterweight to be used as protection and shielding for the unit, this protection would otherwise have to be part of the frame of the unit and thus add extra weight to the unit.
- It allows a seamless integration of the unit with the anchoring.
- Using concrete as material for these anchors would provide a sturdy and heavy base for the unit. This would affect trawl-resistance for the unit in a positive way and in addition be cheap solution which also would satisfy the requirements of easy, low-cost installation.

Frame



It was experimented with some different variations of the frame, mostly with regards to dimensioning and number of beams. ISO standard piping dimensions were also used for the 3D modeling since it is likely that the frame will be made of ISO piping.

Frame

The frame will hold the whole unit together. It will also play a big part in protecting and shielding components and equipment from for example trawl gear, and it has to be strong enough to handle lifting and hoisting the unit in and out of water at the same time has it has to be relatively lightweight to comply with the weight optimization required for buoyancy.

With the decision to place the anchor around the unit was made it guided the development of the frame in a certain direction, it lowered the requirements for sturdiness of the frame and it was possible to make it somewhat smaller in width.

During the early work with design of the frame one concern was that designing the frame so that it would support the weight of the heavy concrete anchor when handled before and under installation could result in an unnecessarily large hand heavy frame and it was decided to see if the unit rather could be lifted by the anchor.

Key points that were considered when working with the frame were:

- Sturdiness and weight optimization
- Space and field of view for leak detection sensors
- Space for foam modules

Release mechanism

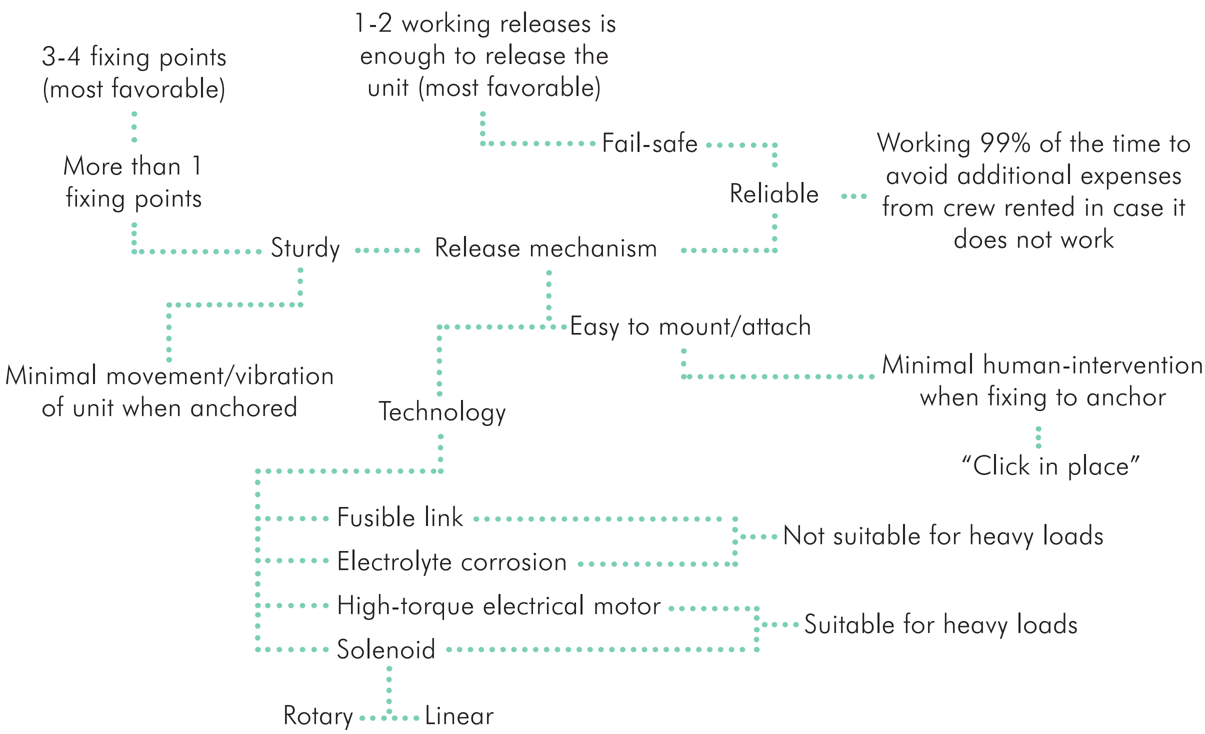
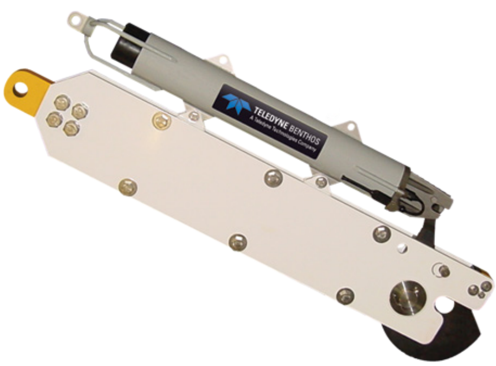
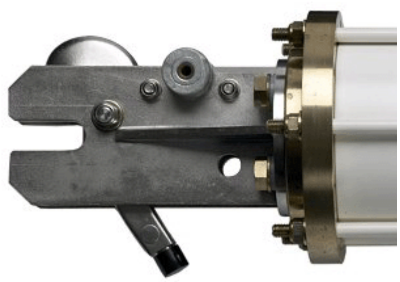
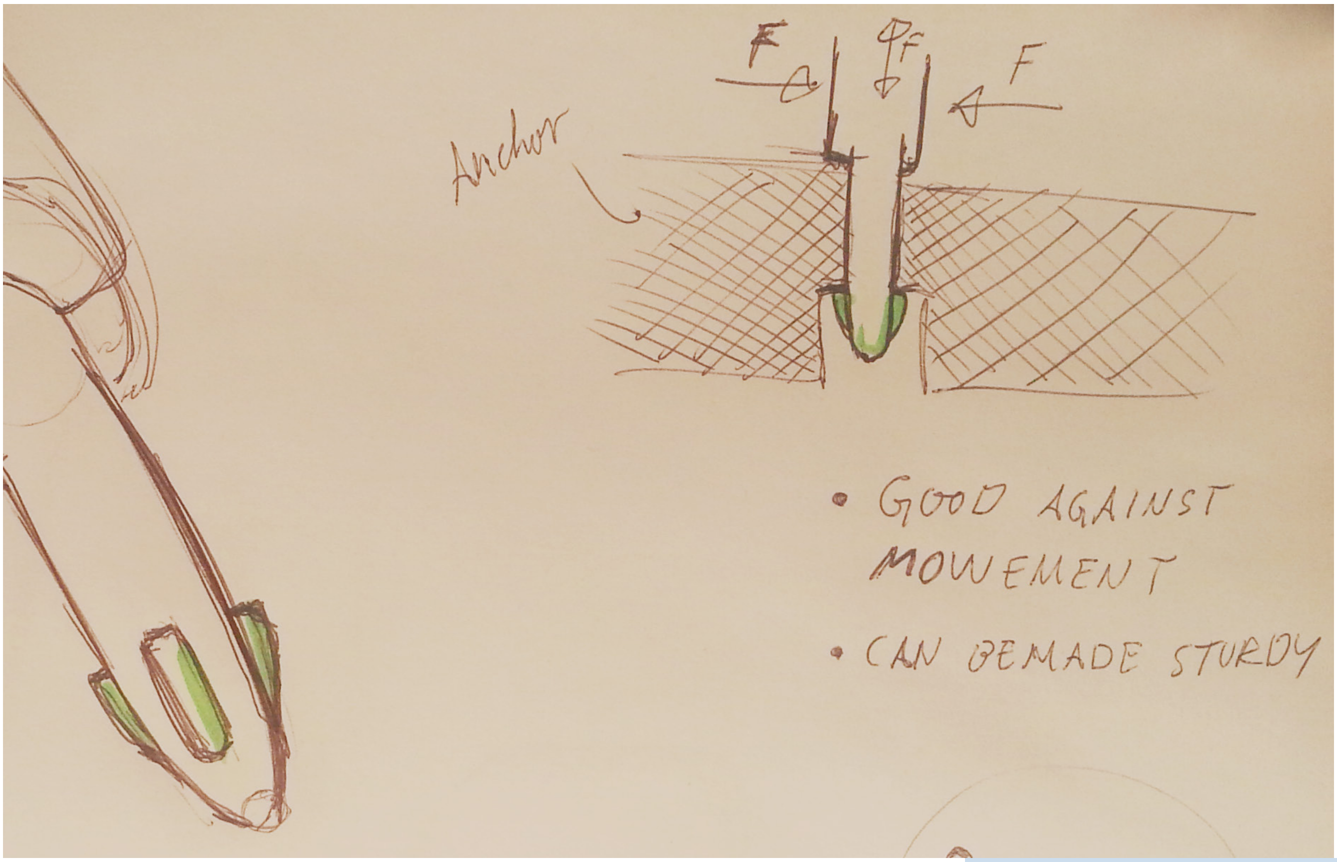


Figure 27: Mind map used during the work with the release mechanism.





Picture 40 and 41: Typical release mechanisms found for subsea use, the smaller versions are designed to hold and release for example moored buoys and the larger heavy duty releases are designed for deployment of underwater constructions etc.



Sketch of locking dog release

One was for a long time hoping to find an existing release mechanism that would be suitable for the surveillance unit but the problem is that most commercially available mechanisms are designed with different use in mind. It was for this reason decided to look into developing a concept for a specially designed release mechanism that would fulfill the requirements from the unit.

The most important points when looking at the release mechanism is that it has to be able to hold the unit safely in place during the deployment time and provide very reliable releasing, it should also be easy to connect to the anchor, preferably "click in place". It should minimize movement of the unit (i.e. shaking from underwater currents etc.) and it must handle potential impacts (i.e. from trawl gear).

Locking dogs

Designing a release mechanism which uses locking dogs as seen in the sketch above would solve many of the aforementioned concerns:

- It will provide good stability in all directions
- It is possible to make it very sturdy to easily handle the weight of the heavy anchor or impact i.e. from trawling activities
- "click in place" is easily managed with this solution, which greatly simplifies fixing the unit to the anchor

Some concerns with this solution were if this solution would be able to hold in the concrete since it leaves relatively small margins (a matter of millimeters) for the locking dogs to have a grip or not.

Alarm buoy

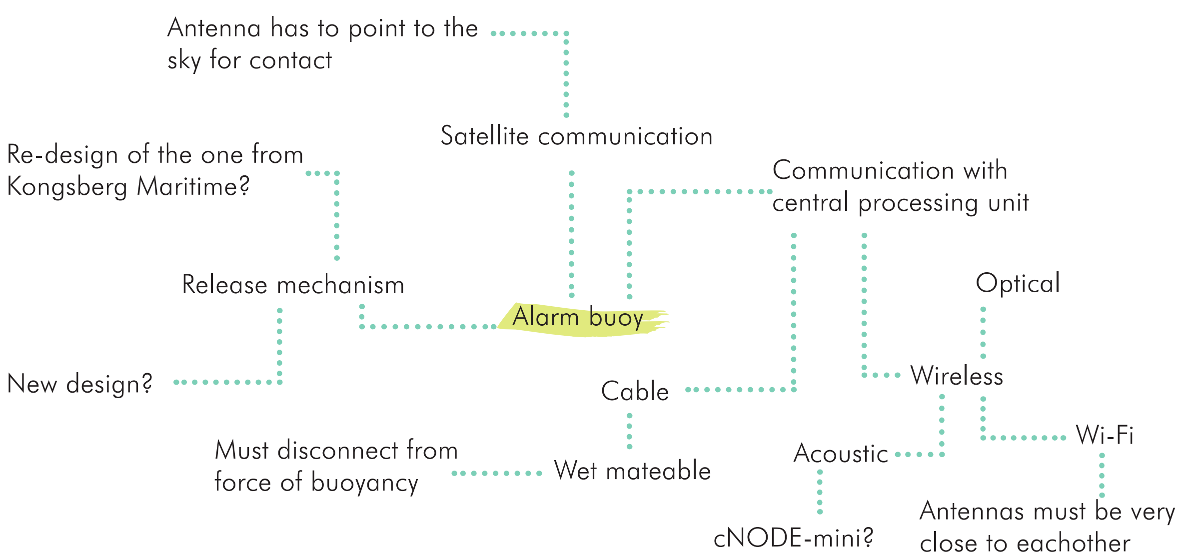
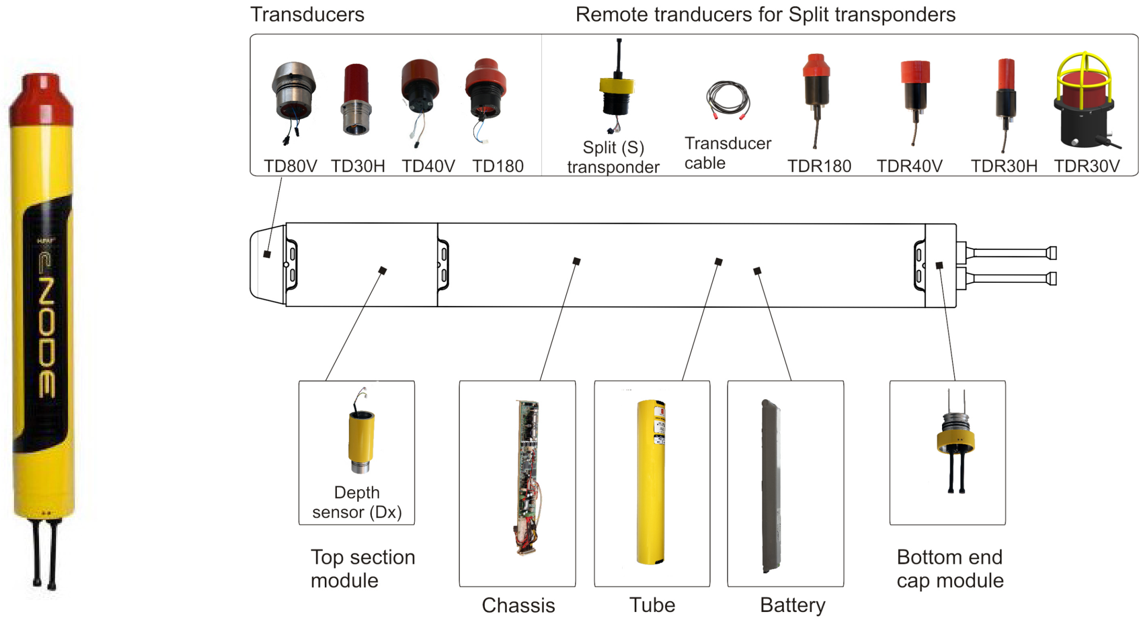


Figure 28: Mind map with an overview of different challenges and possible solutions for the alarm buoy.

As stated at the beginning of this report it was not planned to develop a concept for the alarm buoy, but rather leave this to a collaboration partner of Trollhetta. This was seen as both a necessity and an advantage, apart for the fact that it would probably not be possible to include a ready-shaped buoy in the final concept design of the unit. During the course of the project it became clear that the contacted company, Fugro, did not wish to undertake the task with developing the alarm buoy. This was not a large problem during the early phases of ideation and concept development for the surveillance unit. However, as the concept development moved towards a more final solution it became increasingly difficult to leave such an important part without at least a tentative shape/design.

A possible solution?

