# Final report

## 1. Project details

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| **Project title** | Small scale Smart Power Buoy provides offshore power and data communication. |
| **File no.** | 64019-0043 |
| **Name of the funding scheme** | EUDP I, 2019 |
| **Project managing company / institution** | Resen Waves ApS |
| **CVR number** (central business register) | 21649880 |
| **Project partners** | BM Engineering, Glasfiber.dk, Gravlund, Aqua Leak, DTU-MEK og AAU |
| **Submission date** | 05 April 2022 |

## 2. Summary

The purpose of this project was to bring the patented 300W Smart Power Buoy in small scale from TRL5 to 7 and make it market ready for a demanding and profitable niche market in the offshore oil and gas sector for providing continuous power and data connection to instruments and technical installations under water. In a very conservative technical field, high reliability is the most important factor in winning acceptance and a foot hold in the market. Price is of less importance. When the offshore oil and gas sector has first witnessed high reliability and good reference cases in the sector, they are very loyal customers for many years to come.
This project has demonstrated that the technology is feasible, and we have also lifted our general technical knowledge to a high level of understanding. We have obtained a deeper understanding of small buoy operation in North Sea conditions.
We have also observed that the international market potential is bigger and more diverse because of new applications we had not even thought about before, and which are now possible thanks to our small buoy solutions. Through our customers, we have also learned how to focus our business case, so it is simple to understand and easy to implement. We have also been confirmed in our strategy to go for small scale 300W units, and later also to a 3kW wave energy buoy, as the right thing to do, rather than scaling to big MW wave energy systems with an unclear market situation. At first glance, it might be difficult to understand how our small-scale 300W buoy solutions can have a big impact, with significant cost and CO2 reductions along with improving personnel safety at sea. Our solution can replace expensive ship operation with autonomous underwater robots which can be charged and controlled from land and log all necessary measurements in real time. Documented by BP last year on one project, it reduced the operational costs from 150 million DKK to only 15 million DKK, it is 4 times faster and net zero CO2 emissions.

DANSK:

