everoze

experts | evolving | energy

ADMA – POWER TRANSFER IN SEA STUDY

SCOTTISH ENTERPRISE

CLIENT	Scottish Enterprise
DOCUMENT NO.	SE016-R-01
REVISION	B
ISSUE DATE	20th November 2019
STATUS	Commercial in Confidence
PREPARED BY	Zoe Barnes, Mike Newman, George Gibberd
CHECKED BY	Zoe Barnes
APPROVED BY	George Gibberd

Everoze Partners Limited is registered in England & Wales, Registration number 09588207

TABLE OF CONTENTS

DISCLAIMER

This report has been prepared and is issued by Everoze Partners Limited ("Everoze") to the named Client on the title page in accordance with the contract document SE016-P-01-A dated 30th August 2019, which governs how and by whom this report should be read and used.

VERSION HISTORY

A	First draft for client comment	15th November 2019
B	Final incorporating client comments	20th November 2019

1.Background

1.1 Introduction to project

This report has been commissioned by Scottish Enterprise on behalf of ADMA Energy (Advanced Manufacturing for Energy Applications in Harsh Environments).

It aims to provide a better understanding the challenges and opportunities for ADMA regions, presented by 'power transfer at sea' technologies, as part of integrated offshore renewable energy systems. The report considers the state of the art and barriers to the market for these technologies and if ADMA intervention could be beneficial in realising the potential of these technologies.

Whilst the scale and details of the technical and commercial challenges will vary between 'power transfer at sea' applications, all these applications present a potential opportunity both for R&D, demonstration, deployment and supply chain development for some ADMA member regions.

ADMA Energy, as part of the Vanguard Initiative uses a four-step approach to supporting projects. These steps are; Learn, Connect, Demonstrate, and Commercialise. This study primarily falls within the Learn and Connect stages of the process, and therefore particularly highlights how ADMA members can support demonstration of "Power Transfer at Sea" technologies in order to realise economic development in their regions.

ADMA Energy

ADMA Energy is a project under the EU Vanguard Initiative. 10 European regions are involved with the project;

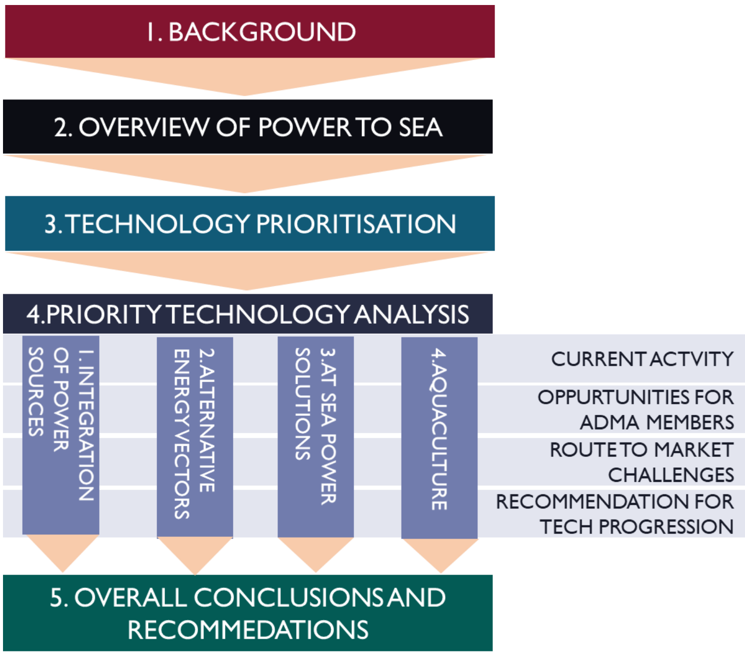
- Scotland
- The Basque Country
- Navarre
- Lombardy
- Norte
- Flanders,
- Asturias,
- Dalarna,
- Scania, and,
- Emilia-Romagna

For more information on these regions see Appendix 1.

The ADMA Energy project seeks to create new business opportunities and increase growth within the manufacturing of components and systems for marine renewable and offshore energy applications.

1.2 Navigating this report

This report introduces the project and ADMA members and provides basic overviews of the power transfer at sea technologies and uses. This is followed by a deeper dive into the technology areas identified as highest priority by ADMA members. These are then pulled together into an overall set of conclusions and recommendation for next steps for supporting power transfer at sea technology development in the ADMA regions.



2. Power Transfer at Sea

The potential for marine industries to benefit from access to low carbon electricity generation is becoming increasingly recognised by energy generators, users and public sector bodies.

Offshore renewables such as fixed and floating wind, tidal and wave generation can be used to supply energy directly to blue economy users rather than transmitting the electricity to shore. This can be beneficial to both the electricity generator and the energy user. As with all energy systems, the end-user could be the direct recipient of the energy or the energy can be stored or converted to another energy vector (e.g. hydrogen). However, the direct use of offshore energy requires the power to be transferred in the marine environment and this presents significant technical and commercial challenges such as managing the variation between supply and demand, marginalisation of components, and development of cost-effective platforms for deployment. There is a wide range of scenarios where power may need to be transferred at sea and they present different technical and commercial challenges, dominant market drivers, routes to market and technology readiness.

The technologies addressed within this report are:

1. **The integration of power sources** – Linking offshore oil and gas platforms to offshore renewable energy sources
2. **Use of offshore energy to produce alternative energy vectors** – Offshore production and storage of e.g. hydrogen or ammonia
3. **Providing at-sea power solutions** – charging platforms for survey ROVs, inspection drones etc
4. **Providing power for aquaculture** – Local standalone systems for integration with fish farms

The following sections provide an overview of the four areas of 'power transfer at sea' outlined within this report.

I. INTEGRATION OF POWER SOURCES

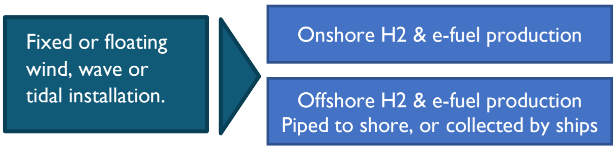
Floating wind, wave or tidal installation local to platform or local to seabed infrastructure → Offsetting platform gas turbine usage; Standalone power & process water @ wellheads

Using offshore renewables - wind, wave and tidal – to fully or partially power Oil & Gas surface platforms and seabed infrastructure. Also, to provide local process and power platforms to support Enhanced Oil Recovery (EOR) such as water injection.