It was already assumed that Kongsberg Maritime will deliver a large part of the sensors and equipment for the surveillance unit, and a part of that equipment is the cNODE mini transponder. As previously explained the cNODEs are built in a modular way. This means that in essence it is a ready pressure-housing where it is possible to incorporate whichever electronics that one can make fit, which could be exactly what is needed for the alarm buoy. It was decided to take this up during the visit with Kongsberg Maritime to see what they would think.



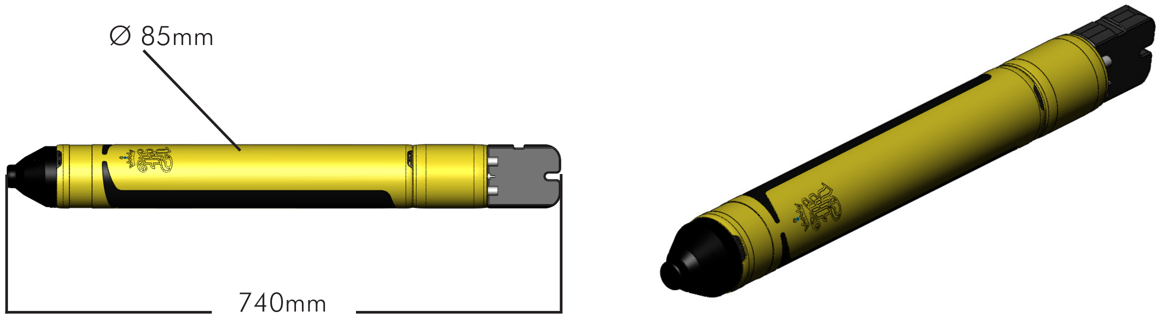
Picture 42: cNODE mini and its components

The alarm buoy - cNODE mini sattelite hybrid

On the visit to Kongsberg Maritime it was concluded that, in theory, it is possible to use parts from the cNODE-mini to build the alarm buoy, one would then need to design a suitable floating collar together with a release mechanism (since this does not exist for cNODE-mini). Still there would be a problem with communication between the buoy and the central processing unit, one possible solution would be to use a watermateable connector and rely on the pull from the alarm buoy to be enough disconnect the cable on release. A better option however, would potentially be to do some changes to the cNODE-mini and incorporate a satellite antenna together with the transponder technology, this way one can have wireless communication with the central processing unit (since one transponder will be permanently connected to the unit for communication, i.e. to send release signal on collection).

Disclaimer:
The solutions building on proprietary technology to Kongsberg Maritime presented in this master thesis are purely based on theoretical possibilities. In no way do these solutions guarantee consent for collaboration/use of these products. This is a matter left up to the respective company and Trollhetta AS.

Alarm buoy



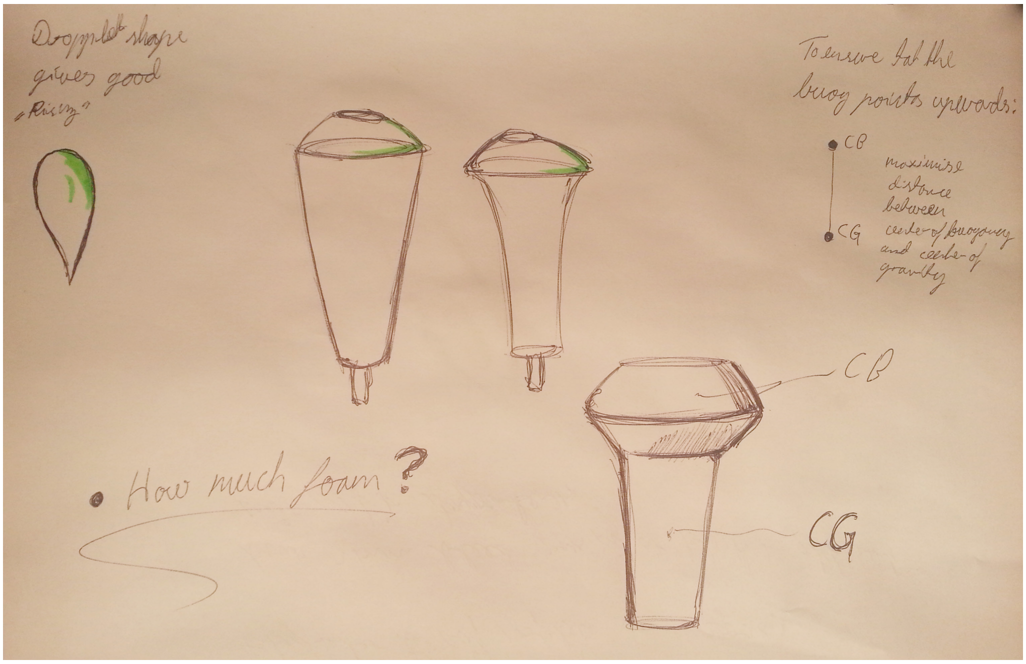
Mockup of the cNoDE mini satellite hybrid with re-designed release mechanism.

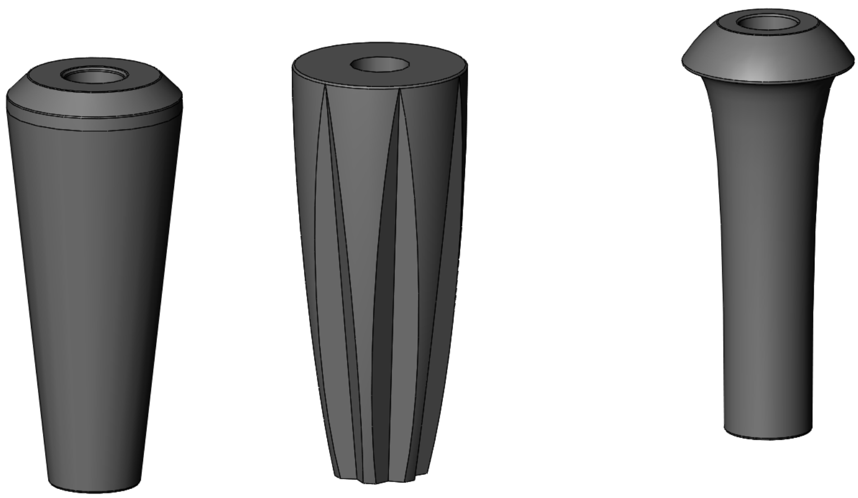
Floating collar and release mechanism for the alarm buoy

Weight is again important when designing the floating collar and to reduce weight one idea was to let the release mechanisms be integrated in the unit rather than in the alarm-buoy. This option would, however, call for a complete new design for a release mechanism and it would further complicate the design of the unit and the choice fell on a re-design of the existing cNODE release mechanism. The existing mechanism is relatively heavy duty compared to what is needed for the alarm buoy (safe working load is 500 kg), so it should be possible to reduce weight and size considerably for a proposed re-design (current weight is not known since it was not possible to obtain). The weight of a cNODE-mini in water is approx. 3,5kg (this is a normal option with aluminum body with a depth rating of 4000m and no add-on equipment) and it is feasible to assume that a cNODe- satellite hybrid with a release mechanism will weigh approximately 6 kg in water. This laid ground for calculations of amount of foam needed for sufficient buoyancy for the alarm buoy.

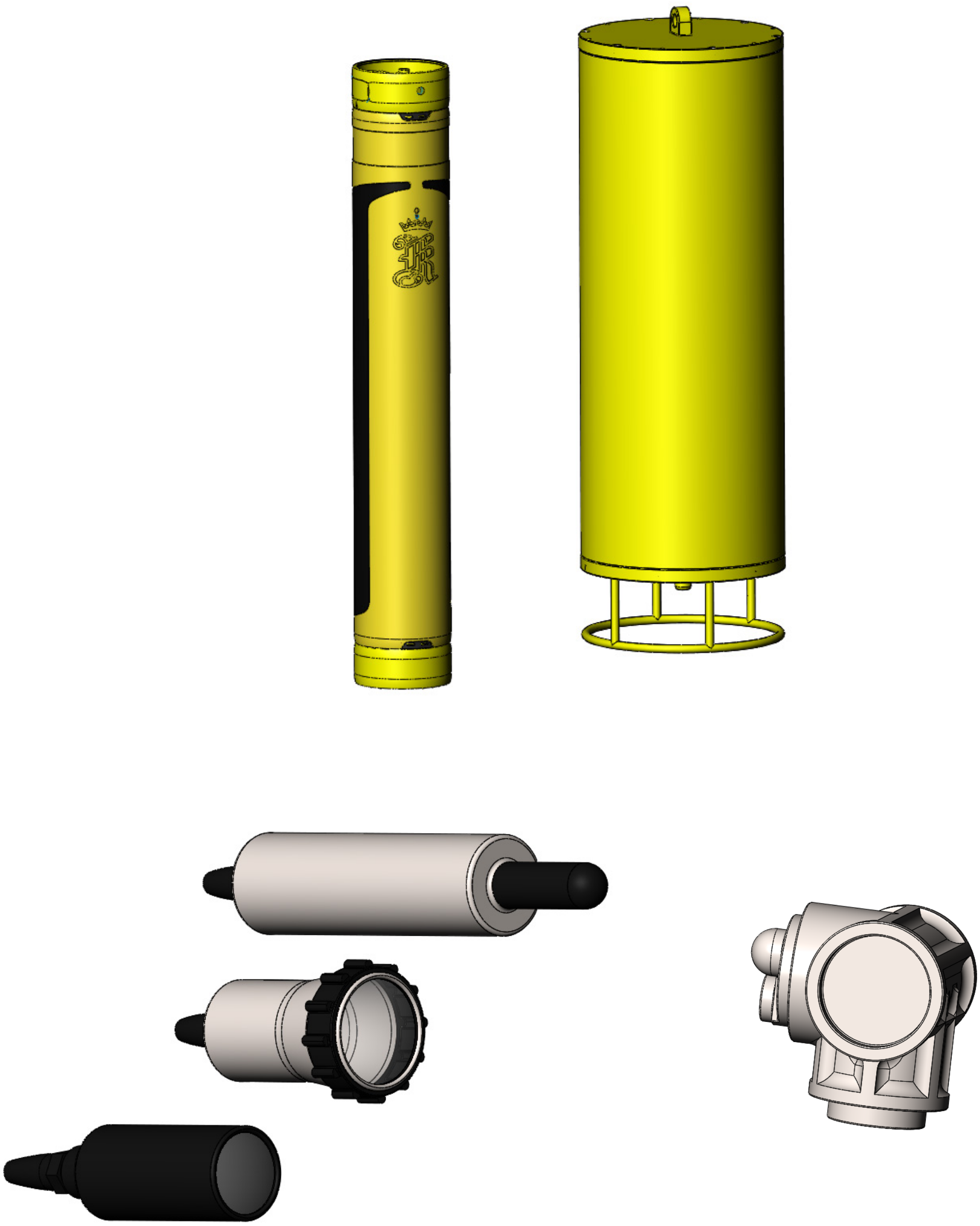
Regarding the design for the floating collar for the alarm buoy main considerations were:

- When at the surface the buoy will have to point upwards enough to allow satellite the satellite signals to be sent, this means that it is necessary to maximize the distance between center of buoyancy and center of gravity for the buoy.
- Constraining the volume of the buoy/floating collar so it easily can be integrated in the unit.
- Making sure the buoy will have good properties for rising to the surface, i.e. sufficient buoyancy and shape promoting straight travel way up to the surface.





Exploration of different shapes for the floating collar



As information regarding the different equipment and sensors became clearer mockups were made and used during the development process. Here are the cNODE battery pack, IEM hub (central processing unit), camera, flash, hydrophone and pan & tilt unit.

Final calculations of weight of sensors and equipment

As the development process carried on one got a more realistic picture of what one could expect regarding weight, especially for the components which were self-developed, and it became possible to do a more precise estimation of the total weight of equipment for the unit.

For the special solutions possibly provided by Kongsberg Maritime, i.e. battery packs and IEM hub, this was clarified during the visit in Horten and later via email. For equipment that is not provided by a supplier, or where it has been too difficult to procure information about, still relatively rough estimations have been done, although, for the parts designed during the project volume and weight calculations in SolidWorks has aided in these estimations.

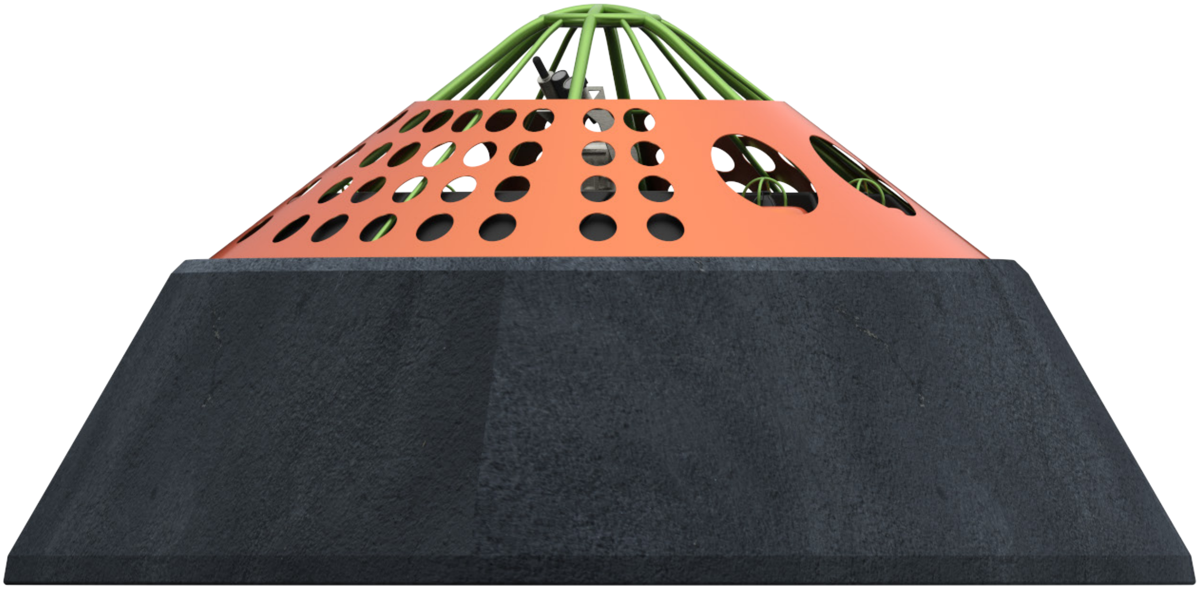
With these final weight estimations it was possible to decide on amount of amount of foam needed and it turned out that the initial estimation of 1,5m^3 would provide sufficient buoyancy even for a fully equipped unit.

Weight estimation

Component	Weight in air		Weight in water	
Central processing unit	165 Kg	**	145 Kg	**
Battery packs (cNODE) x 12	408 Kg	**	300 Kg	**
Pan/tilt	10,6 Kg	*	8,6 Kg	*
Camera (OE14-376/377)	0,37 Kg	*	0,21 Kg	*
Flash/floodlight (OE11-135)	0,38 Kg	*	0,21 Kg	*
Hydrophone (icListen)	0,96 Kg	*	0,6 Kg	*
cNODE- alarm hybrid x4	60 Kg	***	0 Kg	***
Echo sounder WBAT	25 Kg	**	12 Kg	**
CTD	12,5 Kg	*	7,4 Kg	*
ADCP	11,5 Kg	*	5,2 Kg	*
Release mechanism - frame	45 Kg	***	45 Kg	***
Release mechanism - alarm x4	20 Kg	***	20 Kg	***
Cables etc.	30 Kg	***	30 Kg	***
Frame	200 Kg	***	180 Kg	***
Total approx.	990 Kg		745 Kg	

* Values found in data sheets
** Values provided by Kongsberg Maritime
*** Values estimated by the student.