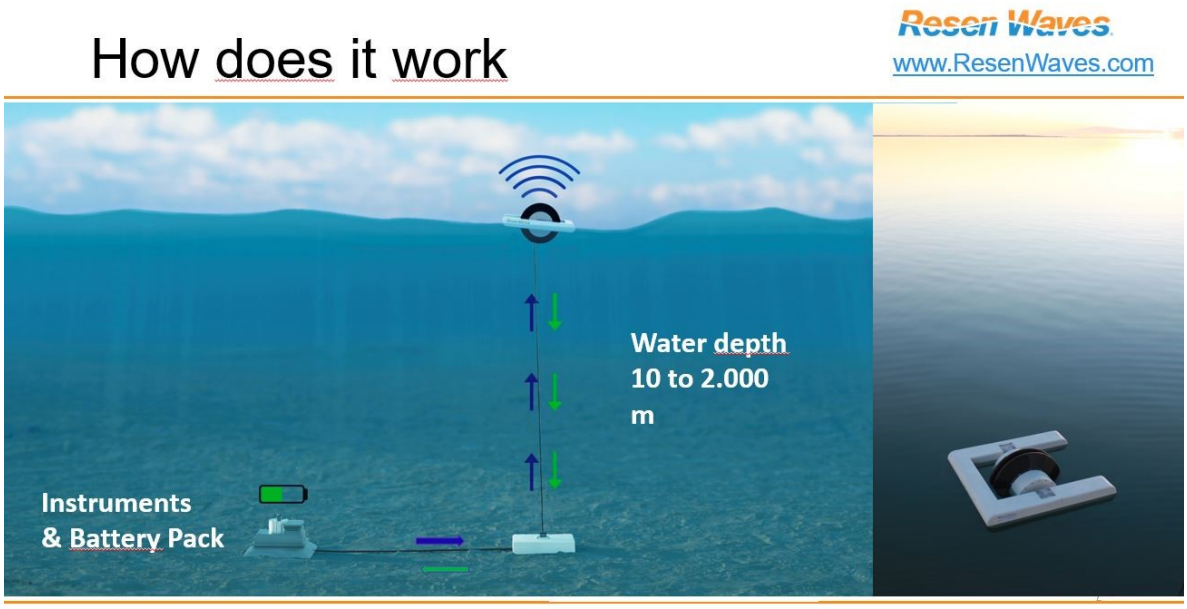
Formålet med dette projekt var at bringe den patenterede 300W Smart Power Buoy i lille skala fra TRL5 til 7 og gøre den markeds klar til et krævende og rentabelt nichemarked i offshore olie- og gassektoren til kontinuerlig strøm- og dataforbindelse til instrumenter og tekniske installationer under vand. I et meget konservativt teknisk felt er høj pålidelighed den vigtigste faktor for at vinde accept og et fodfæste på markedet. Pris er af mindre betydning. Når offshore olie- og gassektoren først har set høj pålidelighed og gode referencesager i sektoren, er de meget loyale kunder i mange år fremover. - Dette projekt har vist, at teknologien er mulig, og vi har også løftet vores generelle tekniske viden til et højt niveau. Vi har fået en dybere forståelse af mindre bøjedrift i Nordsøen.
Vi har også observeret, at det internationale markedspotentiale er større og mere differentieret på grund af nye applikationer, som vi ikke engang havde tænkt på før, og som nu er mulige takket være vores små bøjeløsninger. Gennem vores kunder har vi også lært at fokusere vores business case, så det er let at forstå og let at implementere. Vi er også bekræftet i vores strategi om at starte i mindre skala på 300W nu og senere også til 3kW bølgeenergibøjer som den rigtige ting at gøre, snarere end at skalere til store MW bølgeenergisystemer med en uafklaret markedssituation uden kendte kWh afregningspriser. Ved første øjekast kan det være svært at forstå, hvordan vores små 300W bøjeløsninger kan skabe så betydelige omkostnings- og CO2-reduktioner og ikke mindst forbedre personalets sikkerhed i havet. Vores løsning kan erstatte dyr skibsdrift med autonome undervands robotter, der kan oplades og styres fra land og logge alle nødvendige målinger i realtid i havet. BP dokumenterede sidste år på et konkret projekt at de kunne reducere deres driftsomkostningerne fra 150 millioner DKK til kun 15 millioner DKK, udføre opgaven 4 gange hurtigere og gøre det helt CO2 neutralt.

# *3.* Project objectives

The purpose of the project was to develop a complete 300W Smart Power Buoy system which could work in the sea, in full ocean exposure, as an autonomous system and produce it own power for sensors on the buoy itself or on the seabed and provide data communication to all sensors above and below water from shore.