Applications for this technology include:

General powering of surface platforms	**Local powering of smaller sub-sea plant modules**	**Local power and process modules for sub-sea operations**
Floating wind turbines (or wave energy converters (WECs)) are moored local to a platform and cabled into the platform electrical system. Suitable for new build platforms, retrofitting, or temporary supplies during decommissioning. Most platforms set in relative deep water so floating generation devices will be required. Therefore, the renewable generators can be easily re-located to meet changing energy demands of a particular set of O&G assets (platform or field). Generation capacity set by platform power demand; wind could e.g. range from a single 6-8MW turbine to a small farm (50-100MW). WECs are typically smaller – single units up to say 0.25MW.	Wave or Tidal Energy Converter(s) (WEC or TEC) is moored on the seabed adjacent to, or on the surface above, a subsea asset. The power is generally provided for low power applications (300W to 5kW) including: • Environmental monitoring for engineering and development; • Monitoring and control of low power equipment both subsea and topside; • Real time data analysis of installed equipment performance; • Innovative survey and fault diagnosis solutions. The systems generally integrate generation with battery storage to provide continuous power. As per the General Powering solutions, the units are not permanent and can be augmented and/or relocated to meet changing demand. Cost savings accrue from the avoidance of cabling from a central platform hub out to multiple seabed locations.	Process modules to support Enhanced Oil Recovery (EOR) (e.g. seawater processing and well injection) are integrated into the deck space of a floating wind turbine platform. The unit(s) is moored local to the seabed injection point, thereby saving on central power generation, cabling and pipelines. Process plant is designed to operate at variable capacity, reflecting the variability of local wind regime. Other potential markets in which there is currently a high level of interest include gas processing and compression modules.
Example: **Equinor's Tampen 88MW wind farm project**: Designed to provide ~35% of the power for the five-platforms in the Gulfaks and Snorre fields.  https://www.equinor.com/en/news/2019-02-05-hywind-tampen.html.	***Example:*** **East Coast Oil & Gas (EC-OG) Subsea Power Hub:** The OGTC supported EC-OG to undertake FEED work for a North Sea field trial focusing on the in-place Subsea Power Hub (SPH) design, optimised deployment procedure and de-risking the installation and operational phases. Field trials have been undertaken at the European Marine Energy Centre (EMEC) in 2017.  https://ec-og.com/.	***Example:*** **DNV-GL 'WIN-WIN' project:** DNV-GL has undertaken extensive concept development work on the WIN-WIN water injection project, and in June 2019 completed a Joint Industry Project with Exxon. Development partners are now sought for a full-scale offshore prototype project.  https://www.dnvgl.com/technology-innovation/sri/power-and-electrification/pr-win-win.html

2. USE OF OFFSHORE ENERGY TO PRODUCE ALTERNATIVE VECTORS



An Offshore Wind Farm is used to power production of either hydrogen (by electrolysis or steam reformation) or e-fuels such as Ammonia and Methanol (carbon-free substitutes for liquid hydro-carbon fuels). Production and storage can either be fully onshore, fully offshore (for vessel refuelling or collection), or piped ashore.

Applications for this technology include

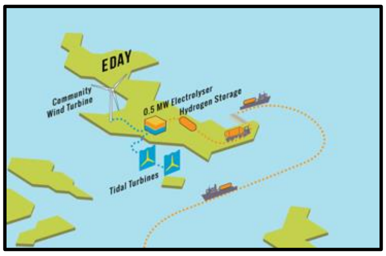
Offshore Wind Farm – power sent onshore for H2 & e-fuels production

Offshore renewable energy (wind, wave, tidal) is cabled to shore, where it is used inshore to power the production of hydrogen or e-fuels (e.g. Ammonia and Methanol).

Where the renewable power is brought onshore for H2 and e-fuel production, there is no "power transfer at sea' as such, and the technologies are largely separate; offshore wind will continue on its development trajectory and so will the H2 and e-fuel production technologies. This technology area is therefore not a focus for the present project.

Example:

EMEC 'Surf 'n' Turf' project: Tidal energy generated by prototype & demonstration turbines at EMEC's test site off Eday, combined with energy from a community wind turbine on the island, are used to power an onshore electrolyser



Once produced, hydrogen is stored and transported to Kirkwall where the fuel cell will convert it back into electricity for use by the inter-island ferries whilst berthed at the pier.

http://www.emec.org.uk/press-release-surf-n-turf-hydrogen-fuel-cell-unveiled-in-orkney/

Offshore Wind Farm – power used offshore for H2 & e-fuels production & storage

There is potential for carbon-neutral production of green hydrogen in large-scale offshore wind farms, and industrial scale solutions are in the early stages of development. Currently, the favoured configuration is to use a platform similar to those used for offshore substations, accommodating all the components required for production – including electrolysis units, transformers and desalinisation plants.

Energy generated in this way is flexible and can be transmitted by pipelines or ships.

Example:

Tractebel; Power consultancy and EPC company, Tractebel is developing a 400MW offshore platform that is intended will produce environmentally friendly hydrogen from offshore wind energy at an industrial scale.

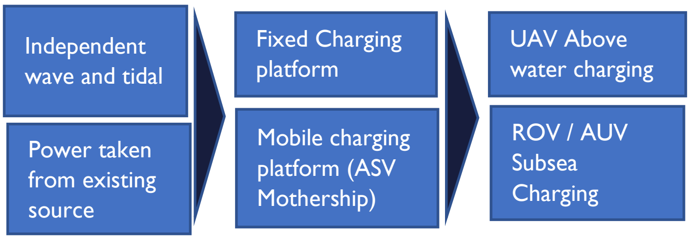
https://www.power-technology.com/news/company-news/tractebel-hydrogen-wind-offshore//

n.b. Gas reforming and full CCS, and gas reforming and CO2 capture onshore and offshore were discussed with ADMA partners and it was agreed that they lie outside the scope of this project because;

(i) the main technologies elements involved in Gas Reforming and Carbon Capture & Storage (CCS), are likely to be developed independently of any offshore renewable power source integration, and are;

(ii) the offshore power element (i.e. floating grid scale electricity production) is similarly undergoing independent development.

3. PROVIDING AT-SEA POWER SOLUTIONS



Self-charging Remotely Operated Vehicles, Autonomous Underwater Vehicles (AUVs) and Unmanned Aerial Vehicles (UAVs) are increasingly being deployed in the offshore energy, aquaculture and scientific research sectors. On-site charging and housing of ROVs and UAVs using offshore renewable energy could remove the need for and the cost of vessel charter. Existing offshore infrastructure provides the required power and high-bandwidth communication capabilities to install strategically located fixed or mobile hubs for charging and communicating with AUVs and UAVs.

Applications for this technology include

Charging platform for wind farm and other inspection drones

UAVs are currently deployed in offshore Oil and Gas and offshore wind to undertake visual inspections of the assets. Costly vessels must be deployed in order to launch, pilot and recover the UAVs. There is a drive to move towards autonomous systems that can be deployed remotely to undertake inspections. This could significantly reduce vessel costs, however charging platforms on or near offshore assets must be deployed.