Figure 29: Table showing the final weight estimations.

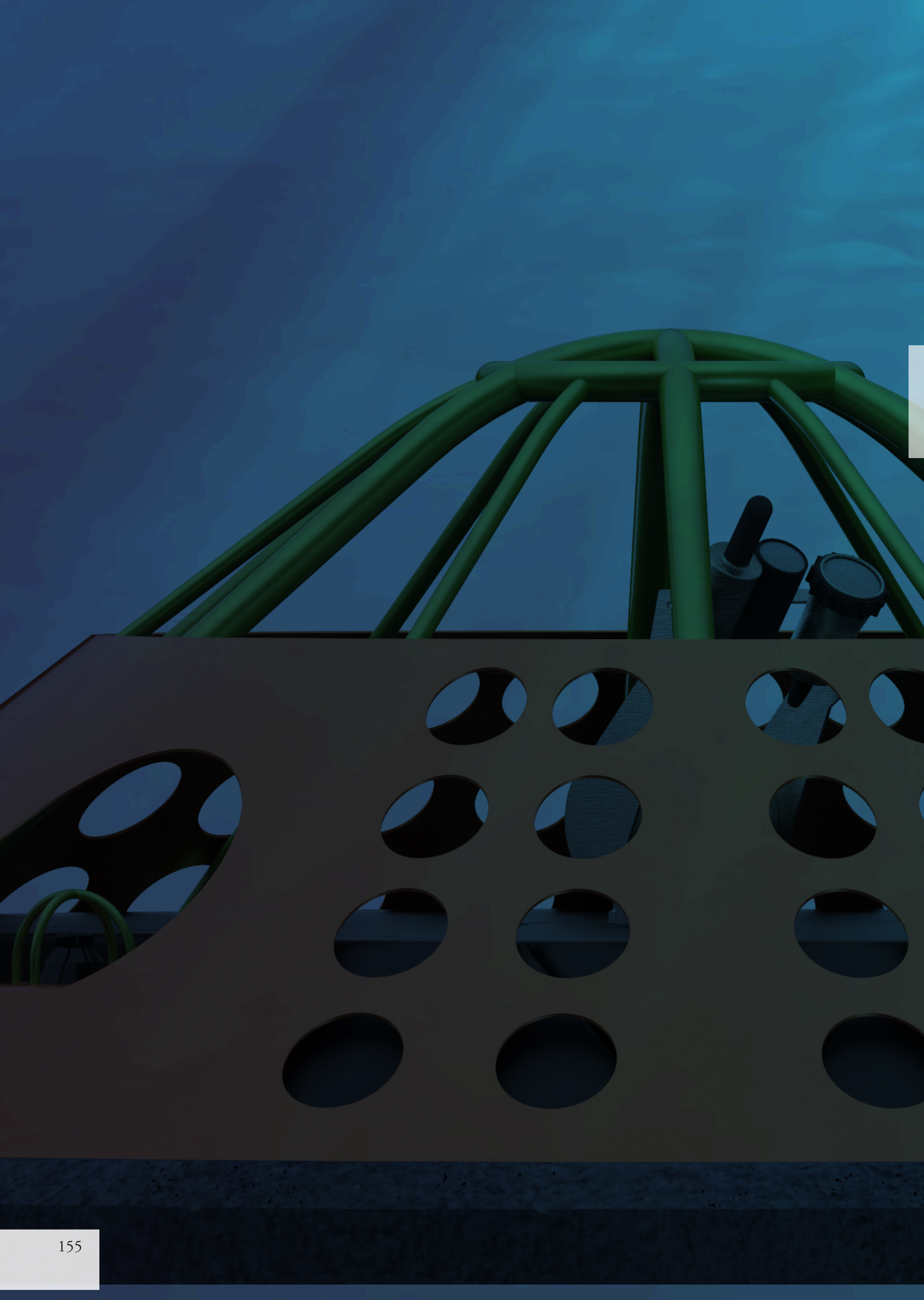


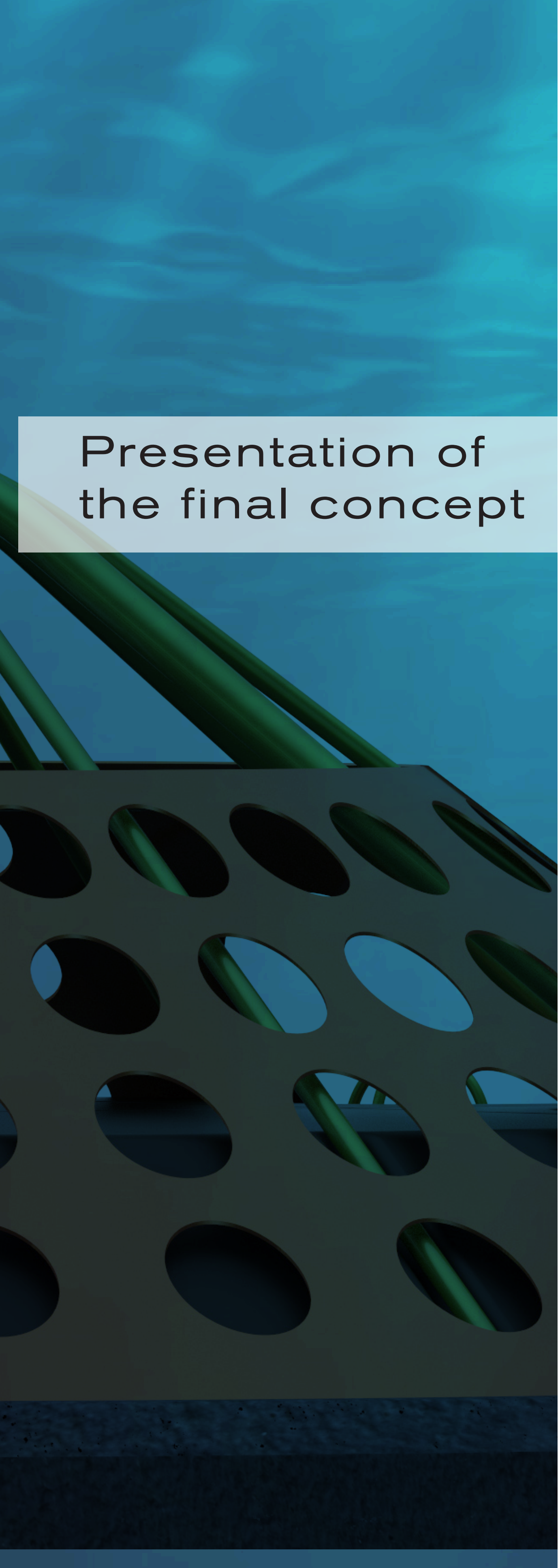
3.3 Final Concept

Presentation of the final concept

Evaluation of the final concept

Concluding stage





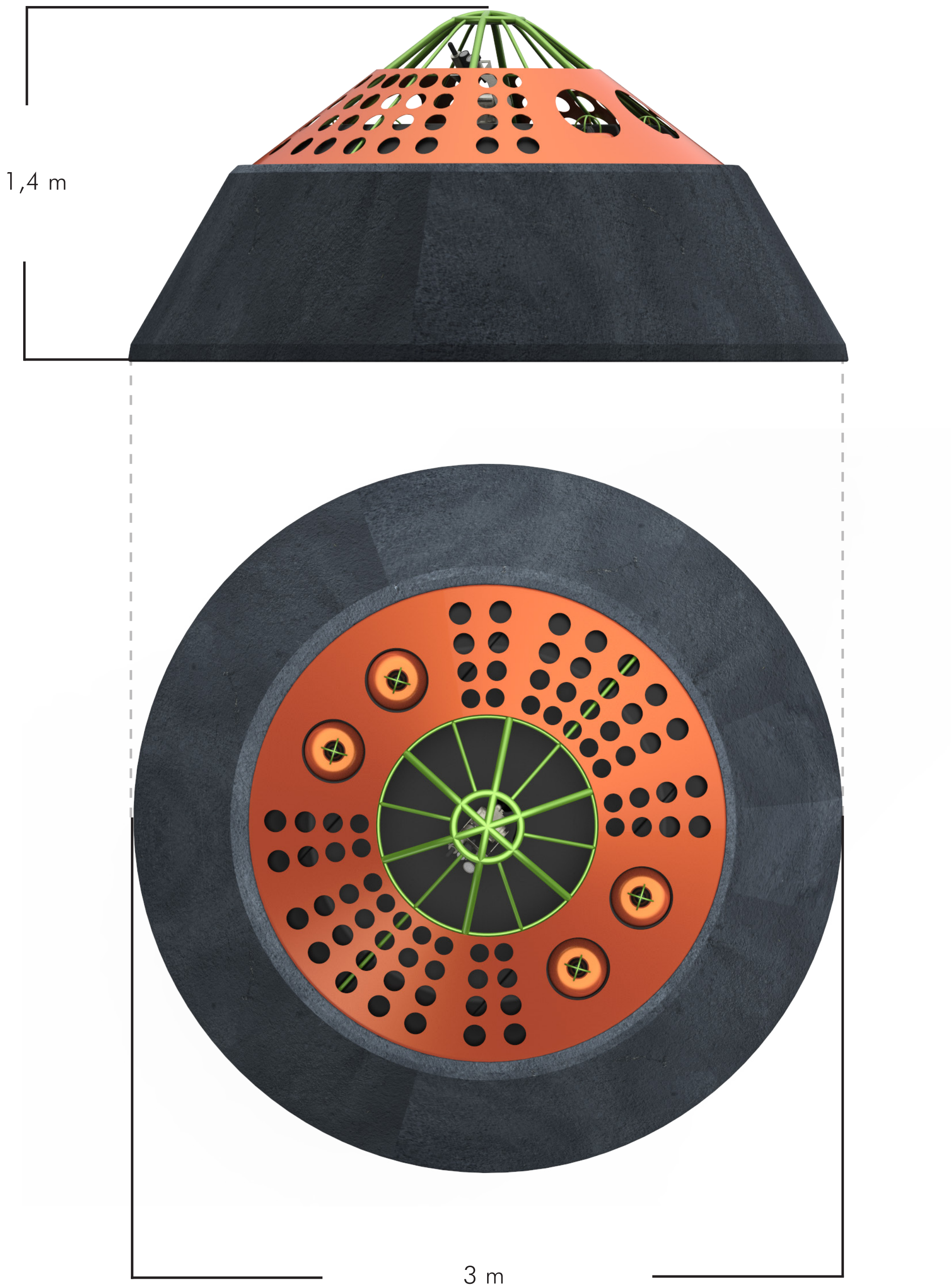
Presentation of the final concept

TROLL

A W L D

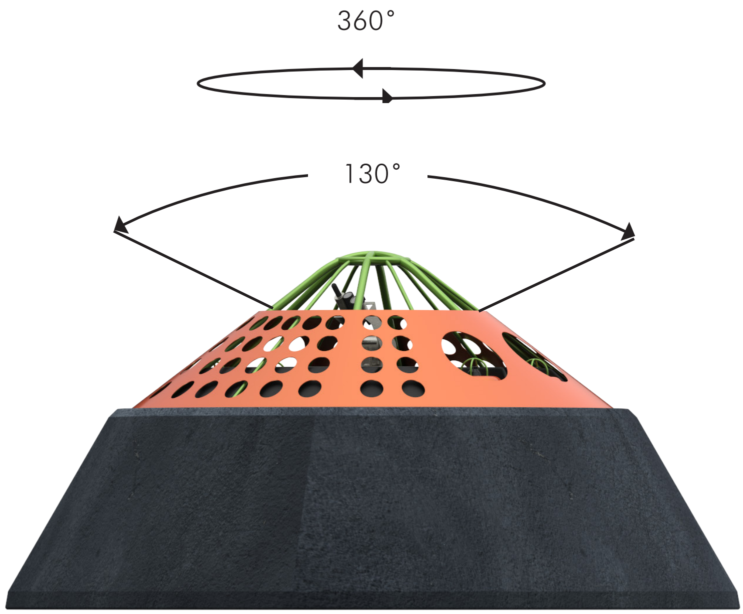
Autonomous wireless leak detection unit

- Standalone unit with up to one year deployment time
- Suitable for deployment also in remote locations
- Non-intrusive leak detection technology
- Easy installation and recovery
- Possibility for customizing sensor package to customer needs
- Robust and trawl resistant design

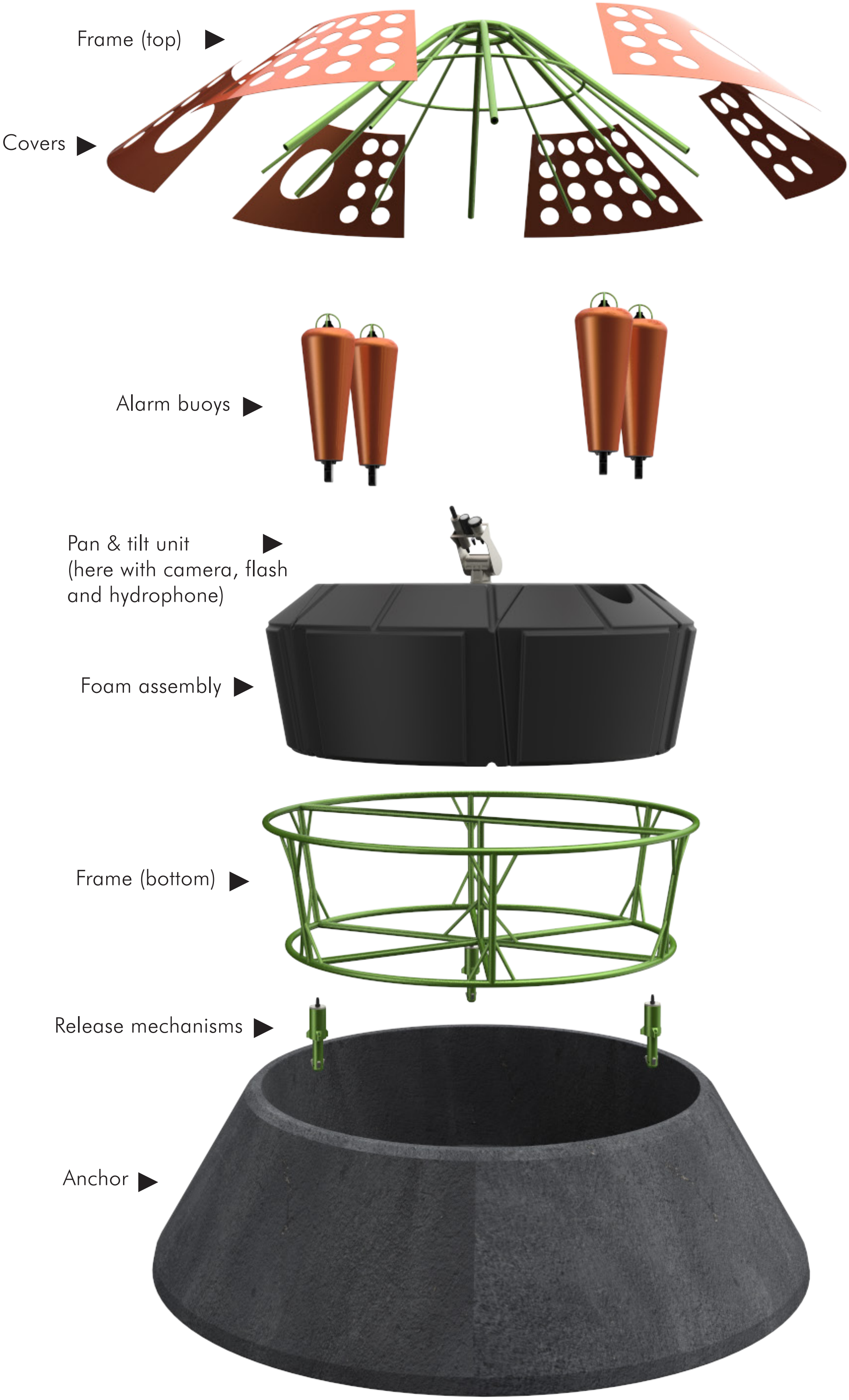

1,4 m
3 m

Size, shape and field of view

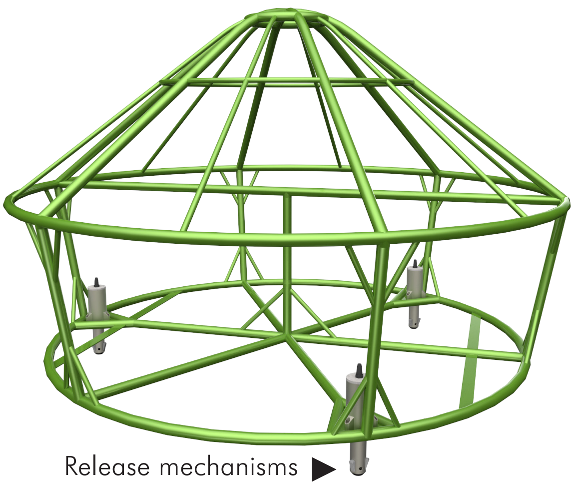
With a height of 1,4 m and width of 3 m the final size and shape of the unit are well within the criteria set down for overtrawlability and possibility of the unit sinking into the seabed. The relatively small size of the unit gives it good flexibility for placement at the deployment side. Regarding the field of vision for the unit this largely depends on the sensory equipment which is chosen. For directional sensors such as camera and hydrophone a pan & tilt unit provides possibility of directing. The design of the unit allows for a 360° view horizontally and 130° view vertically (as seen on the illustration).