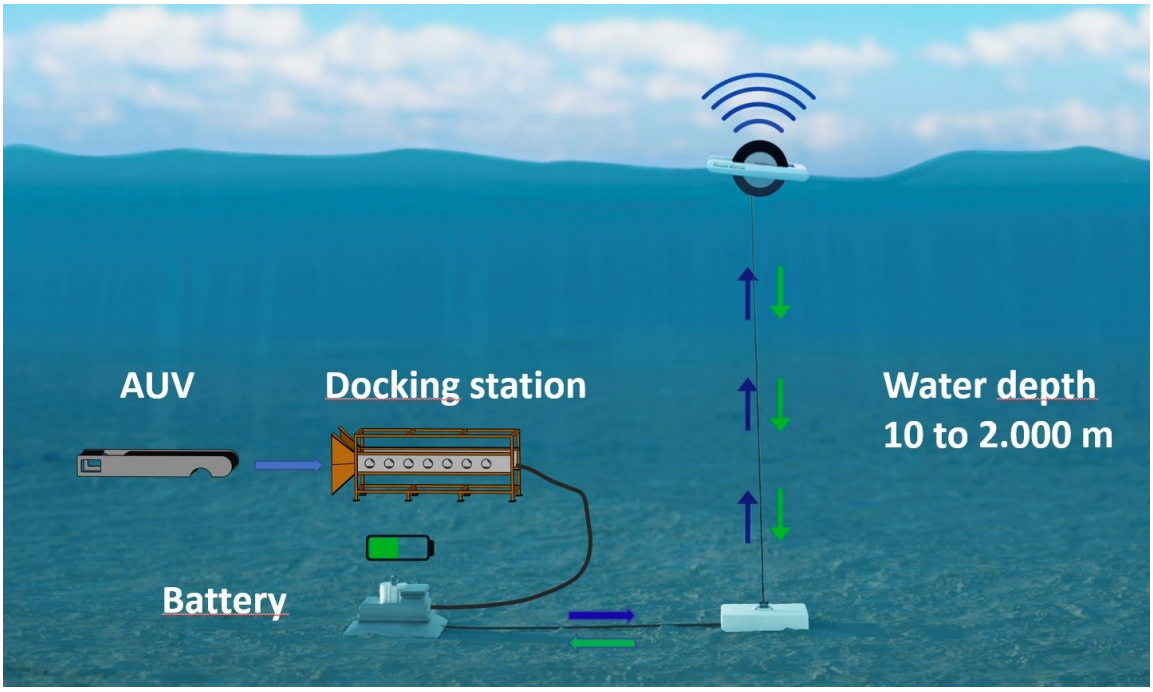
This is a complete “plug and play” system, so the customers do not have to “fiddle” with under water cables and connectors and special interfaces. We also provide a Scada display so the customers can follow the buoy operation from shore and have access to collected data in real-time, as required, and follow the power production from the buoy along with getting notifications for service inspection. The customers specify what they want to measure, and we work out a complete system for them with the necessary adaptations.

Please see the graphics below on how it is set up in the sea. At present the water depth is limited to 400m, but we already have inquiries for systems that can work in up to 2.000m water depth for special seismic and tsunami early warning systems.




During the project we have realised there is also a big future for operating Autonomous Underwater Vehicles, so called AUV`s, which can be recharged at a docking station on the seabed and send collected data back to shore after each seabed survey. From shore, the AUV at the docking station can be set up with new instructions for the next under water survey task. This replaces traditional ship operations in the sea and reduces survey costs by 90%. This is net zero and it improves personnel safety.

One ship produces 10.000 tons of CO2 /year. 200 ships in the North Sea produces 2 million tons of CO2, equivalent to 5% of the total present Danish CO2 emission. It illustrates how our small wave energy buoys could have a big climate impact by changing the way things are done. But it also creates a big incentive for the offshore industry to apply our technology because of the massive cost savings and dramatically improved safety for the personnel, which is also high on their agenda.



The 300W Smart Power Buoy has been a big step forward to generate a real commercial and profitable wave energy activity worldwide, which can put wave energy on the landscape and attract investment and political support. As the next step we see a 3 kW buoy (double size buoy in all 3 dimensions) as our next step to support the bigger AUV`s, which at present can travel up to 150 km under water between charging. The 300W and 3kW buoys will together suit our future market in providing power and data communication on the seabed for all applications.

Later the Smart Power Buoy can be further up scaled to 30kW and 300kW respectively, for new markets and applications which will require a new business model for a totally different market.

Based on lessons learned from the wind industry, we prefer to scale gradually from small to big in incremental steps, because it reduces the risk dramatically and makes the products more cost effective at each step.