Example:

Skyspecs: A leader amongst many companies offering autonomous inspection UAV services to offshore wind farm operators, Skyspecs has delivered many offshore campaigns for companies such as Ørsted and RWE. The company's system is proven to fly autonomously around the turbine to obtain optical images of the blades of an 8MW scale turbine.

http://skypecs.com

Offshore charging platform for ROVs/AUVs

Oil & Gas companies have progressed resident hybrid Autonomous Underwater Vehicles (AUVs)/Remote Operating Vehicles (ROVs) for integrated field support. Similar technology is being considered for offshore wind. Sub-sea charging for these is needed to fully maximise the benefit of this technology. On offshore wind farms, it is likely that the power for this will come directly from the turbines.

Example:

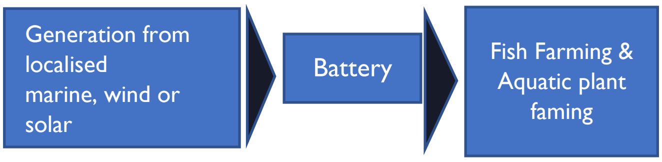
Eelume subsea resident robot: In May 2019, Eelume, backed by Kongsberg Maritime and Equinor completed trials of a subsea resident mission for longer than one month, where a subsea garage or charging platform was based on the seabed. The system was remotely operated from shore for the duration of the trials. They will be installed in Norway in 2020 for long term residence trials.

https://eelume.com/

Offshore charging for vessels

The use of electric or hybrid vessels is increasing, largely deployed so far for short ferry connections and in some cases trials of Crew Transfer Vessels (CTVs) have been demonstrated. Due to increased range offered by liquid fuels and the requirement for a new network of offshore charging points for electric CTVs, these vessels are unlikely to gain much market traction. Other technologies such as hydrogen or conventional diesel have so far taken precedent and are likely to continue, therefor offshore charging of vessels is no longer discussed in this document.

4. PROVIDING POWER FOR AQUACULTURE



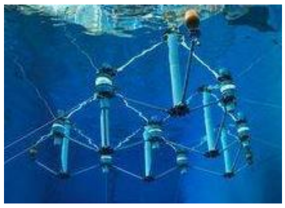
Aquaculture farms are currently paying for high electricity prices due to the need to import diesel for use in generators located offshore. This typically leads to relatively high energy costs, higher than some forms of offshore renewable energy. Wave, wind, solar or tidal generation could be located at an aquaculture site, and potentially provide an economically viable alternative.

Applications for this technology include

Local standalone power systems with integrated storage and/or diesel generators for coastal fish farms or aquatic plant farms

Use of offshore wind, wave or solar devices on aquaculture farms to reduce diesel use looks potentially economically and technically viable. It is unlikely that any of them can viably fully replace diesel, even with the use of a storage technology, due to the mis-alignment of the end-demand and energy use profiles. There is also challenges around regulation, where long planning cycles for delivery of both aquaculture and offshore renewable energy sites can challenge a project.

Example: **WaveNET SQUID**



In 2013, Albatern installed 3 WaveNET SQUID devices at Marine Harvest's salmon farm off the Isle of Muck in Scotland. A further pilot was deployed near Ardnamurchan, in conjunction with Scottish Salmon Company, which used a hybrid power management system. The pilot aimed to validate the use of Albatern's device for powering fish farms. Following the success of the pilot project, Albatern and Aquabiotech Group were planning a commercial project in Malta, however it is not clear on the current status. Plans stated that the energy needs of the fish farm are roughly 720 kW peak which will be provided by wave energy as well as storage and back up diesel generators. The fish farm will be located approximately 6 km offshore.

3. Prioritisation of technology areas

In order to ensure focus on areas of most relevance to the ADMA members an initial prioritisation was carried out. Factors taken into account were; ADMA member interest, market pull and the technical viability. The priority areas are taken forward for further analysis within this report. It should be noted only two ADMA members - Scotland and Emilia-Romagna - expressed an interest in 'power transfer at sea' technology.

The top priority areas identified were:

		Priority	Justification
Integration of power sources	General powering of surface platforms	**High**	Clear driver market-pull from O&G sector for decarbonisation and localised supply of power. Stated as a priority area for Scotland. Increased maturity of floating wind and other offshore generation means that it is becoming increasingly commercially and technically viable.
	Local powering of smaller sub-sea plant modules	**High**	
	Local power and process modules for sub-sea operations	**High**	
Use of offshore energy to produce alternative vectors	Offshore wind farm - power sent onshore for H2 and e-fuel production	**Low**	Limited 'power transfer at sea' technology required as power use is on land. Technology required to export electricity from wind farms already mature.
	Offshore wind farm – power used offshore for H2 and e-fuel production	**Medium**	Interest from members but significant concerns were expressed over the mid-long term business case both for the hydrogen and e-fuel market and the economic benefit for ADMA regions.
Providing at-sea power solutions	Charging platforms for wind farms and other inspection drones	**Low**	Little interest from partners. Technology considered to be relatively mature – no significant adaption needed for offshore use.
	Offshore charging platforms for ROVs/AUVs	**High**	High level of interest from Scotland and Emilia-Romagna. Good alignment to partner capabilities and significant market pull.
	Offshore charging platform for larger vessels	**Low**	Lack of market pull and technical and safety barriers to market mean the is limited interest in pursuing this from ADMA partners.
Providing power for aquaculture		**Medium**	Previous Everoze studies show that providing power to aquaculture from wave energy is close to being commercially and technically viable and there is pull from the aquaculture market. Scotland expressed an interest in the technology.

Technology areas scored High or Medium are discussed further within this report.

4. Technology Area 1: Integration of power sources at sea

4.1. Current activity in developing or deploying this technology

As identified above, this generic technology area has three streams, each of which is at a different stage of development and has a unique set of technical and commercial challenges and funding and support needs. The three areas are:

- General powering of surface platforms
- Local powering of smaller sub-sea plant modules
- Local power and process modules for sub-sea operations

This section discusses examples of current activity in developing these technologies. They have been broadly split into: Demonstration projects, Development projects and Research projects. This is not an exhaustive list of activity in the area but aims to provide an overview of the current technology development landscape.

4.1.1 Demonstration projects

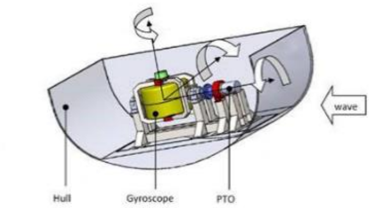
Demonstration projects are pre-commercial full system deployment. The following section outlines some key demonstration projects across the three technology areas.