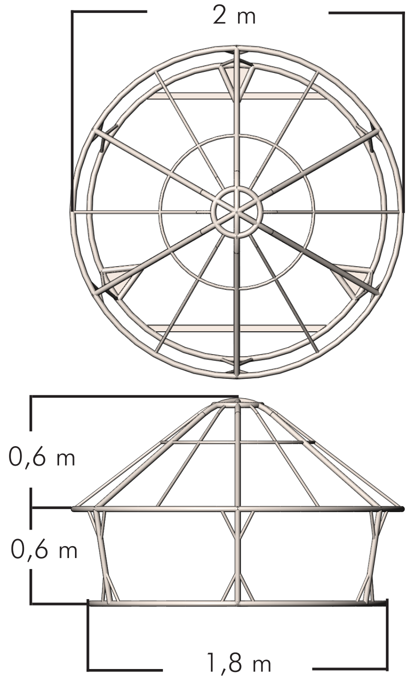


The color choice for the unit is motivated by two factors: firstly the orange and green colors used on the unit is proven to be some of the most visible colors for objects floating at sea [21], secondly these colors offer a welcome variation to the standard yellow usually found on subsea appliances.


Frame (top)
Covers
Alarm buoys
Pan & tilt unit
(here with camera, flash
and hydrophone)
Foam assembly
Frame (bottom)
Release mechanisms
Anchor

Components of the unit

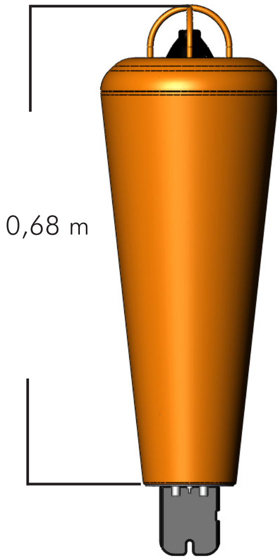


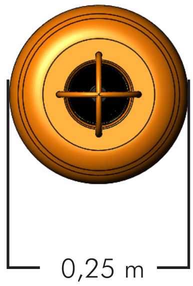


Frame

To give good access when the unit is assembled the frame is divided in two parts in the horizontal plane where the diameter of the frame is at its largest. This allows conveniently placing and installing all the parts contained by the frame such as the release mechanisms, foam assembly, battery packs, central processing unit, alarm buoys and leak detection sensors. The 6 beam construction makes the frame sturdy and robust. Further protection and shielding of the sensors and equipment is given by the covers which are meant to be made out of steel sheets. The covers are perforated to reduce weight and those holes are small enough to avoid trawl gear getting caught in them, the exception are the holes for the alarm buoys, however this is a necessary tradeoff.

During the work with the final development it became clear that lifting the unit by the anchor would unnecessarily complicate the installation process since one would have to have more than one lifting point to securely lift the unit. However, it was also discovered that the changes that would need to be done to the design of the frame to accommodate for lifting with the anchor (and meeting required safety factors) will not be more extensive than what anyway is expected during further work with detailing. The lifting point of the unit will hence be at the very top of the frame.

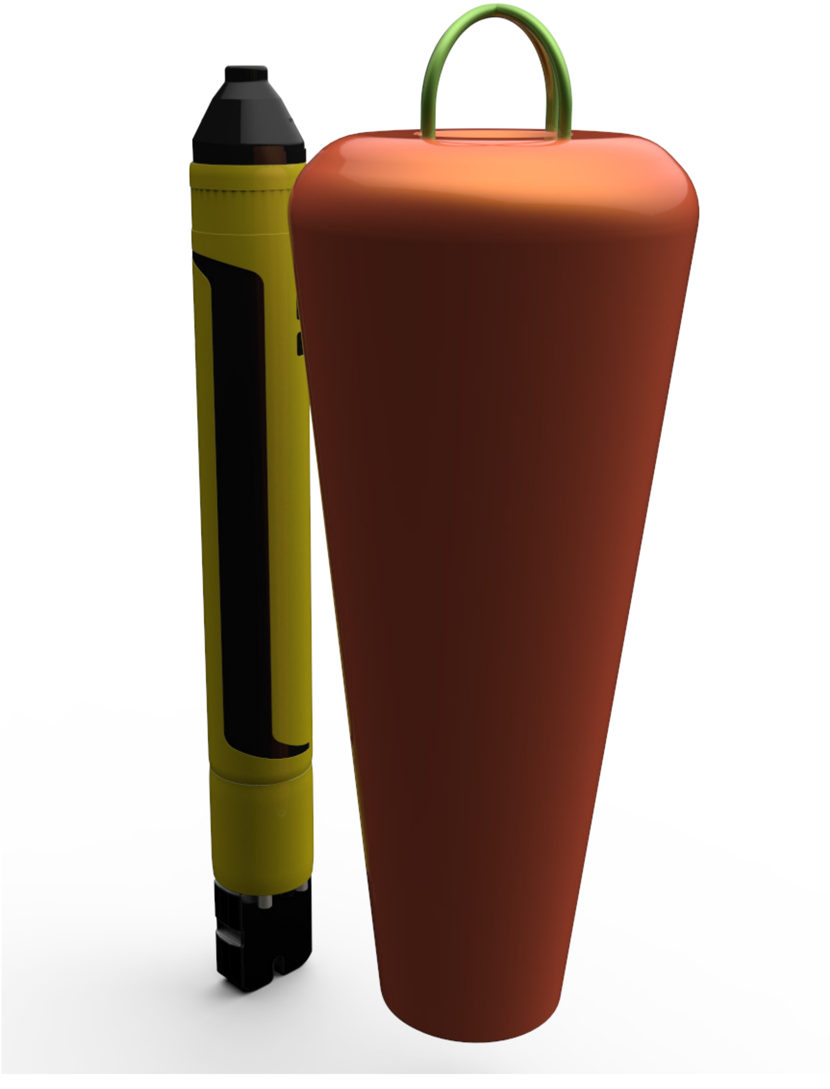


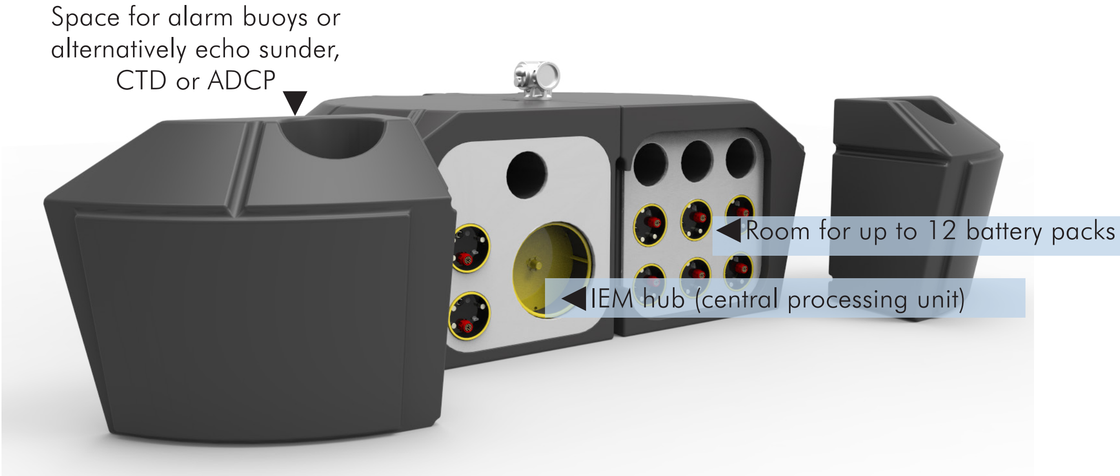


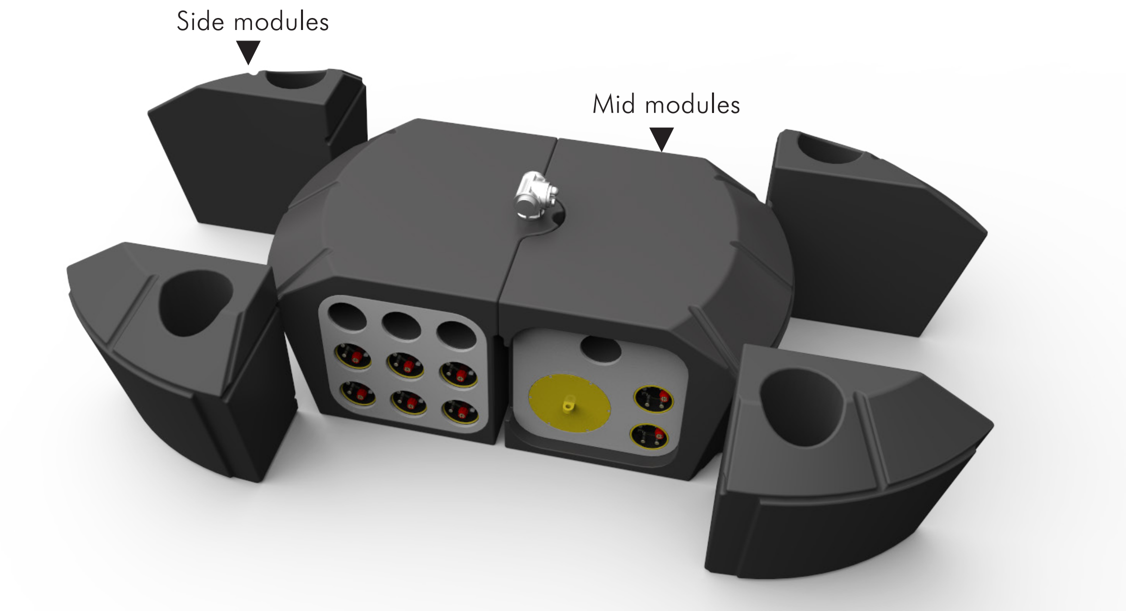
Alarm buoys

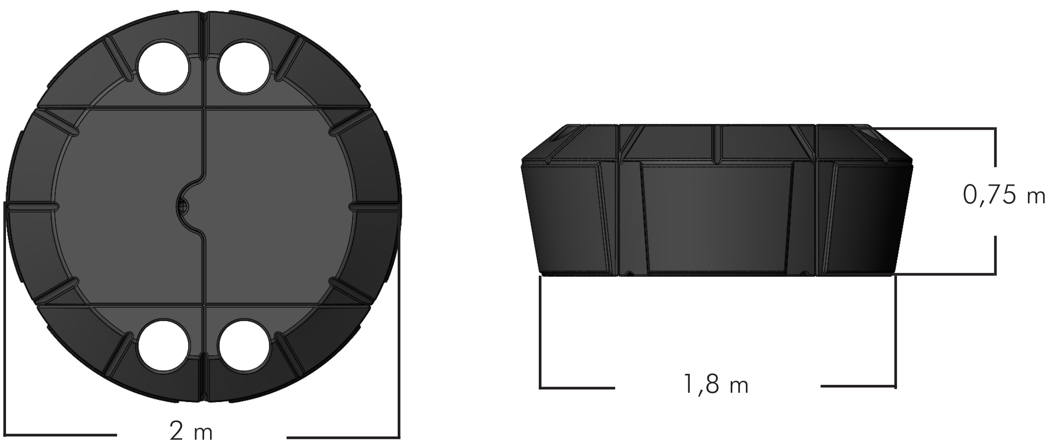
The alarm buoys are cNODE satellite hybrid transponders fitted with floating collars.The drop-shaped form of the floating collar discourages idle movement for the buoy during its travel to the surface and should provide enough stability for the cNODE hybrid to obtain satellite contact and send the alarm signal. It is thought that one alarm buoy will be permanently connected to the unit via cable to function as the systems acoustic communication transponder. An additional advantage with this is that it gives the unit an opportunity to communicate via satellite, i.e. for GPS coordinates, on collection.