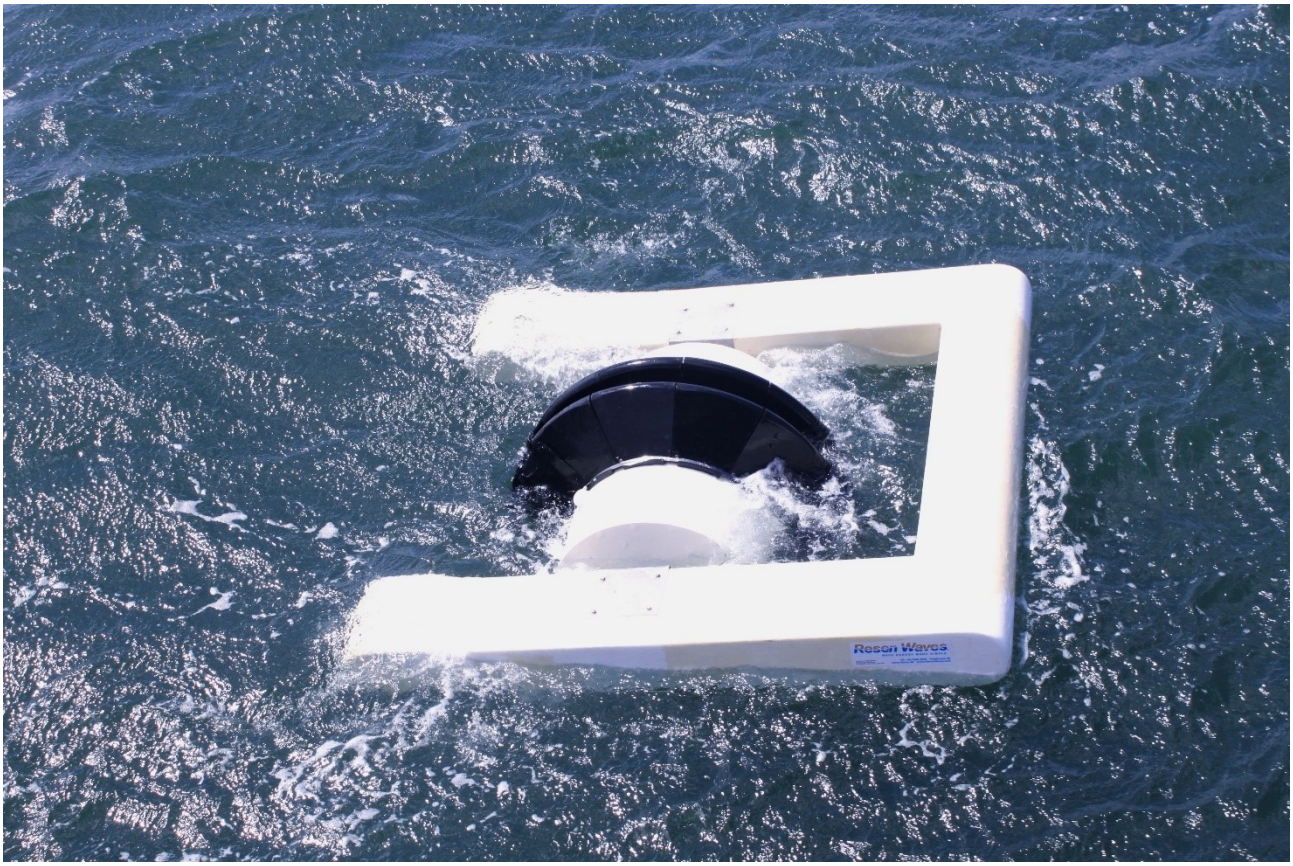
In this project small scale Wave Energy has been developed for specific commercial applications, which seems to be the right strategy from the market reaction. At present we do not have any real competition, because it takes much more knowhow to develop complete systems, than just wave energy knowledge. This builds on our many years of background in RESON.com, where we developed sonars and multi beam echosounders that could work on under water vehicles in up to 6.000m of water depth.