Area: General powering of surface platforms	**Location: Norwegian Continental Shelf**	**Project dates: FID Oct 2020 / COD 2022**
Equinor's Tampen 88MW wind farm project:	This project is considered a demonstration project now that financial close has been reached and contracts signed. It is clearly too early to assess in terms of operational feedback. Funded by Equinor and its partners, and the Norwegian government.	
The wind farm will consist of 11 wind turbines based on the Hywind technology developed by Equinor. The 8 MW turbines will have a total capacity of 88 MW, capable of meeting about 35 percent of the annual power demand of the five exisitng Snorre A and B, Gullfaks A, B and C platforms. Life extennsion of the Gullfaks field to 2036 and the Snorre field to 2040, up to 20 years longer than when the fields were initially planned, has been essential to realizing the project. The oil and gas platforms will be the first ever powered by a floating offshore wind farm. The wind farm will be located some 140 kilometres from shore in 260-300 metres of water between the Snorre and Gullfaks platforms. About 80 % of the global resource potential for offshore wind is in deep waters, and floating offshore wind may play an important part in the energy transition towards more sustainable global energy supply. The Hywind Tampen investments will total almost NOK 5 billion. Norwegian authorities through Enova have made a funding commitment of up to NOK 2.3 billion for the Hywind Tampen project. In addition, the Business Sector's NOx Fund has decided to support the project by up to NOK 566 million.	 	
https://www.equinor.com/en/news/2019-02-05-hywind-tampen.html).		

Area: General powering of offshore platforms	**Location: Italy**	**Project dates:**
ENI / ISWEC project installed at Ravenna	Funded by ENI consortium	

The first hybrid power plant in the world producing energy from waves and photovoltaics has been installed offshore at the Ravenna facility, San Donato, 27 March 2019. ENI has successfully installed and activated the Inertial Sea Wave Energy Converter (ISWEC) production unit, capable of converting energy generated by waves into electricity and adapting to different sea conditions, so as to guarantee a high continuity in energy production, particularly for offshore energy applications.

The pilot plant was installed at the Ravenna offshore site by Eni's Central Northern District and has been integrated into the world's only hybrid smart grid system featuring photovoltaics and energy storage as well. It reached a peak power output of over 51 kW, or 103% of its nominal power. This technology is suitable for powering medium and large offshore assets and, in the future, will enable Eni to convert mature offshore platforms into renewable generation hubs. The device was developed and supplied by Waveforenergy (W4E), a spin-off from the Politecnico di Torino. Research started ten years ago, and the first Italian full-scale 1:1 device for the production of electricity from sea waves was moored 850 m from the coast of Pantelleria Island (south of Italy).



ENI's four partners in the project are; CPD (an Investment Bank), Terna (Italian Grid company), Fincantieri (Shipbuilder/Naval Arch.).

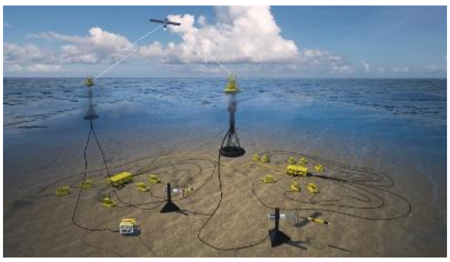
http://www.waveforenergy.com/

Area: Local powering of smaller sub-sea modules	**Location: UK North Sea**	**Project dates: 9-month field trial 2018**
Ocean Power technologies (OPT) Powerbouy PB3	Funded by OGTC & Premier Oil	

The OGCT co-funded a successful project with Ocean Power Technologies (OPT) and Premier Oil to study the feasibility of using the PB3 PowerBuoy for decommissioning operations in the North Sea. OPT's PB3 can act as an Uninterruptable Power Supply (UPS) which constantly recharges itself by harvesting energy from the waves. It is ocean-deployed, moored and floats over the point of use and can operate in any ocean depth over 20 meters and up to 3,000 meters.

The PB3 supplies power continuously to on-board payloads or equipment located on the seabed while also providing real time data transfer and communication to remote shore facilities. The PB3 is sized and designed to store sufficient electric energy to provide reliable "ride through" power in extended periods of flat-calm seas. While the power levels offered by OPT's current PowerBuoys® are not sufficient for power hungry applications such as pumps and compressors, there are numerous other equally important applications that are better suited. Such applications include:

- Environmental monitoring for engineering and development;
- Monitoring and control of low power equipment both subsea and topside;
- Real time data analysis of installed equipment performance;
- Innovative survey and fault diagnosis solutions.



https://www.oceanpowertechnologies.com/oil-gas.

Area: Local powering of smaller sub-sea modules	**Location: US/ UK**	**Project dates: 2017 subsea at EMEC, 2019 onshore trial**
Ocean Power Technologies Powerbuoy PB3	Funded by US Navy/Eni	

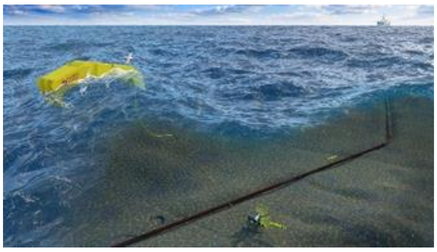
Demonstrators of the Powerbuoy have been deployed in a range of locations. The PB3 technology was demonstrated for a US Navy project to provide power to coastal security networks and survived rigorous sea trials, including operation off the New Jersey coast through Hurricane Irene in 2011.

In a subsequent deployment, the Powerbuoy has been deployed in the Adriatic Sea since November 2018 by oil and gas company Eni in a project aiming to demonstrate suitability of wave energy technologies in oil and gas operations. Operating continuously for six months, as part of Eni's MaREnergy project, PB3 Powerbuoy has produced more than 1 MWh cumulative energy to date. The demonstration will see OPT's device used for subsea battery charging, which eventually may lead to adoption of the device as a standalone charging station and communications platform that would enable the long-term remote operation of AUVs.

https://www.oceanpowertechnologies.com/pb3

Area: Local powering of smaller sub-sea plant modules/Local power process modules for sub-sea	**Location: UK Scotland**	**Project dates: OGTC 2018/19**
Mocean Energy – Seabase	Funded by Scottish Enterprise & OGTC	

Seabase is a wave energy machine small enough to fit in a shipping container yet robust enough to generate power in the harsh environment of the North Sea. Initially viewed as being used to provide backup power to subsea equipment where, for example, an umbilical fails. Longer term, Seabase will also provide green power to future generations of field-resident ROVs and Autonomous Underwater Vehicles (AUVs), reducing vessel costs and emissions (see Section 6 of the main text below).