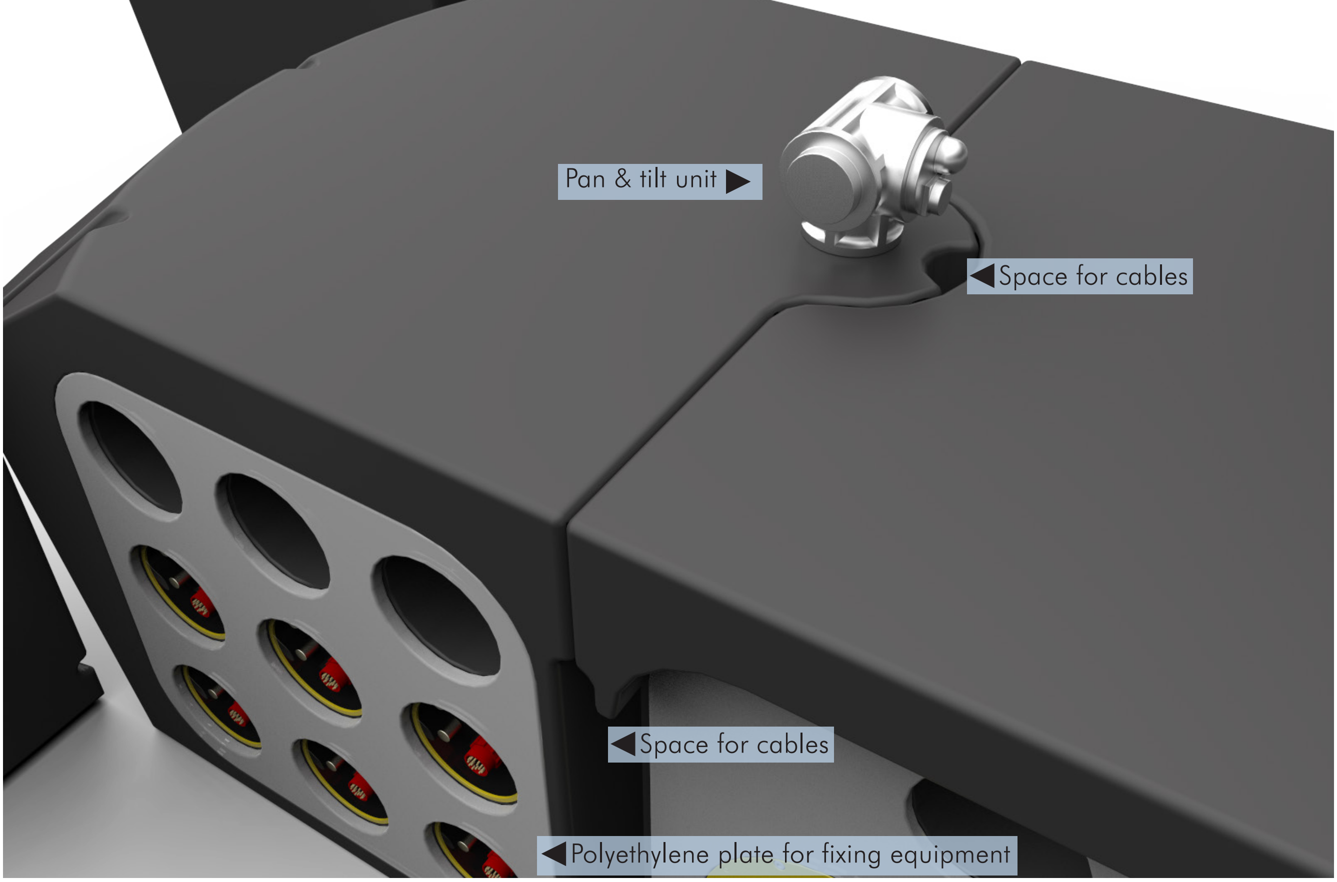
Given the approximation of the cNODE hybrid to weigh 6 kg in water, this design of the floating collar provides approx. 8-10 kg of uplift (depending on the quality of foam used for the floating collar), this will give an estimated time of 8-9 minutes for the buoy to reach the surface from 500 m depth.




Space for alarm buoys or
alternatively echo sunder,
CTD or ADCP
Room for up to 12 battery packs
IEM hub (central processing unit)


Side modules
Mid modules


2 m
0,75 m
1,8 m

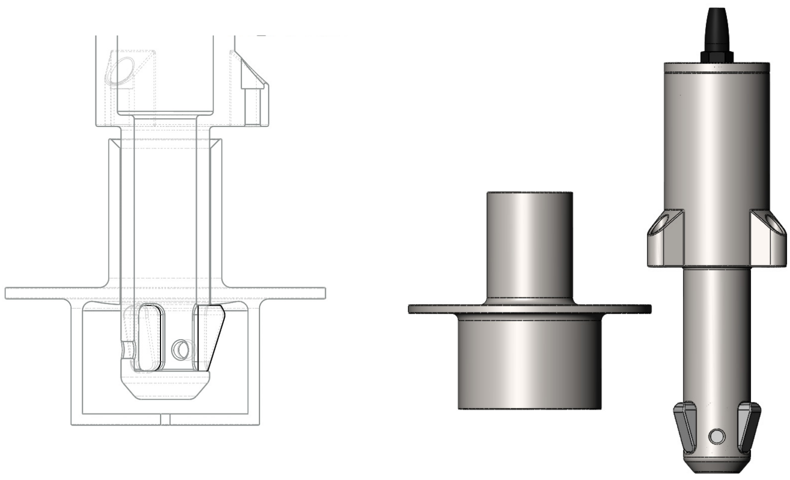


Foam assembly

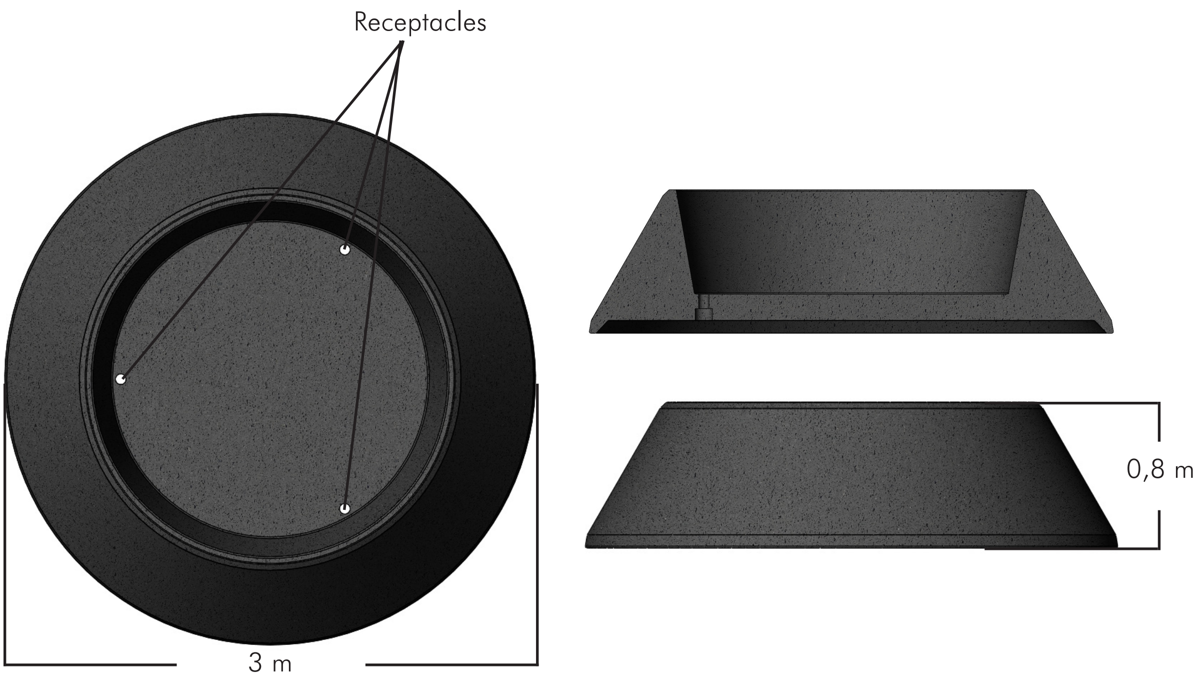
The final foam assembly consists of six parts, two mid modules and four side modules, this breakdown allows for easier handling during building of the unit. At first glance it may seem like the mid modules are the same, and they are very similar, although they do differ a bit to accommodate for fixing of the pan & tilt unit at the center. The battery packs and the central processing unit are contained within the mid modules. Here up to 12 cNODE battery packs (the need of battery changes with choice of sensor package) can be fitted together with the IEM hub. These heavy components are placed lying for two reasons, the most obvious being that vertically placing would put them directly in the way of the leak detection sensors. The other reason is to improve stability of the unit when it is floating, by placing these components this way the center of gravity is lowered respectively to the center of buoyancy which gives better stability i.e. keeping the unit from flipping upside-down when at the ocean surface. The side modules provide room for up to four release buoys, but it is also though that this space can be used for other equipment, such as an echo sounder, CTD or ADCP. There is further made room for cables and connectors between the two mid modules as well as the four side modules. Plates of polyethylene-plastic will securely fix the IEM hub and the battery packs in the foam modules.

Pan & tilt unit

Directional leak detection sensors will be mounted on the pan & tilt unit which is placed in the center of the unit.



Release mechanism and receptacle



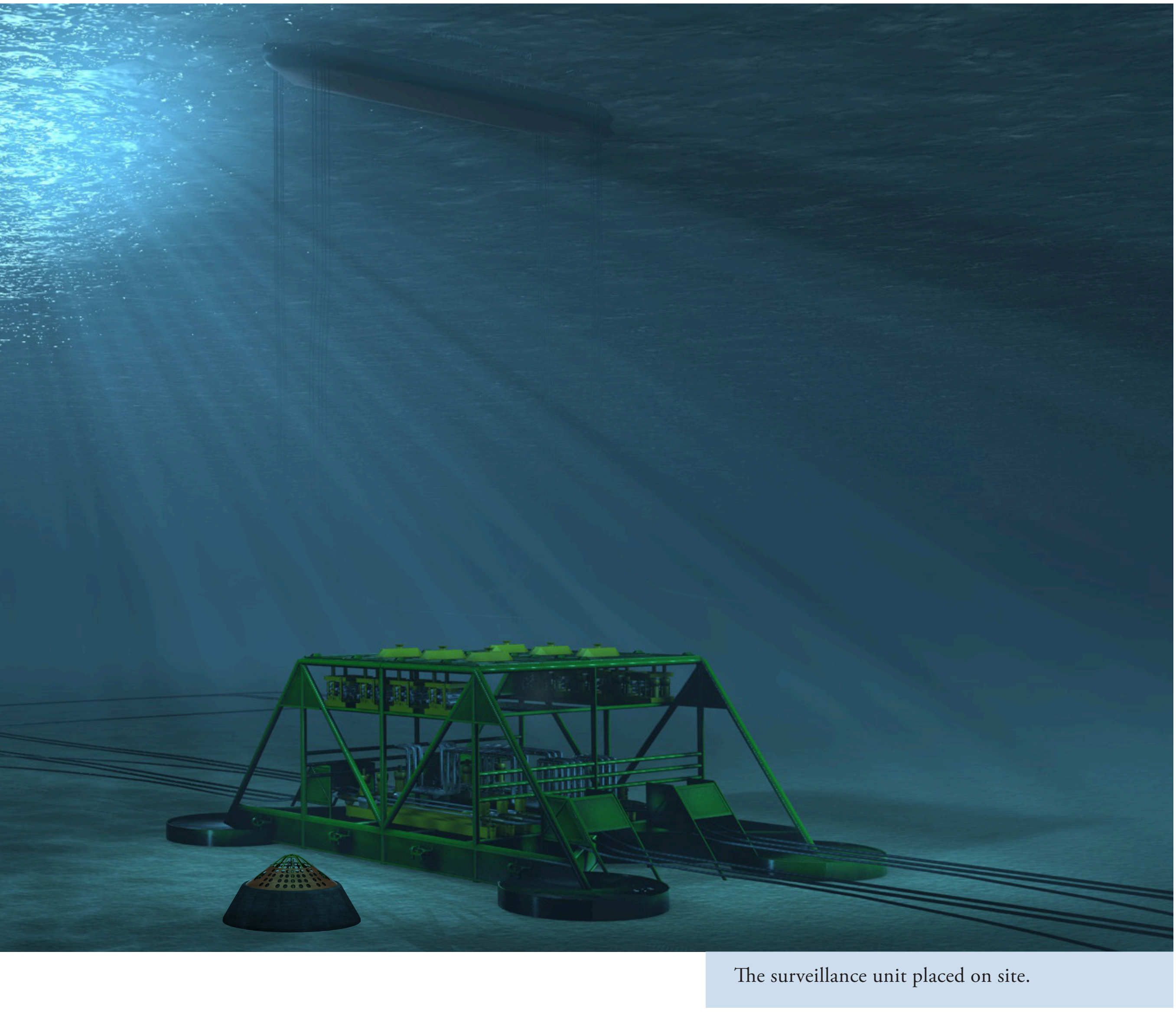
The concrete anchor

Release mechanisms

Three release mechanisms equally distributed around the bottom of the frame securely fix the concrete anchor to the unit. The motivation for choosing to use three release mechanisms was to ensure an even weight distribution on the frame of the unit during lifting operations as well as minimizing the number of fixed points (one centered release mechanism would also have given an equal weight distribution, but the construction and form of the frame leaves the center point too weak to handle this). Steel receptacles for the release mechanisms, which are cast into the concrete, further ensures secure fixing of unit and anchor.

Anchor

The massive concrete anchor functions as a sturdy cradle for the unit and weighing approximately 3000kg when placed at the ocean floor (and 5400 kg in air) it will give good protection i.e. against impact from collision with a trawl door. Since the anchor is closed in the bottom it will also help preventing mud and debris from soiling the foam assembly and respective equipment of the unit. By using EMGS concrete for the anchor (provided a license is bought) one ensures that nothing is left behind on the deployment site since this concrete deteriorates completely in water after a preset time. This will also work as a fail-safe option in case the release mechanism does not work, the unit will then be released when the anchor has dissolved, although, this will happen at a later point than the scheduled collection it is not necessary to intervene with ROV to collect the unit.

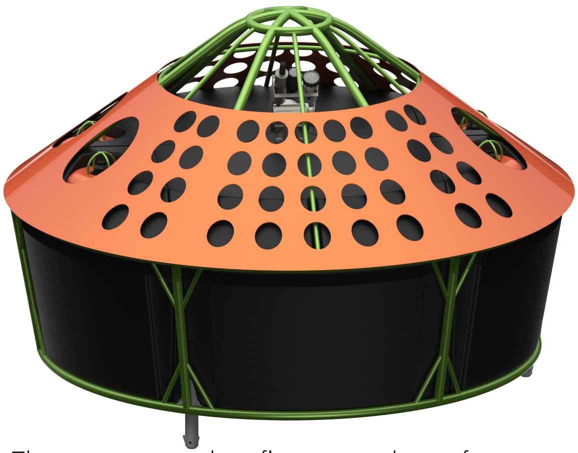


The surveillance unit placed on site.

The surveillance unit in use

Installation process

Installation of the unit is very straight forward and unless it is going to be deployed on very large depth ROV is not needed for placing and positioning. A wire with a remote release shackle, or other similar common offshore lifting equipment, connected to the top lifting point of the unit allows the whole unit (with anchor) to be lifted and lowered down to the deployment site. It will then have to be positioned utilizing normal acoustic positioning protocols, the on-board transponder (cNODE) on the unit can also aid during this process. The unit will have to be positioned within detection range of the object which will be monitored and this range will depend on the conditions at the deployment site with regards to field of vision for the camera (visibility and light). A live camera feed (from cable connected to the unit during the installation) will help in this process.



The unit as it is when floating to the surface

Deployment

The leak detection solution is completely standalone, after installation and direction and calibration of sensors the unit can be left alone until it is time for service and maintenance one year later. In the meantime the unit will autonomously monitor the designated surveillance object, for instance a temporarily abandoned subsea well. Automatic and continuously analysis of the video feed through cutting edge image analysis together with artificial intelligence and machine learning allows the unit to assess situations and avoid false alarms, which is a well-known problem in condition and leak detection monitoring today. On detection of an alarm situation, or if there occurs an error with the system, an alarm buoy is released which initiates communication through satellite technology.

Collection

The process of retrieving the unit is also easy and does not require ROV. Usually one will collect the unit after a year of deployment, unless leaks have been detected or errors have occurred. A release signal is sent to the on-board transponder of the unit which in turn activates the release mechanisms and the unit lets go of the anchor and floats up to the surface where the recovery vessel picks it up. The colors of the unit are highly visible on water which will make it easier to see the unit when it surfaces, furthermore GPS coordinates with the units position can be sent form the on-board cNODE satellite hybrid to help localizing the unit.