### a) Resen Waves basic technology:

From day one, when Resen Waves was established in 2010, the purpose was to make small-scale cost-effective wave energy buoys, which could work in full ocean exposure. At the time, the general opinion in wave energy was that small scale systems could only work in small waves and big scale systems in big waves. With a totally new approach we demonstrated that even a lab test unit for wave tank testing could be operated in the Bay of Biscay during a Winter storm in up to 11m waves, with excellent survivability.

Over the years that technology has been refined into the current Smart Power Buoy system through several funded projects, including this EUDP project. Grant funding has been necessary to get this far and now into the commercial phase.

Besides excellent survivability, the basic wave energy buoy has been designed so it has minimum structural weight and a direct mechanical to electric drive – and no hydraulics! The low total weight is directly related to low manufacturing cost. Weight is proportional to costs. In the future it could be as low as 200 kg/kW generator and with a capacity factor of 50%. (In comparison a big scale 15 MW wind turbine has a weight of 350 kg/kW generator and a capacity factor of 50 to 60%.)




The buoy consists of a low weight syntactic float and a centre waterproof cylindrical drum which contains the full drive train consisting of:  A clock spring, a gear, a unidirectional gear, a generator and a pre tensioning motor inside the drum. These listed components have gone through extensive dry accelerated fatigue testing. During a life span of 20 years in the sea, we expect up to 200 million cycles, which set the standard for fatigue testing. The mooring line is wrapped around the cylinder in the middle of a rubber belt and is automatically pre-tensioned to the seabed. When the wave pushes the buoy up and down, or back and forth, the drum turns back and forth to drive the generator in one direction, thanks to a uni-directional gear, and produces power which charges a battery in the buoy as well as on the seabed. The power is transmitted to the seabed through the mooring line, which also contains a fibre optic link for a local area network between the buoy and the seabed installation with sensors. 4G and satellite communication is installed on top of the float. The basic design of the float with the listed main components has been patented and it applies to most of the global markets in the World with access to the sea. Even though we have stripped down the design of the buoy as much as we could, there is also a lot of hidden critical design features and know-how which has been added during the project, so the buoy design is well protected.

The buoy has been demonstrated in the sea and a customer has bought the first buoy which has already been installed in the Hong Kong region.

Now we have a “pipeline” of new projects mainly in the North Sea and in the Gulf of Mexico, which we are negotiating for delivery later this year and for 2022 and 2023.

# 4. Project implementation

All members in the project team have worked on the project for at least 3 - 5 years, so the team is well established, and all knew the goals and how we would evolve the project. That has worked out to our full satisfaction. The team is very collaborative, which is also good when problems arise.

Risk is always a big issue in wave energy, because we must deal with the elements, and we do not have direct access to offshore installations except on good days with “flat” water. Focus on risk is part of our DNA. Before and during the project we must, as a routine, constantly involve all parties to identify possible new risk areas as the project evolves.

The project implementation has developed as foreseen, and we have not had any significant delays that we could not catch up with. Delays have mainly been due to delays in material supplies and delays in the wave tank due to unforeseen leak/repair work. All milestones in the project have been met.

We have experienced some minor problems of a technical nature which is something we first saw during accelerated testing. We have had some problems with the manufacturing method for a very critical carbon spring which is part of the drive train in the buoy. After intensive work we have made some important breakthroughs in how we can control the quality of the spring in manufacturing, which has been a major improvement for the future. We have also had issues with the quality of the carbon fibre materials. That has also been solved. We have found a way to specify the quality of the carbon fibres, so we reach the quality we want.

We have also seen galvanic corrosion on aluminium parts of the buoy, which we are solving together with Hempel and other suppliers of offshore coatings. When operating and testing in the sea we always observe new technical issues, which we cannot plan for in advance. Instead we must learn from what occurs in the sea and mitigate the problem. Galvanic corrosion is one of the difficult areas to mitigate. But then we involve experts and make new sea trials until it is solved.