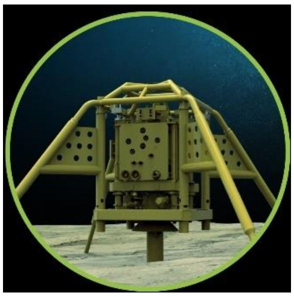
A prototype of Seabase has already undergone detailed tank testing at the world-leading facilities at Centrale Nantes, France, and they are now setting up base in Aberdeen, based on what they see as the clear ambition of the oil and gas market to decarbonise. The OGTC Tec-X programme is providing office space within their incubation centre as part of TechX Plus. Mocean Energy is an Edinburgh start-up – which has already secured £100,000 from Scottish Enterprise for the technical development of Seabase and further £100,000 from the Oil & Gas Technology Centre for its commercial development – is now seeking oil and gas partners to help bring their innovative technology to market.

https://www.theogtc.com/newsroom/news/2019/techx-pioneer-mocean-makes-waves-with-new-base-in-aberdeen/

Area: Local power and process modules for sub-sea operation	Location: UK	Project dates: 2017 subsea at EMEC, 2019 onshore trial
East Coast Oil & Gas (EC-OG) Subsea Power Hub	Funded by OGTC and Shareholders; seeking crowd funding for next phase	

In April 2019, a test programme was success completed demonstrating the Subsea Power Hub's capabilities for powering subsea production equipment using battery power alone. During workshop trials, supported by the Oil & Gas Technology Centre (OGTC) and a North Sea Operator, the Subsea Power Hub (SPH) was used to power a commercial Subsea Control Module (SCM) and local power distribution system.

The test was completed using a 3rd Generation Aker Solutions Subsea Control Module and power was delivered via a subsea distribution unit and inductive couplers, representative of a high percentage of the subsea infrastructure typically found in North Sea brownfield developments.



It successfully confirmed the Subsea Power Hub's capabilities for operating North Sea wells without a power umbilical from a topside installation. Critical to operability, the trial successfully demonstrated the full operating range of SCM functions through both operating modes; battery power and battery charging.
All testing was completed at Cohort company SEA's facility in Aberdeen, where in April 2018. The most recent test was conducted on the North Sea Operator's SCM, using an AC power supply from the Subsea Power Hub

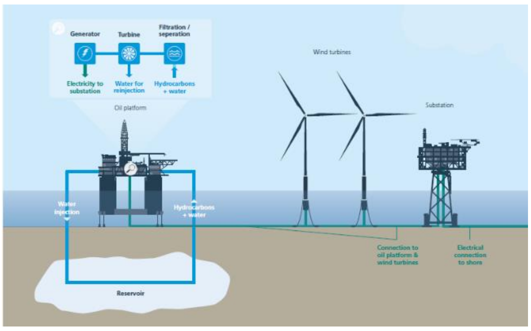
https://ec-og.com/.

4.1.2 Development projects

This section provides examples of demonstration projects. These have been categorised as projects which are under development, typically the front-end engineering having been substantially completed for a specific site/project. Projects may have secured construction finance but may still be seeking it.

Area: General powering of surface platforms	Location: N/A	Project dates: Feasibility 2013-2019
Atkins Wind Energy Reservoir Storage (WERS)	Self-funded by Atkins	

Existing O&G infrastructure and subsea wells use water injection to improve hydrocarbon production and maintain well integrity. Atkins has developed an innovative energy storage system, Wind Energy Reservoir System (WERS) which aims to utilise the existing and aging offshore production platforms and their associated spent reservoirs (partially or fully) as a high-pressure water store.



The reservoir would be pressurised using existing water injection pumps powered using wind turbines when demand is low or overnight. When demand is high and/or when the wind farm is not generating, the accumulated well pressure would drive turbine generator sets on the platforms, using the wind farms existing electrical connections to the mainland to export the electricity to the national grid.

https://www.all-energy.co.uk/__novadocuments/235256?v=635971611446400000

Area: Local power and process modules for sub-sea operations	Location: TBC	Project dates: Feasibility 2013-2019
DNV-GL 'WIN-WIN' project	Self-funded initially; JIP to end of feasibility	
The WIN-WIN project is looking to develop an integrated system consisting of a floating wind turbine supplying power to a water injection system for sub-sea oil recovery. DNV-GL has undertaken extensive concept development work on the WIN-WIN water injection project since 2013, and in June 2019 completed a Joint Industry Project with Exxon. Development partners are now sought for a full-scale offshore prototype project. DNVGL considers the business case for the technology is sound and has been proven. The development road map has been as follows, culminating in conclusion of the Phase 2 concept work:  DNVGL envisages the next step will be to build a physical prototype, potentially starting with a series of small-scale onshore units, progressing to scale equipment in a representative offshore environment. Systems integration and interface management of the different plant items are seen as critical areas of focus. A prototype could be led by an offshore facility operator or a supplier OEM, or a consortium, but will most likely be led by an offshore operator who can provide access to a suitable injection site.		
https://www.dnvgl.com/technology-innovation/sri/power-and-electrification/pr-win-win.html		

4.1.3 Research projects

Research projects are categorised as activities looking at early TRL levels (1-3). There is extensive research being carried out within universities looking at various components of integrated offshore power sources, such as the development of marine energy devices. They are not listed within this report. No pure research projects focusing on integration of power sources at sea were identified during preparation of this report.

4.2 Overview of organisations active in this area

4.2.1 Technology developers, providers and installers

The technology for large-scale general platform powering and for powering of seabed water injection for EOR is being developed primarily by oil and gas majors, notably Norway-based Equinor with their Hywind technology, and DNVGL with their wind-powered WIN-WIN water injection system. This situation is likely to remain the case because of the uncertainties in the commercial case, and the fact that platform powering is a niche market compared with global grid scale electricity production.

With the exception of the ISWEC integrated wave/storage technology which, as identified above is being progressed by ENI via an industrial consortium, the technology for powering small-to-medium scale applications is generally being led by small entrepreneurial companies such as EC-OG, OPT, and Mocean Energy. Globally there is a very large number of wave energy technology developers, however only a small number are actively involved in developing integrated renewables + storage solution bespoke for powering O&G assets.