Given approximations of the weight of the unit in water, depending on both chosen equipment and quality of syntactic foam used, it can be estimated that the unit will use about 8-10 minutes to rise to the surface from a depth of 500 m. The unit will rise with a speed of approx. 0.8 – 1 meter per second.

Evaluation of the final concept

The final concept for a surveillance unit displays features and qualities which are not available on the market today and should this way be an inspiring and advantageous starting point for further development of a subsea monitoring and leak detection unit. As a standalone wireless unit with a built-in solution for notification and communication in alarm situations it is suitable for deployment in all places, also in remote locations. Straightforward installation and collection together with a very trawl resistant construction makes it easy in handling and deployment. With state of the art software and technology form Trollhetta and reliable suppliers of equipment such as Kongsberg Maritime the solution should provide oil-companies and other potential customers comfort in reliability and function.

Use of the unit

The surveillance unit offers flexibility and simplicity in use and function. The platform supports integration of some different leak detection sensors and equipment and this can be chosen depending on needs and requirements from the surveillance task. The concrete anchor allows the unit to be securely placed and tethered to the ocean floor almost without any concerns apart from position of the unit within monitoring range of the designated object. Self-recovery eliminates the need for ROV on collection which both simplifies the recovery process and reduces costs. One possible concern regarding the chosen self-recovery method is that the unit might drift a bit during the ascent due to currents, however, as GPS positioning of the unit when it has surfaced is an option it is not regarded as a major concern.

Costs and market

As one of only a handful of leak detection units on the Norwegian market it is difficult to say how this solution will be welcomed in the market. Regarding price of the unit it is also hard to say at what price range the final solution will end. However, even if the unit should end up being more expensive compared to competitors there may still be money to save choosing this option since costs from lease of ROV can be avoided in most cases both for deployment and collection.

Apart from the syntactic foam, where there are a large variety in prices depending on quality and depth rating, the other components of the unit, i.e. frame and anchor, should be rather inexpensive to get produced and delivered. Even if it has not been possible to procure quotations on the sensors and equipment that has to be bought for the unit (i.e. camera, pan & tilt unit, battery packs, IEM hum etc.) it is safe to assume that the largest part regarding cost of the unit will come from this equipment. Another factor which raises the price of the unit is depth rating, both with regards to sensors and equipment that has to be bought and the syntactic foam. For these reasons one can consider to market the solution with a basic sensor package and with a lower depth rating than 3000m as standard (i.e. 1000m which still covers most deployments sites on the NCS). By doing this one reduce the standard cost of the product and leave higher depth rating and additional equipment optional for the customer to choose.

Production

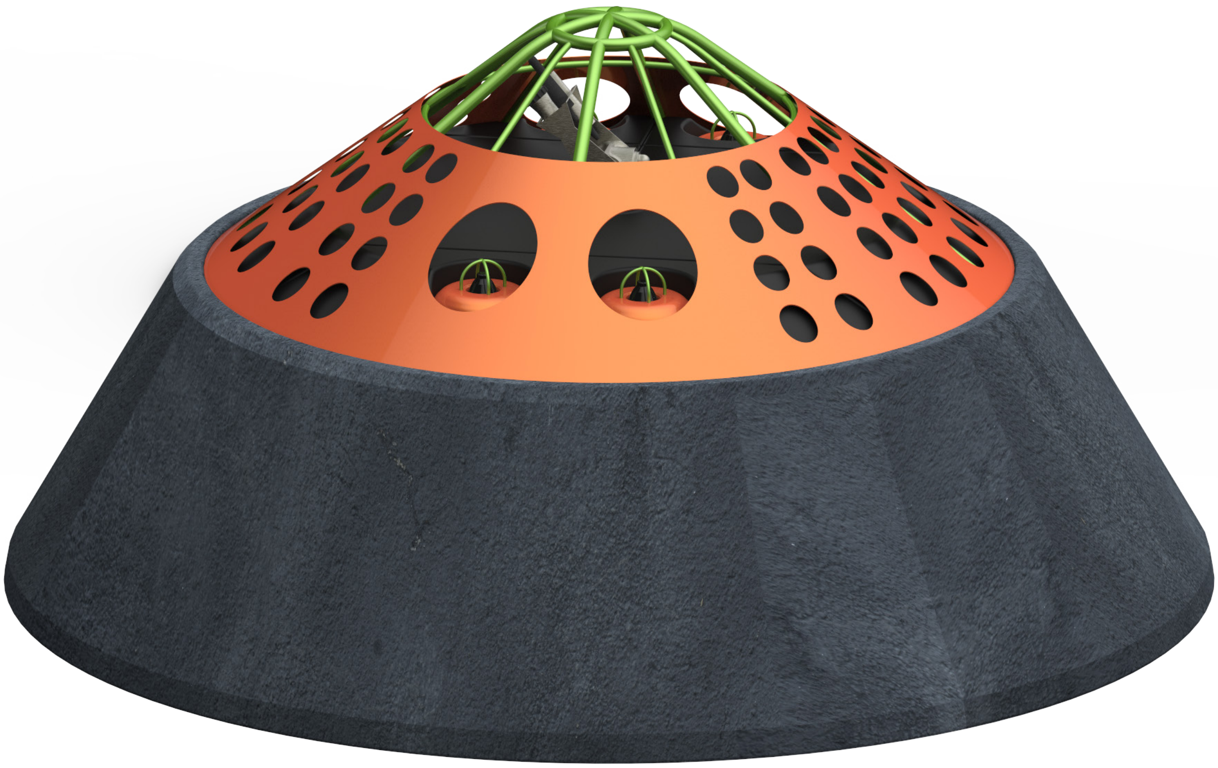
The production of the unit and components of the unit will have to be left to either collaboration partners of Trollhetta or subcontractors. Still the design of the unit is developed with relatively simple production in mind. For example the frame is meant to be made out of standard steel piping and should only require normal machining and welding techniques for production, and the concrete anchor has a very basic shape for easy casting. Furthermore, due to the choice of malleable materials, syntactic foam and concrete, changes in the design of the unit can be quite easily handled.

Biofouling

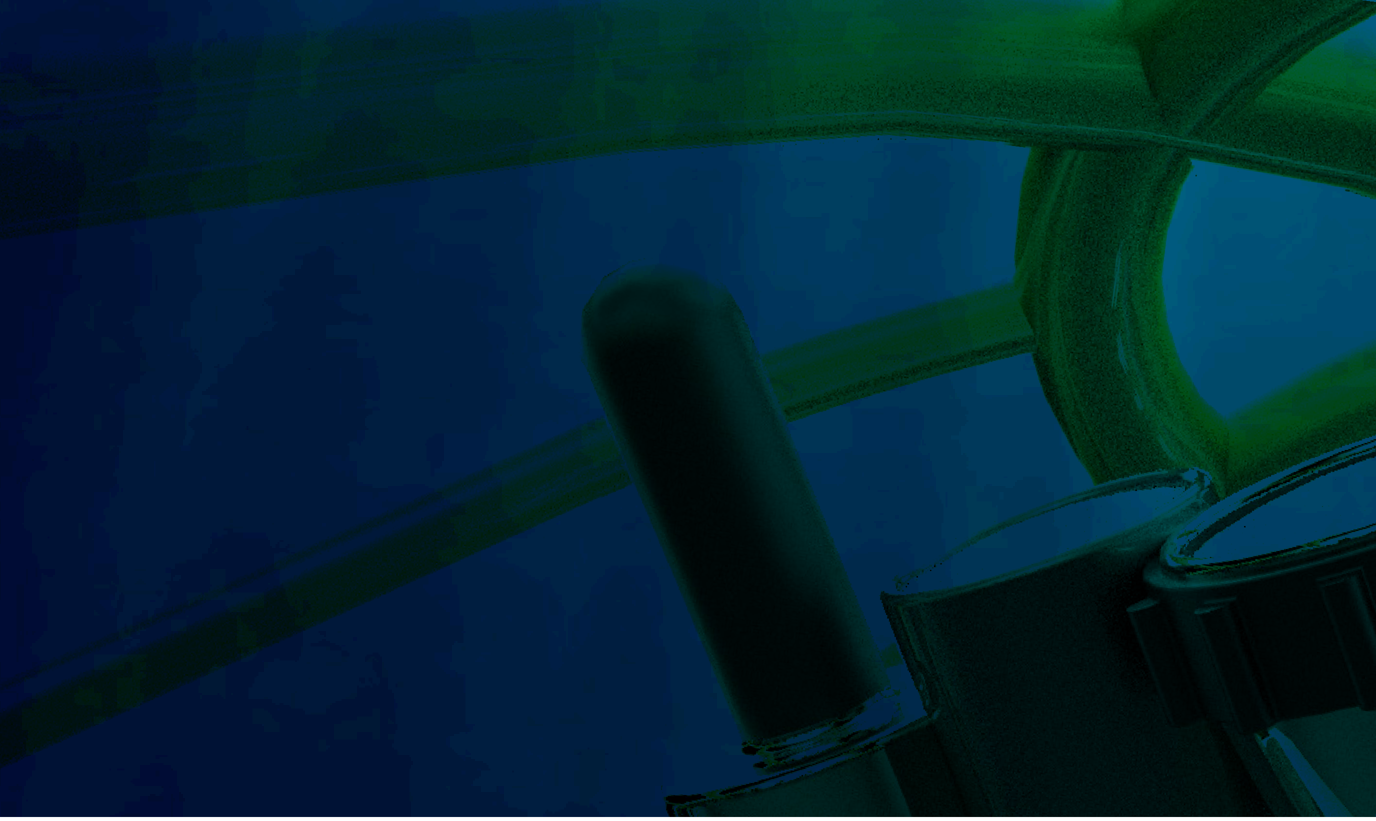
A weakness and potential large problem for the solution since the primary leak detection sensor is meant to be a camera is biofouling. Due to limited time for the project and the fact that even professionals struggle with finding a way to combat this problem it was decided not to address biofouling in the final solution at all. However, this can be a major problem, especially with regards to the use of optical camera, and should be addressed if it is chosen to work further with development of a leak detection unit.

Ethics

Unless the unit is deployed in a place close to infrastructure one can imagine that it will be far too costly to spend time searching for and retrieving the buoy. This means that the alarm buoy will, after being released and sending an alarm signal, most likely be left floating freely around in the ocean. At a first look one can see this as a rather unethical and not very environmental friendly practice. However, if one compares the impact on the environment from some buoys to the potentially waste environmental impacts one will get from a severe oil or gas leakage this practice may be justified.



Concluding stage



Conclusions

During this master thesis a concept for a subsea surveillance unit intended for leak detection in the petroleum industry has been developed. The project was done in collaboration with Trollhetta AS, and in addition several other companies and educational institutions have aided with knowledge, information and counseling during the development process, worth mentioning among these are Kongsberg Maritime and EMGS.

The final concept is developed with a basis in a statement of requirements which in turn hold grounds in analysis and findings from research as well as requirements and wishes put down by Trollhetta. The focus for the concept was to provide a flexible and practical solution which is completely standalone. The identification of a protruding market caused, amongst other reasons, by amendments in regulations for petroleum activity in Norway shows that there is a need for such a product. Leak detection and monitoring is the main activity for the unit and layout and design is meant to accommodate for this in an optimal way.

The final concept displays, amongst others, features such as:

- Modularity and tailorability; different sensors for leak detection can easily be changed or integrated in the unit and flexibility in both foam modules and anchoring allows for changes in the design to be made without too large difficulties.
- Easy and inexpensive installation and collection since ROV or other intervention can be avoided for both processes; on-board equipment such as optical camera and transponder assist during placing and positioning and the unit is self-recovering and will float to the surface i.e. if given a signal.
- Sturdy anchoring and very trawl-resistant design.

Suggestions for further work

The objective for this project has been to make it an introductory part of the development process for the subsea surveillance unit Trollhetta AS plan on making. The final concept presented in this thesis proposes solutions which hope to inspire and give ideas for further design of this standalone unit.

A possible next step in further work could be for Trollhetta to present this concept to possible collaboration and development partners to see if they are interested in getting involved in a project like this. Even though the concept could be developed to an even higher degree it provides good insight in the suggested solutions and ideas and should be suitable for this purpose.

In any case, if it is chosen to proceed working with the concept there is still much work left to be done. Firstly a thorough reevaluation of the concept should be done and the solutions which are least developed, such as the release mechanism for the unit, should be closer considered. With regards to technical and mechanical aspects the layout and design of the unit is developed with future realization in mind. This means that there should be a certain degree of feasibility to the suggested solutions, although they still need a lot of work with development and detailing. The further work should eventually also prepare the different components so they comply with the required standards, regulations and guidelines. Furthermore, since the final concept builds on some solutions which are dependent on collaboration with other companies, or requires licenses, these are matters that also should be looked into. Additionally subcontractors or collaboration partners should be considered for production and delivery of for example foam modules, frame, release mechanism and anchors. For foam modules Balmoral Offshore Engineering and Matrix Composites & Engineering can be mentioned as possible subcontractors.

Evaluation of the process

This master project has been very challenging and it has been a lot of new material and information to get acquainted with and a lot to keep an overview over. Having Trollhetta as a collaboration partner have been helpful for the project, they have been supportive throughout the process and been of assistance wherever they have been able. Through Arild Brevik at Kongsberg Maritime and Audun Sødal at EMGS have the project and the final solution been given a more tangible and feasible standpoint with regards to subsea design.

It has been interesting and informative to see how dramatic the changes in requirements for design and construction of subsea appliances are compared to what I am used to form previous projects where design have been above the ocean level. As with almost all design projects trade-offs and compromises have colored the development of a final concept and solution.

In-between companies

Seeing as neither I nor Trollhetta has experience with designing for subsea it has been necessary to gather information and knowledge from other places. This has been one of the major challenges and it has also resulted in that my role in the project has been to serve as a link between two bodies where Trollhetta on one side has functioned as an employer and companies and institutions such as Kongsberg Maritime and SINTEF have functioned as (external) resources. One could say that it would have been desirable if Trollhetta would have more in-house experience with regards to subsea design, especially since this would have lessened the challenge with gathering knowledge and information considerably. However, I see it as just another experience to take with me and I think the final result in a good way reflects a diversity which can be attributed to the fact that input and information came from several places.

Boundaries

Since it has been made clear form Trollhetta that they possibly wish to proceed with development of a surveillance unit it has been important for me to make the result of this concept study a feasible solution which potentially can be further developed and used. Consequently choices and decisions have been made with this in mind, and factors such as economics and producibility have been important in these processes. However, this can have led to the project being carried out with too much constrains and maybe a freer reins would have given another result. In addition, the scope of the project has also been very large and it has been necessary to limit and decrease the workload wherever it has been possible to make sure I would be able to carry out and complete the project in time. In retrospect I think that it could have been better to further narrow down the scope of the project from the beginning and focus on the development and conceptualization of only some parts of the unit rather than the whole. That being said, it has been interesting and engaging to get insight into and to work with subsea-design and the challenges and problems one meet in this field.