# Project results

### b) Commercial advances:

The original project objectives have been met. We have sold the first buoy and we have new customers in the offshore segment lined up for later this year, 2022 and 2023, which is fantastic. We need only sell 5 300W Smart Power Buoys per year to be profitable, so we are on the right track.

Our solutions are mainly directed towards the global offshore market which requires real-time access to instruments on the seabed. This is a big virgin market because nobody, except us, has a commercial solution for that.

Three things have been a big positive surprise for us in the commercial market:

1) With reference to Section 3 above: Project Objectives, and to our early market focus 2 years ago before this project started, the emphasis was on providing power and real-time data communication for instruments and sensors on the seabed. This has not changed but in the meantime, it has expanded into a bigger market segment, powering Autonomous Underwater Vehicles (AUV´s) from a docking station on the seabed, and providing data communication with the AUV in the docking station. AUV´s are the future in replacing expensive ship operation and obtaining net zero operation.

2) The Danish political decision in 2020 on CO2 storage in the North Sea is very important for us. Our technical solution for powering instruments in the sea and data communication is a key to monitoring changes in underground CO2 storage, as well as monitoring seeping CO2 into the water column.
3) The interest for monitoring seismic activity on the seabed in real time is a new emerging activity, which can give early indications of early damage to underwater installations exposed to earth quakes.

In addition, we can also mention that no new competitors have shown up in the Global marketplace.

**c) Technical advances:**

The technical results have mainly been related to accelerated fatigue testing, which is very important for us to prove high reliability.

In addition, the development of the **Numeric Model of the buoy operation** has opened a new world for us. In short, it helps us to accelerate and predict the ideal geometry of the buoy and the power output in all wave climates, without having to do expensive trial and error testing in the sea. When we observe an unexpected behaviour of the buoy in the sea, we now have a tool to find out why it happens. As an example, we have observed that the buoy does not always automatically orient itself against the waves, as we would expect. The numeric tool can help us solve the problem in a foreseeable time and has stepped up our professional level in wave energy.

The goal of DTU Mekanik's work during this project has been to create a numerical simulation that accurately represents the Smart Buoy's behaviour in ocean waves. This simulation tool predicts the forces acting on the buoy and the cable, identifies the buoy's motion response, and calculates the electrical power generated by the system. Whilst the basis of the simulation is linear potential flow, a detailed nonlinear representation of the power take-off (PTO) system has been included. The accuracy of the simulation tool has been verified by comparing the numerical results with experimental data obtained from small-scale model testing, performed at Aalborg University.

The numerical model includes two software tools:

1) A **hydrostatic equilibrium module** that identifies the static location and orientation of the device. This module can either find the static position of the buoy for a given centre of gravity or identify the centre of gravity required to generate a defined static pitch angle.
2) A **hydrodynamic motion simulator** that predicts the response and power absorption associated with a particular device geometry and configuration in a pre-defined wave climate.

These tools, together with their associated documentation, are DTU's main project deliverables.

The numerical simulation activities undertaken during this project have served to **advance the state of the art, and our scientific understanding of the Smart Buoy**, in the following ways:

1) Comparison with experimental measurements has confirmed the accuracy and utility of a weakly-nonlinear potential flow approximation for this type of wave energy converter. Based on this theory, a simulation tool has been developed that can accurately predict the forces and loads on the Smart Buoy in everyday operating conditions at any installation site.
2) Quantification of the loading on the device has provided insight into how the conflicting demands of efficiency and survivability can be balanced, so that power generation can be optimised while operating the buoy safely.
3) A preliminary model for capturing the nonlinear hydrostatic and incident wave forcing effects due to large-amplitude waves and motions has been developed. This has the potential to improve the accuracy of the model and give further insights regarding the Smart Buoy's behaviour in extreme conditions.