Equinor	**DNVGL**	**ENI**
Norway / global	Norway / global	Italy / global
Norwegian state oil company (formerly Statoil). In Oil & Gas, active in exploration and full supply in 31 other countries with partners across Europe, the Americas, Asia, Australia and Africa. Owns and operates 3 UK wind farms and are engaged in further large-scale wind projects offshore the UK, Germany, and the US. Pioneering their '*Hywind*' floating spar buoy technology for deep water offshore wind. Developing the Tampen Project. A mapping study carried out by Equinor made of own-operated Norwegian Continental Shelf (NCS) fields identified other opportunities for asset powering by offshore renewables which it is pursuing.	Leading global provider of risk management and quality assurance services to the maritime, oil and gas, and power and renewables industries. Also global leaders in certifying management systems of companies across all types of industries, including healthcare, food and beverage, automotive and aerospace. Offices worldwide. Leading the WIN/WIN project.	ENI is one of the major global oil and gas players, operating in 67 countries worldwide and employing more than 30,000 people. Activities include oil and gas exploration, production, refining and selling operations, electricity and chemistry. Eni, CDP, Fincantieri and Terna join forces to create a new company for the construction of wave energy power stations on an industrial scale Ravenna, 28 October 2019.
https://www.equinor.com/en.html	https://www.dnvgl.com/	https://www.eni.com/en_IT/home.page

Mocean Energy	East Coast – Oil & Gas (EC-OG)	Ocean Power Technologies (OPT)
mocean energy	EC-OG	OPT OCEAN POWER TECHNOLOGIES
Mocean Energy is an Edinburgh-based wave energy development company that in 2019 has established a based in Aberdeen to commercialise their Seabase technology. The company previously secured £100,000 from Scottish Enterprise for the technical development of Seabase and a further £100,000 from the OGTC for its commercial development. Mocean is now seeking oil and gas partners to help bring their innovative technology to market. The wave energy converter will use battery storage to provide continuous power for range of subsea applications – from control systems to ROVs and AUVs, and monitoring and communications systems.	Based in Aberdeen, EC-OG is a small team of professional engineers experienced in developing subsea technology for first tier Oil & Gas manufacturers and operators, including subsea, well-critical equipment including wellheads, X-mas trees and intervention systems. With OGTC support, EC-OG is developing a seabed power pack comprising a vertical axis ocean current generator integrated with a battery storage system. They are now seeking £15k crowd funding for the next phase of their development.	OPT's is a New-Jersey (USA) based developer of standalone wave buoy systems with integrated battery storage for remote offshore powering applications. They are active in the environmental monitoring/surveying, defence, Oil & Gas and communications markets. Current development work is based around cost reduction (CAPEX & OPEX) to improve the economics of existing and marginal fields.
https://www.mocean.energy/	https://ec-og.com/services/	https://www.oceanpowertechnologies.com/

Waveforenergy (W4E)
WAVE FOR ENERGY
Wave for Energy (W4E) is a Turin-based spin-out from Polytecnico Turina. In the last decade W4E brought the Wave Energy Converter ISWEC from concept to a full scale 100 kW device following the stages of the roadmap proposed in the Protocols of the EU FP7 Equimar Project.
https://www.waveforenergy.com/

4.2.2 Research groups

There are numerous companies and universities in the ADMA regions involved in researching aspects of floating offshore wind, wave and tidal energy and battery storage systems. Very few groups dedicated to the integration of power sources offshore were identified during this study as most of the activity is later stage system integration. However, the University of Bologna is active in developing wave devices with a view to potentially powering oil and gas assets and the Politechnico de Torina were actively involved in the development of Wave for Energy.

4.2.3 Enabling bodies/Working groups

There are a range of both public and private sector enabling bodies and working groups supporting the development of technology for integration of offshore power sources. The key groups are listed below that are known to be actively support this technology areas and relevant to Scotland and Emilia Romagna (the only ADMA members that expressed an interest in this technology area).

Offshore Wind Industry Council (OWIC)	
Offshore Wind Industry Council	UK wide
The Offshore Wind Industry Council (OWIC) was established under the Offshore Wind Sector Deal in 2019. It consists of all the major offshore wind developers and has the remit to deliver industries commitment under the Deal. As part of this commitment, it launched a task force to look for opportunities to 'make the best use of electricity generated by renewable sources, including offshore wind'. This is being realised through the 'Solving the Integration Challenge' project, launched in March 2019. It focuses on connection of offshore oil and gas platforms to renewable energy sources and includes more innovative options such as the use of hydrogen as a vector.	
https://www.offshorewind.biz/2019/05/22/uk-tackles-offshore-wind-power-integration-challenge/	

Oil & Gas Technology Centre	
The Oil & Gas Technology Centre	UK wide
The OGTC was established in 2016 as part of the Aberdeen City Region Deal. Its aim is to help maximise economic recovery from the UK continental shelf, anchor the supply chain in the North-East of Scotland, and create a culture of innovation in the region. It funds a large number of research projects (currently over 80) across seven technology streams, to developing and deploy new technology in the UK North Sea. Several of these including EC-OG, Mocean and the OPT PB3 Powerbuoy are relevant to this current ADMA project. To date the ADMA-relevant projects have been carried out within the Marginal Fields and Decommissioning solution centres, however in 2019 the OGTC opened a new Net Zero Solution Centre and have recently held workshops with industry and academia to try and shape the initial focus areas. Future ADMA-relevant projects are likely to be undertaken within this stream.	
https://theogtc.com/	

Oil & Gas Authority	
Oil & Gas Authority	UK wide
The Oil and Gas Authority's role is to regulate, influence and promote the UK oil and gas industry in order to maximise the economic recovery of the UK's oil and gas resources. The OGA is an Executive Agency with direct accountability for exploration and development decisions and approvals. Its work includes facilitating EOR, cost reduction and decarbonisation of O&G operations, and in this role it works with OGTC and other organisations to promote technology uptake. The OGA is working closely with OGTC in the area of renewables integration.	
https://www.ogauthority.co.uk/	

ORE Catapult	
Catapult Offshore Renewable Energy	UK focused, active globally
The Offshore Renewable Energy Catapult (ORE Catapult) is a UK based National R&D centre for offshore renewables. It launched it Centre of Excellence in Floating Wind in October 2019. The centre is primarily focused on delivering cost reduction and commercial deployment of floating wind but it is one of its initial workstreams addresses powering of oil and gas platforms using floating wind plan .	
https://ore.catapult.org.uk/	

ART-ER	
ART-ER ATTRACTIVENESS RESEARCH TERRITORY	Emilia-Romagna
Formed in 2019 after the merger of two existing organisation ART-ER provides and coordinates access to over 80 regional R&D organisations, to allow access to facilities and capabilities that would be outside the reach of SMEs that dominate the regional industrial base. It has a remit both supporting innovation and R&D and building a sustainable economic development. They are an ADMA Energy member and have expressed interest further supporting development of integrated offshore energy systems.	
https://en.art-er.it	

4.3 Summary of technology status

The three areas of technology that are categories under 'integration of power sources' are at different technology readiness levels and have different drivers for and routes to development; they are therefore considered separately within this section. TRL ranges are indicated by the boxes highlighted in maroon.