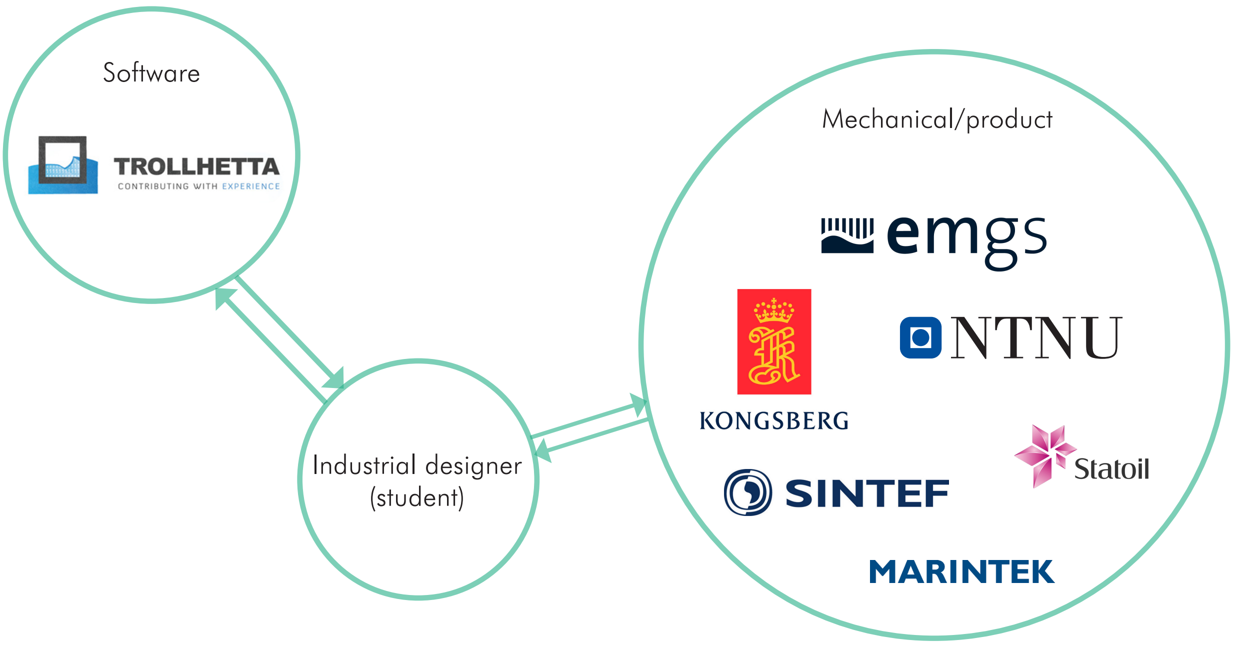


Figure 30: In-between companies

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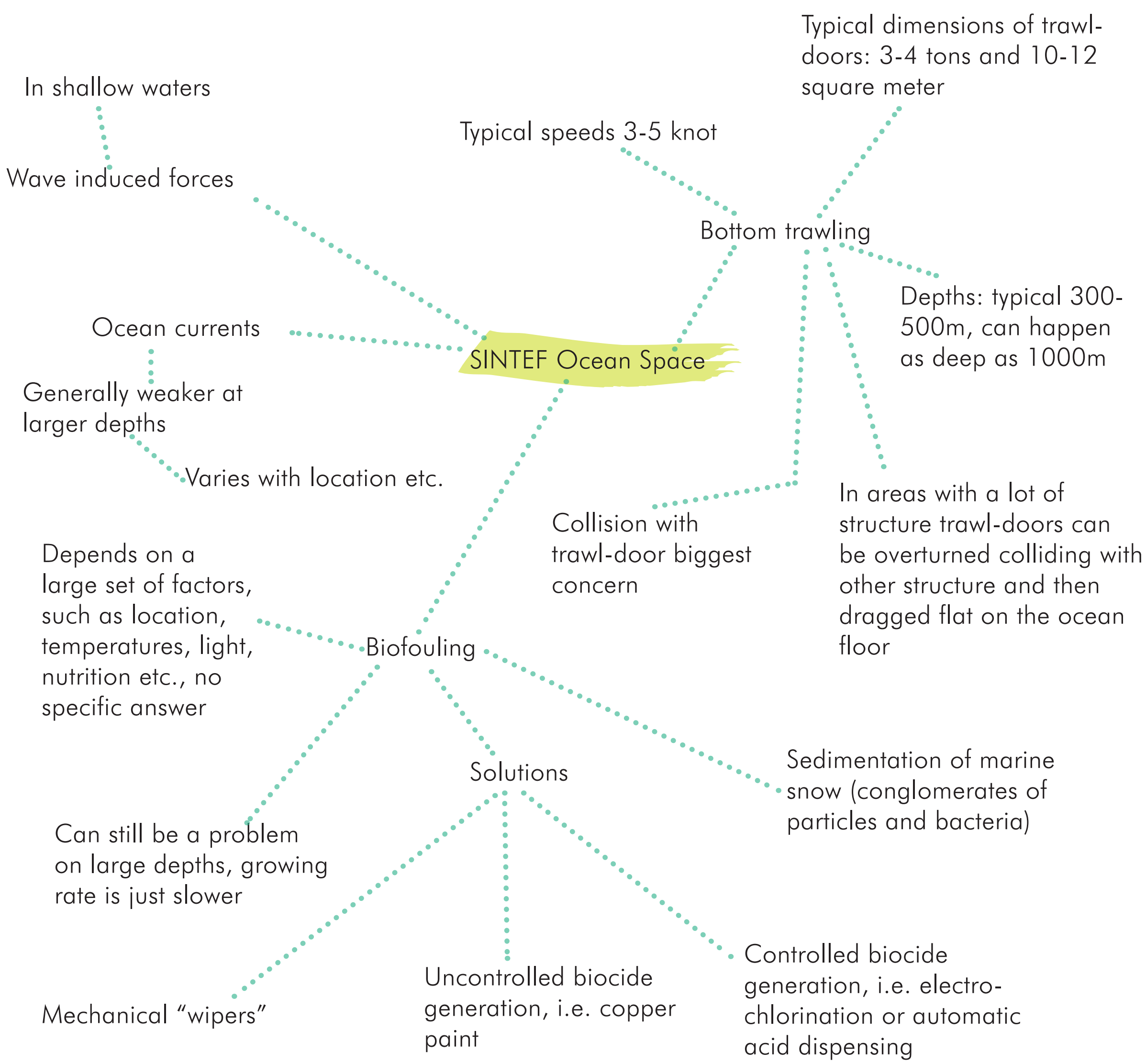
Appendices

Appendix 1

Interviews and visits

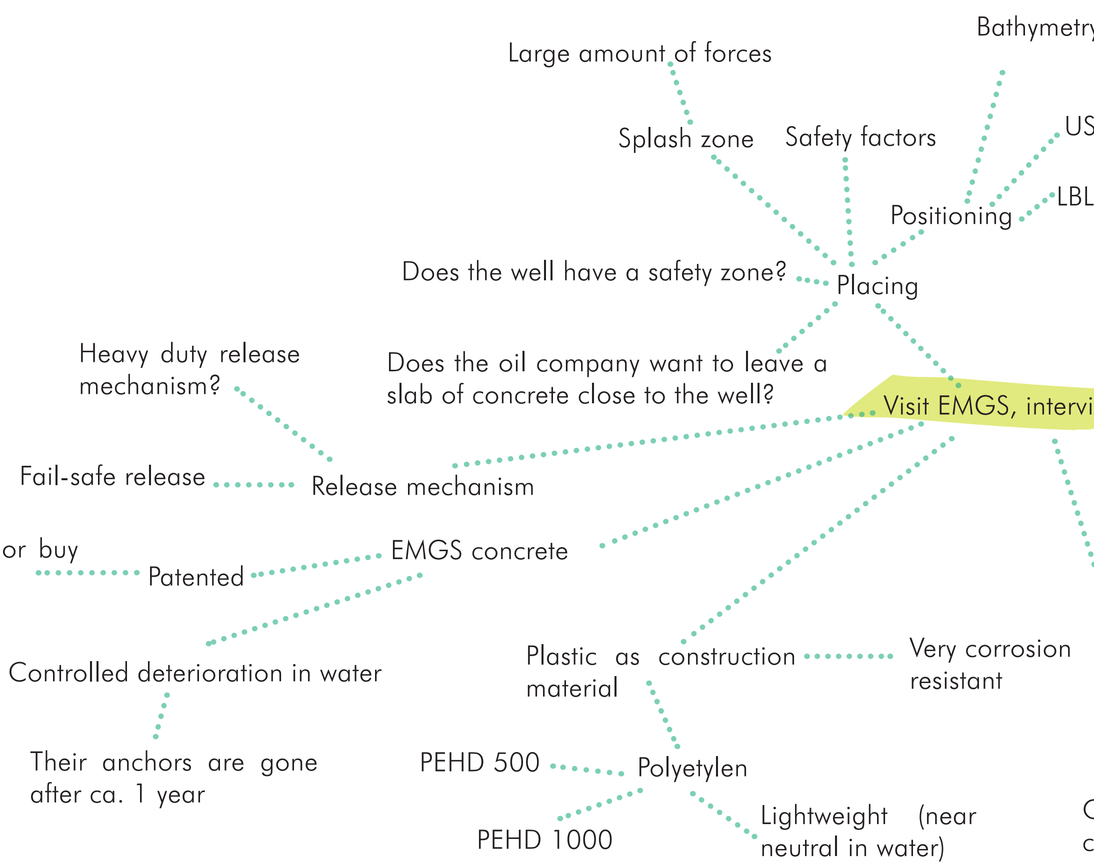
SINTEF Ocean Space

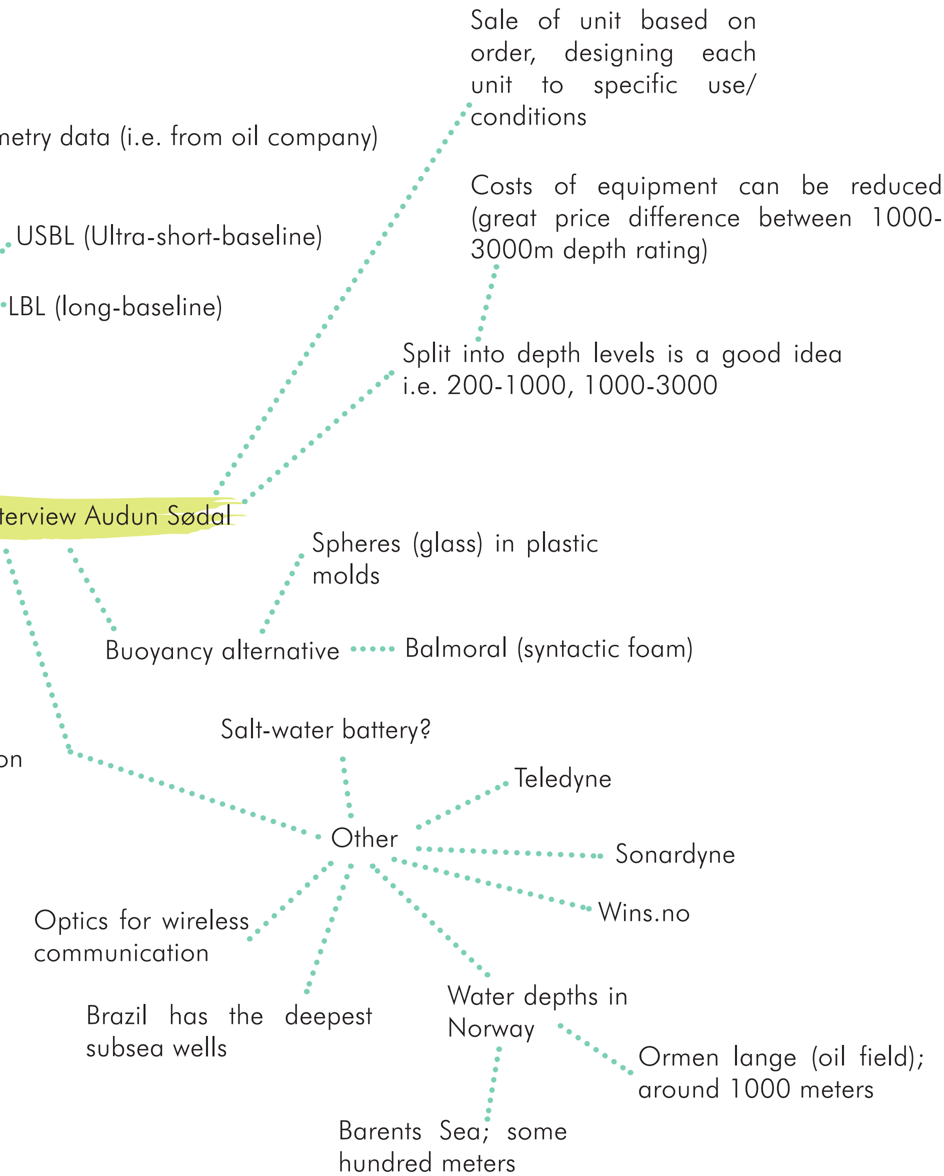
Information gathered from visit and interviews the 17th of Mach and email communication with David Kristiansen, Jørgen Jensen, Nina Blöcher, Lars Gansel, Ingrid Ellingsen at SINTEF Ocean Space.



EMGS

Visit at EMGS (Electro Magnetic Geo Services) and interview with Audun Sødal, senior development engineer at EMGS, 8 April 2015.

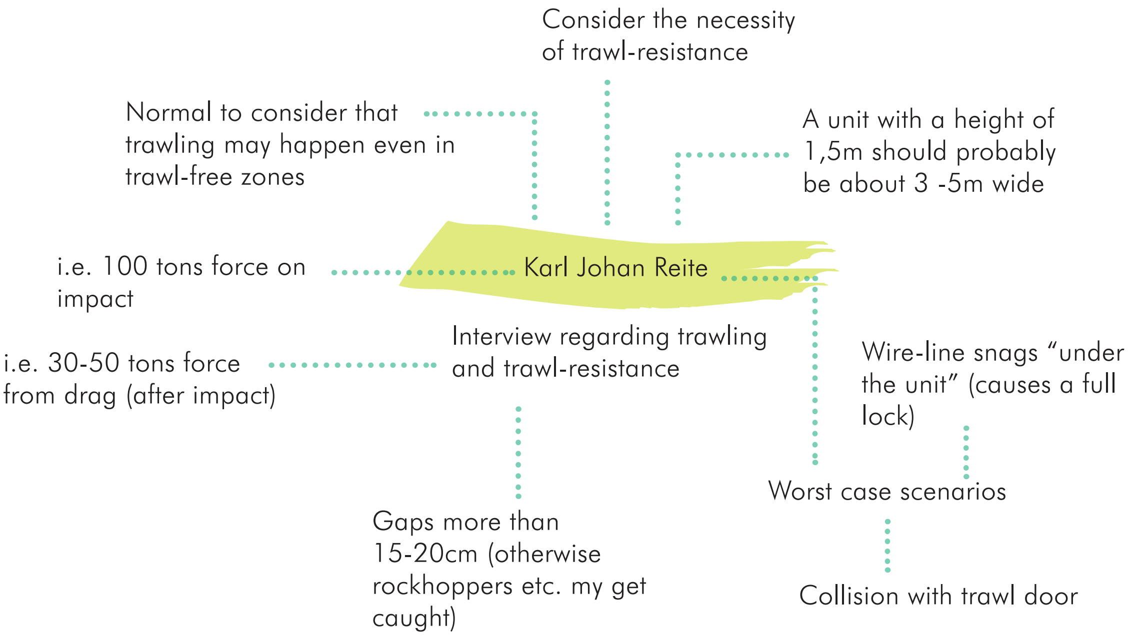




Sale of unit based on order, designing each unit to specific use/ conditions
netry data (i.e. from oil company)
Costs of equipment can be reduced (great price difference between 1000-3000m depth rating)
USBL (Ultra-short-baseline)
LBL (long-baseline)
Split into depth levels is a good idea i.e. 200-1000, 1000-3000
terview Audun Sødal
Spheres (glass) in plastic molds
Buoyancy alternative
Balmoral (syntactic foam)
Salt-water battery?
on
Teledyne
Other
Sonardyne
Wins.no
Optics for wireless communication
Brazil has the deepest subsea wells
Water depths in Norway
Ormen lange (oil field); around 1000 meters
Barents Sea; some hundred meters