**Two associated MSc thesis projects** have also been undertaken to further develop and verify the simulation tool:

1) **Numerical and experimental investigation of the RESEN wave energy device** submitted by Daniel Enevoldsen in February 2021. The focus of this thesis was the successful verification of the simulation tool using experiments performed at Aalborg University.
2) **A numerical study on hydrodynamic optimization of the RESEN® wave energy device deployed in the North Sea** submitted by Alicia Belda Leandro in June 2021. The focus of this thesis was identifying the impact of different geometries and operating parameters on the energy absorption and survivability of the Smart Buoy.

Both project theses are extra project deliverables.

**Dissemination:**

We aim at international conferences and exhibitions on offshore underwater technology. The North Sea is our highest priority with Denmark, Norway, and the UK, but the Gulf of Mexico and Brazil are also picking up.

So far, we have the following list of activities:

Ocean Energy Europe November 2020: Presented at conference: Smart Power buoy applications.

UTC Norway May 2021: Conference participation. Most important under water technology event.

SUT Aberdeen October 2021: Conference: Smart Power Buoy application, savings and CO2 reduction.

Ocean International UK December 2021: Conference and exhibition

GEOGULF2021 Texas November 2021: Paper: Smart Monitoring of offshore industrial sites

DTU MEK intends to report the advances at the 2022 International Workshop on Water Waves and Floating Bodies (IWWWFB) conference in Naxos, Italy, and through a journal paper which is in preparation.

# 5. Utilisation of project results

Resen Waves will be the driving force in the activity. Resen Waves owns the patents and the basic engineering design. All the other partners in the project will participate as subcontractors in manufacturing and hydrodynamic studies, as the company grows. We have a very simple and focussed business plan for growth, with focus on our near market in the North Sea and step by step expanding into all parts of the World where our solutions create value for our customers.

The goal is to develop the company into a global market leader in powering instruments and technical installations on the seabed and providing data communication from the seabed to the shore, as a total

service and “plug and play” solution, so the customers do not have to worry about technical details. It involves sales of total solutions and service contracts for maintenance. In the beginning we sell directly to our customers, no matter where they are in the World. When the sales are well established, we can consider setting up dealers or local offices. We do not see any barriers in the market, except decision making in big companies can be slow.

We have so far invoiced 1 M DKK to our first customer in Hong Kong and we are currently negotiating new contracts for 2 M DKK in 2021 and 3 and 5 MKK respectively for contracts in 2022 and 2023. When we invoice 5 M DKK per year, we are a profitable company, which will kick start external investment in Resen Waves. Later this year we will meet Equinor´s investment team, which has shown interest in our activity.

So far, we have not seen any competitors in the market, which is almost too good to be true! We have the big advantage of being the first mover in the market, which we know from past experience in RESON.com. From outside our solution looks simple but it is fairly sophisticated, so it is not easy to enter as a new competitor and we also have a strong patent in all major countries located next to the open sea.

From the earlier description of our solution for the offshore industry, we provide an enabling technology which can replace traditional ship operation in the sea, reduce operational costs by 90%, make the operation net zero emissions and improve safety as well. If it replaces 200 ships in the North Sea, it reduces the CO2 exhaust from ships by 2 million tons of CO2 per year equivalent to 5% of the total Danish current emission.

# 6. Project conclusion and perspective

With this project we feel we are on our way to a big future activity. We are confident we have a good business proposition for our customers.

We are about to open a big new market by powering AUV`s in docking stations on the sea and we believe our technology combined with standard AUV`s, is the solution which can minimize ship operation in the future and replace it by an economic and green net zero operation.

Now we can only charge small AUV´s with a 300W Smart Power Buoy. The next step for us is to develop a 3kW buoy, as the next EUDP project, so we can charge the bigger and more powerful AUV´s with an underwater range of up to 150km under, between charging and will cover the full range of commercial AUV`s.

To design and build a 3kW Smart Power Buoy means that is has to be scaled to double size in all three dimensions. This could be done with current team.

# 7. Appendices

- The Resen Waves website contains a lot of information and short videos of how the buoy works: www.resenwaves.com