4.3.1 Tech Summary: GENERAL POWERING OF SURFACE PLATFORMS[1]								
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TR9
Level of current activity in this area		None		Few scattered projects		Extensive range of projects		Range of large well-coordinated programmes

Powering or repowering O&G platforms using floating wind or wave generators appears to be technically feasible from studies carried out to date. There are no demonstration projects currently in the water. However, Equinor is leading activities, with the planned development of Tampen projects, due to be commissioned in 2022. A number of other oil and gas major are also considering options. There is a range of significant public sector programmes and support opportunities for these projects, many of which have been launched in the last year, reflecting the increased interest in decarbonising the oil and gas sector.

The preferred generation type for powering platforms, at present, is floating offshore wind. Floating wind technology is under development by a number of players globally. This technology is expected to be deployed and cost reduction achieved in due course, much as happened with fixed wind. There is already strong public sector government support for floating wind and technology innovation.

Some floating wind and wave energy technology developers, such as IDEOL, are pursuing the O&G asset powering market as a major part of their commercialisation programmes, although it is generally considered an intermediate step to full scale deployment as the market is quite niche. Technical development and project roll-out is generally being driven by the O&G majors.

ENI, a major O&G player, has established in 2019 an industrial consortium in Italy to commercialise the ISEWEC wave energy technology, with a view to providing energy solutions offshore, however, wave energy technology is some years behind floating wind in its development maturity.

[1] TRL scale based on EU Horizon 2020 TRL scale https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/support/faq/2890

4.3.2 Tech summary: LOCAL powering of smaller sub-sea plant modules								
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TR9

Level of current activity in this area	None	Few scattered projects	Extensive range of projects	Range of large well-coordinated programmes

There are several small entrepreneurial technology developers of both surface wave-buoy and seabed ocean-current generators, integrated with solar and/or battery storage capacity to provide continuous power for small to medium-powered applications (typically 10s of Watts to a few 10s of kW).

The TRL range varies between technologies, but most of the known devices have been ocean tested at full or near-full scale. The key challenge is cost reduction and system integration with the central platform. Ocean current-based systems have to operate with very low energy densities in the water, given the low speed of typical seabed oceanic currents (0.1-0.3m/s peak). Most of these developers are currently in the so-called "valley of death" situation, seeking uptake for commercial demonstration scale projects by the offshore operators and contractors.

4.3.3 Tech area: LOCAL POWER AND PROCESS MODULES FOR SUB-SEA OPERATIONS								
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TR9

Level of current activity in this area	None	Few scattered projects	Extensive range of projects	Range of large well-coordinated programmes

There has not yet been demonstration at scale or a fully integrated system. The most advanced project on this is the WIN-WIN project. It has been under development since 2013, but remains largely a desktop feasibility study and design, awaiting uptake of a prototype development programme by an O&G major. Development work would probably start with onshore component testing and system integration, before progressing offshore. A suitable offshore site has yet to be identified, and uptake is therefore likely to be only feasible by an O&G major who can bring a site and an in-depth technical. This option carries high technical risk and is probably too large and complex (and O&G-specific) for small entrepreneurial companies to pick up. To date, DNVGL's WIN-WIN project is the only major project identified in this area.

4.4 Barriers to market entry

It is important to understand the barriers to market when considering the need for intervention in the development of technology. The barriers to deployment for integration of power sources at sea are outlined in the section below. They can be broadly split into technical, commercial (including funding and access to testing and demonstration opportunities. The challenges presented by the three technology areas covered are significant different so are presented separately within this section.

4.4.1 Challenges to market entry for general platform power

Level of challenge		
TECHNICAL	**Low**	Solutions are expected to be available for key technical challenges so technical barriers are not expected to be critical. The main technical challenges to general platform powering are: • Matching the variable supply of renewable power with platform demand; • Minimising the potentially damaging cycling of existing gas turbines; • Identifying the type and capacity of energy storage system, if required. In addition, unless significant storage capacity is included, the variability of wind energy means that it is only possible for renewables to provide part of the energy requirements of a given platform or field, which reduces the commercial attractiveness. A range of technical challenges remain in developing floating offshore wind technology (fixed wind is not feasible in the typical platform water depths) and higher-power wave energy devices.
COMMERCIAL	**High**	The commercial case for general platform repowering using renewables is currently generally weak, although it is highly site and project specific and will improve with scale deployment. Projects to date have required a high level of government subsidy. For example, there is a large (~50%) additional investment needed in Tampen (partly provided by the Norwegian government) in order to bridge the gap between the cost of floating wind energy (£250/MWh) compared with gas turbines (£130/MWh). However, the Tampen project is widely seen as a sensible stepping-stone for Equinor to develop its own Hywind floating wind technology, which it is seeking to roll out globally, by means of an intermediate scale deployment. The key commercial challenges are: • Achieving significant cost reduction in floating wind and wave energy, recognising that individual projects are likely to be relatively modest scale installations. Wave energy has much further to go in terms of cost reduction and maturity than floating wind; • A regional mapping approach to project planning, considering basin characteristics and plant details and asset location, should maximise the benefit from powering platforms from offshore renewable sources but this is likely to require cross-company co-operation. On current demonstration projects, the economics are generally better the bigger the scale, however the commercial case currently remains insecure without significant government support -

FUNDING	**Medium**	Private investment in development to date, such as the Tampen project, has been led by O&G majors but has had a large element of public funding. If more demonstrations like Tampen are developed in the near future, public funding initiatives need to step in to fill the gap. EU initiatives that provide project finance to novel offshore projects may be applicable. These include InnovFin loans or InvestEU instruments, but a further investigation would be required to clarify their applicability once a project-specific example is presented. There is a high chance that these initiatives would not fit the requirements of a demonstrator and that a separate funding award may need to be crafted to get a designated project off the ground (e.g. one-off CAPEX grant). On both the EU level and UK level, smaller technology companies could apply directly to calls designed to provide funding to late stage development for SMEs (e.g. the EU's EIC Accelerator or Innovate UK's SMART Grants). Innovate UK has also previously hosted theme specific calls that fit the sector well and some technologies have been funded through (e.g. Technology for Harsh Environments from Innovate UK). The Oil and Gas Technology Centre would also be able to support later stage companies to develop their technology with indirect funding or via their accelerator programme TechX. There is also a H2020 call ES-3-2020: Integrated local energy systems, closing in January 2020 which may also be applicable to this technology area, but the budgets will be limited and would not cover the capital shortfall demands of a full-scale demonstrator.
ACCESS TO TEST AND DEMO	**Medium**	Demonstration needs to be led and at least partially funded by an and oil and gas major. It is likely that it will look to secure commercially viable projects (or near-viable projects that require only modest public sector funding) located in representative offshore environments. This has been shown to possible.
CONCLUSION ON BARRIERS TO MARKET ENTRY		
No significant technical barriers. The main challenges are commercial and securing funding. Demonstration and deployment will need to be led by the oil and gas majors with assets requiring offshore power. Evidence suggests there is growing interest from the sector in this type of technology for both reducing costs and decarbonisation. The commercial and technical case for floating wind technology is currently much stronger than for wave-based approaches.		