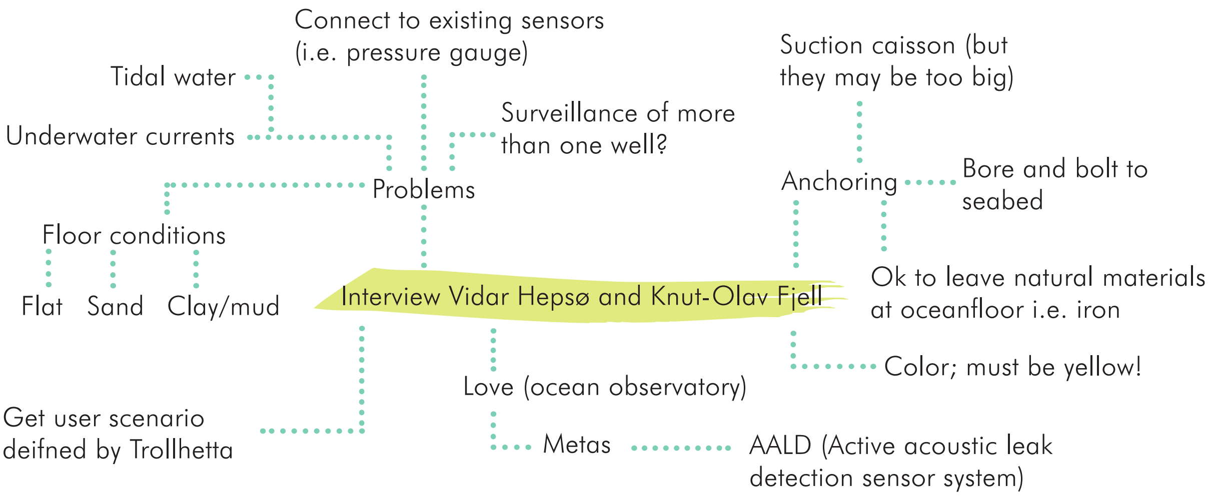
Karl Johan Reite

Karl Johan Reite Research Scientist, PhD SINTEF Fisheries and Aquaculture. Telephone interview about trawling, 12 April 2015.



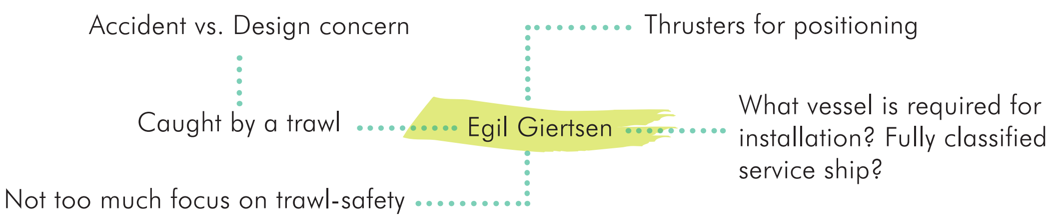
Statoil Research-center, Rotvoll

Visit at Statoil Rotvoll and interview with Vidar Hepsø, Principal researcher and Project Manager at Statoil ASA, and Knut-Olav Fjell, Principal Researcher Environment Monitoring Technology, 14 April 2015.



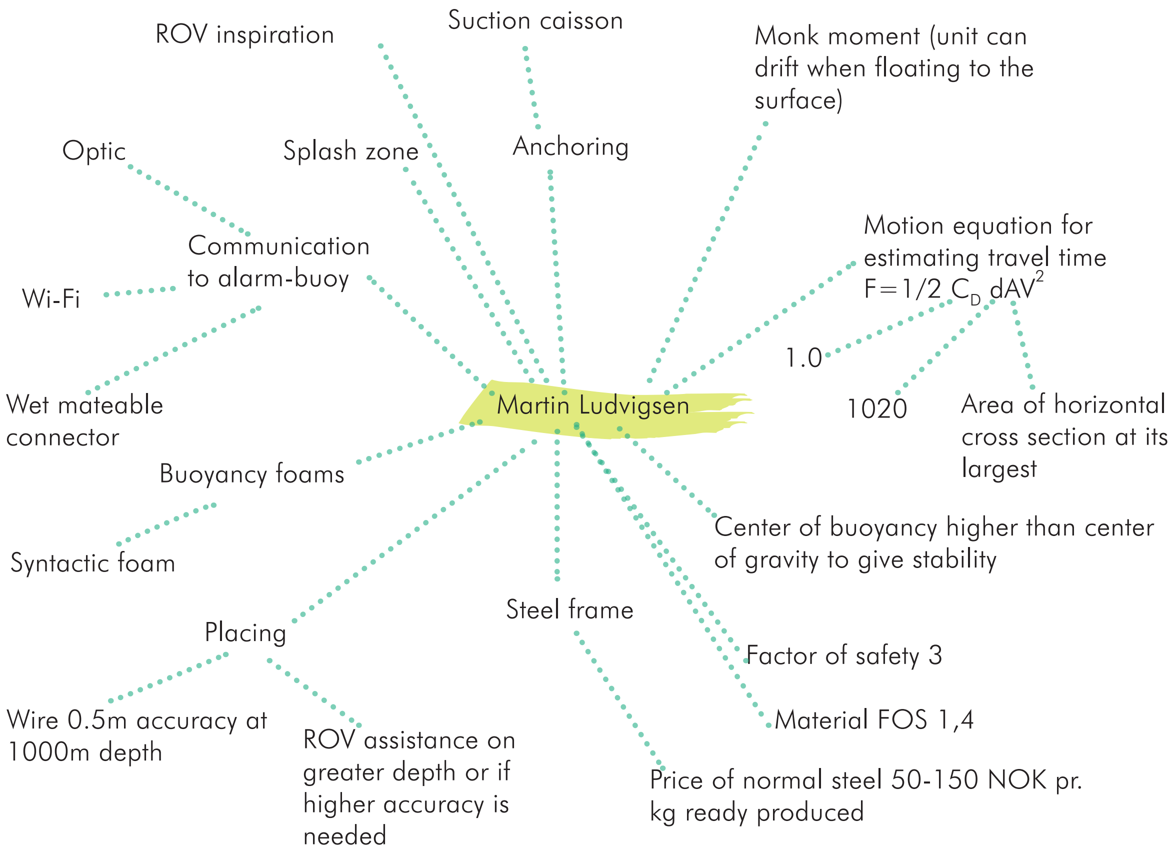
Karl Johan Reite

Interview with Egil Giertsen, Research Director at MARINTEK, 16 April 2015.



Karl Johan Reite

Interview with Martin Ludvigsen, Professor at Institute for Marine Technology, 24 June 2015 (and 4 November 2014).



Kongsberg Maritime

Visit at Kongsberg Maritime in Horten, and interview with Arild Brevik, head of business development and sales for subsea monitoring at Kongsberg Maritime Subsea, 28 May 2015.

Arild Brevik

Self-recovery good idea

Syntactic foam

Battery and equipment must be limited

"Lightweight" possible

5-600 kg

Release mechanism has to be designed for the purpose, Kongsberg solution not suitable for this project.

Release mechanism for unit should be tailormade

Solenoid or el-motor

Rope-recovery

Tank with ballast that has to be emptied

Biofouling a problem

Kongsberg sensors do not implement prevention

Design concrete anchor good idea

Reuse of anchor?

Solid

Probably very trawl-resistant

Depth rating

Evaluate need 500 vs. 3000

Projects can easily become too expensive

Placing at seafloor no problem

If sufficient weight, ocean currents are not strong enough to move the unit (usual current speed 2-3 knot, but not even 10 knot would move the unit).

Most likely flat and quite soft foundation. Unit may sink down, which just will secure that it stands steady. Worst case scenario: unit sinks down approx. ½ meter.

Installation: lowering with wire.

Use of ROV on large depths

K-Lander uses "claw"-type lowering device

Echo sounder (transducer and transceiver), transforms el-signals to sound, detects fish or gas/oil bubbles via acoustics. Active (sends and listens to signals). Needs more power than hydrophone.

Depends mainly on sampling frequency and sensor pack

K-Lander going to Tromsø has 16 cNODE battery packs which will last for approx. 1 year with a sampling rate of 1 pr. hour. Relatively similar sensor pack to what is interesting for Trollhetta

Sleep mode prolongs battery lifetime

Battery lifespan

Can collect data and forward it

Can send control signals i.e. to release mechanism

cNODE transponders (uses telemetry)

HiPAP system, capable of communication with cNODEs, is very common equipment on offshore vessels and other boats

cNODE network possible (range up to 1500m horizontal and near unlimited vertically)

At production wells geohazards (seabed collapsing or moving) can be a problem.

Super duplex steel

Can't deliver hydrophone – icListen might be an option

Kongsberg Maritime can deliver

ADCP (acoustic Doppler current profiler) monitors ocean currents

CTD monitors conductivity (salt content of water), temperature and depth (pressure)

Hydrophone, detects fish or gas/oil bubbles via acoustics. Passive (only listening).

Echo sounder EK15 alternative – but needs design of subsea pressure housing

Echo sounder EK80 WBAT (very power efficient)

Camera

Flash/floodlight

cNODE – cNODE mini most relevant

Battery pack – either cNODE or quad pack

Central processing unit – IEM hub

cNODE release mechanism – however redesign should be considered

cNODE mini satellite hybrid – solution as alarm buoy (theoretically possible, no promises)

Maintenance, service and calibration

What should be done?

Corrosion

Anodes on everything!

Galvanic corrosion

Accelerated corrosion due to electrochemical process

If possible isolate electric components from non-electric components (i.e. from the frame)

Appendix 3

About EMGS concrete

About EMGS concrete

Concrete is one of the most important building materials of our time, widely used in the construction and building industries and no fiend to contact with water. It is used in constructions such as dams, piers, bridge pillars, oil platforms etc. Although displaying high compressive strength, the tensile strength of pure concrete is rather poor and the material is viewed upon as brittle. To counter this, it is common to reinforce the concrete with either steel bars or steel fibers.

EMGS Concrete

"A concrete formulation, which undergoes controlled deterioration in water, that can be used for making anchors for releasable tethering submarine devices at the seabed. The anchor may have handles for a device release mechanism or a central hole for a central device release mechanism. The formulation includes additives, which cause the cement to transform into non-binding Thaumasite over a pre-set period of time, leaving only natural material on the seafloor." – cited from U.S. Patent No. 8,075,685

Seabed logging surveys is a large part of the services EMGS provides and during these surveys they deploy data logging units that needs to be secured in a stable position on the seabed. The company, which uses concrete anchors to tether their data logging units to the seabed, developed their water-soluble concrete together with SINTEF as a measure to lessen their imprint on the environment. The concrete disintegrates, after a pre-set period of time, into components that are not harmful to the environment and marine life. This way, no anchor is left on the seafloor presenting an obstacle for fishing or other industrial activity.

The process of deterioration is a gradual process which starts when the concrete comes in contact with water. The concrete disintegrates from a binding formulation to a non-binding formulation because the mixture contains ingredients which react with water. By studying the specification of the patent one can unmask the curious behavior of the EMGS-concrete. The mixture is based on a reaction caused by the following substances:

- Calcium silicate, the binding substance of normal Portland cement
- Calcium carbonate, found in limestone
- Sulfate, i.e. found in gypsum

Shared features of these substances are that they are all found in common low-cost materials, in other words cheap to make. Under the right conditions, at temperatures lower than 15°C and with sufficient access to water, these substances react and form Thaumasite, which is non-binding and causes the concrete to crumble. Because of this the deterioration of the concrete is dependent mainly on two factors; the blending proportions of the ingredients and the shape and design of the concrete anchor.

Although the deterioration process will weaken the concrete until it is fully disintegrated, it is possible to adjust and tune the time it takes for the concrete to break down by altering the blending proportions of the ingredients. This way, one can ensure that the concrete holds, more or less, the required properties needed for the time the anchor is in use. The anchors EMGS is using today, which are 180 kg square slabs of concrete, is estimated to last between half a year to one year before they are fully disintegrated.

Material properties for the concrete

Given the nature of the EMGS concrete the mechanical properties of the concrete varies while deployed, therefore, these properties have to be estimated and clarified when adjusting the concrete to accommodate for the purpose of this project. Apart from possible collisions with trawls, the anchors will be subjected to the largest loads while still dry, which are loads due to handling of the anchors such as lifting for transport or installation. It is important that the anchors can withstand the stress related to these loads and that the properties of the anchors falls within the appropriate safety factors required.

In construction it is a common practice to reinforce the concrete. This improves the mechanical properties in the concrete, the tensile strength is increased and it becomes more ductile. Weather the concrete anchor should be reinforced or not is a question that is not possible to answer at the moment. There are, however, not very large forces (in terms of concrete structures etc.) ant it may not be necessary to reinforce the anchor.

If reinforcement is needed on should consider either normal reinforcement bars or fiber reinforcement. Both options are viable. Fur petroleum industry the Norsok standard N-001 - Structural design for subsea structures suggests following the NS 3473 standard for design of concrete structures and this should also ensure a good and safe design for the anchor.

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Appendix 3

Weight estimations

Weight estimations

Weight estimation "full spec"		
Component	Weight in air	Weight in water
Central processing unit	165 Kg	145 Kg
Battery packs (cNODE)	408 Kg	300 Kg
Pan/tilt	10,6 Kg	8,6 Kg
Camera (OE14-376/377)	0,37 Kg	0,21 Kg
Flash/floodlight (OE11-135)	0,38 Kg	0,21 Kg
Hydrophone (icListen)	0,96 Kg	0,6 Kg
cNODE- alarm hybrid	60 Kg	40 Kg
Echo sounder WBAT	25 Kg	12 Kg
CTD	12,5 Kg	7,4 Kg
ADCP	11,5 Kg	5,2 Kg
Release mechanism - frame	45 Kg	45 Kg
Release mechanism - alarm	20 Kg	20 Kg
Cables etc.	30 Kg	30 Kg
Frame	200 Kg	180 Kg
Syntactic foam	800 Kg	
Total	1790 Kg	745 Kg

* Values found in data sheets
** Values provided by Kongsberg Maritime
*** Values estimated by the student.

Weight estimation "normal spec"		
Component	Weight in air	Weight in water
Central processing unit	165 Kg	145 Kg
Battery packs (cNODE)	408 Kg	300 Kg
Pan/tilt	10,6 Kg	8,6 Kg
Camera (OE14-376/377)	0,37 Kg	0,21 Kg
Flash/floodlight (OE11-135)	0,38 Kg	0,21 Kg
Hydrophone (icListen)	0,96 Kg	0,6 Kg
cNODE- alarm hybrid	60 Kg	40 Kg
Echo sounder WBAT	0 Kg	0 Kg
CTD	0 Kg	0 Kg
ADCP	0 Kg	0 Kg
Release mechanism - frame	45 Kg	45 Kg
Release mechanism - alarm	20 Kg	20 Kg
Cables etc.	30 Kg	30 Kg
Frame	200 Kg	180 Kg
Syntactic foam	800 Kg	
Total	1540 Kg	570 Kg

* Values found in data sheets
** Values provided by Kongsberg Maritime
*** Values estimated by the student.