4.4.2 Challenges to market entry for local powering of smaller sub-sea modules

Level of challenge		
TECHNICAL	Medium	The key technical challenges for development of small localised sub-sea modules are: • Reliability of devices and systems; • Ensuring adequate storage capacity (and energy) to meet continuous power demands • Ensuring battery cooling and system safety; • Management of O&M in marine and sub-sea environments (3-year scheduled maintenance period is typical offshore target); • Marinization of technologies typically used on land; • Management of marine growth. These are significant challenges, given the harsh operating environment but should not be insurmountable.
COMMERCIAL	Medium	Cost reduction is will be necessary for small-to-medium subsea power applications, most of which are currently in the "Valley of death" stage, requiring financial and political support for demonstration projects. However, the benchmark energy cost for O&G operations is currently high due to the cost of sub-sea cabling allowing some scope for relatively high cost generation assets. There is potential for a large global market, allowing economies of scale should the relatively modest initial financing be found.
FUNDING	Medium	To date, the industry has benefited from private finance from O&G industry majors and the investment case has so far been led by these companies, but in many cases, there has been a level of public intervention. On both the EU level and UK level, smaller technology companies could apply directly to calls designed to provide funding to late stage development for SMEs (e.g. the EU's EIC Accelerator or Innovate UK's SMART Grants). Innovate UK has also previously hosted theme specific calls that fit the sector well and have provided some funding (e.g. Technology for Harsh Environments from Innovate UK). The OGTC would also be able to support later stage companies to develop their technology with indirect funding or via their accelerator programme TechX.The OceanDEMO programme is an EU-funded project or group that release funding calls to support innovative ocean energy technology demonstrators. If the generator anticipated for use in a project identified by ADMA members is innovative (e.g. a wave generator), this call might be applicable. There are no specific funding calls available for integration into O&G infrastructure but applications to general calls could be built from the generator developer's perspective, focussing on power to smaller sub-sea modules as a niche market (e.g. MOCEAN). The companies making these technologies are well advanced and to approach a significant "valley of death" period on the route to commercialisation. They risk getting stuck in a gap that is not led by O&G majors and a very competitive funding landscape. Localised demonstration funding or subsidised demand side incentives could significantly improve their chances of success. A soft programme that supported matching O&G majors (end users) and local technology developers would also be a low cost but high impact activity for ADMA members to undertake.
ACCES TO TEST AND DEMO	Low	In the early stages of development, this is likely to be least challenging of the three technologies for integration of power at sea to test and demonstrate. Initial testing it does not need to link to a fixed oil and gas asset and system integration tests can be carried out onshore. The systems are relatively small and easily deployable. As a result, early stage significant support for an end user is preferable but not completely necessary until relatively late in the development process. It also allows flexibility of where the technology is demonstrated.

CONCLUSION ON BARRIERS TO MARKET ENTRY
No insurmountable technical barriers but reliability will need to be proven. Main technical barriers are reliability and maintainability of the subsea systems and the integration and marinization of the subsea power distribution hubs. Seabed ocean currents have low energy intensities which will require large rotors to overcome friction and generate even relatively small amounts of power. The immaturity of the marine generation technology is also likely to a challenge. Commercial challenges should theoretically be less than for the large integrated offshore power systems and there is a potentially large global market, however, as this technology is being primarily driven but small entrepreneurial companies there is a significant risk of some falling into the financing 'valley of death'.

4.4.3 Challenges to market entry for local power and process modules for sub-sea operation

Level of challenge		
TECHNICAL	**High**	There are some significant technical challenges to overcome in deploying local power and process modules for sub-sea operation and the technology still represents a high level of technical risk. The key technical challenges are: • Managing system engineering and plant interfaces; • Accommodating the variability of energy output; since storage is not generally feasible at the high power levels demanded, the process plant will need to operate either intermittently, or with a highly dynamic duty cycles). Initial activities suggest there are no critical technical barriers to deployment.
COMMERCIAL	**Medium**	The commercial challenge for floating wind-powered water injection technology for EOR is currently uncertain as it still at an early stage of development. The DNVGL feasibility works identifies the circumstances under which the case can be made, however the technology has not yet been prototyped or ocean tested. There is potentially a significant global market, but as with other technology supporting critical oil and gas activities, early buy-in from oil and gas majors is critical to commercial success.
FUNDING	**Medium**	Similar to powering smaller sub-sea modules, the private investment case has so far been led by O&G majors but the investment case very often does not stack up without public intervention. Likewise, both the EU level and UK level, smaller technology companies could apply directly to calls designed to provide funding to late stage development for SMEs, including Innovate UK's specific themed calls (such as the previous Technology for Harsh Environments). There are no specific calls for development of sub-sea power hubs however, funding is available for development activities for novel offshore generators (e.g. Innovation find (NER3000 successor) and Ocean DEMO). Again, the OGTC would also be able to support later stage companies to develop their technology with indirect funding or via their accelerator programme TechX. Whilst the oil and gas majors may support one or two selected technology through the deployment, localised demonstration funding may be necessary to see a significant number of companies succeed in bring technology to market in this area. of success. A programme that supported matching O&G majors (end users) and local technology developers would also be a low cost but high impact activity for ADMA members to undertake.
ACCES TO TEST AND DEMO	**Medium**	As with developing power sources for platforms, the main system demonstration challenge is to secure commercially viable projects (or near-viable projects) and this will require a high level of support and, most likely, funding from an oil and gas asset owner. This is necessary to demonstrate that the technical challenges have been successfully overcome and set the technology up for full commercialisation. However, a significant level of component testing can be carried out before this site is secured.

CONCLUSION ON BARRIERS TO MARKET ENTRY
Main technical barriers are system integration of plant from multiple OEMs into a reliable offshore process module that can accommodate variable power output. The commercial challenges are to secure a demonstration offshore O&G site where the operator is willing to undertake a trial, and secure backing from (what will most likely need to be) an O&G major.

4.5. Opportunities for ADMA members

An opportunities review was carried out for member regions that expressed an interest in integration of power sources at sea. These were Scotland and Emilia-Romagna.

4.5.1 MEMBER: SCOTLAND Overview of the region

Scotland is part of the United Kingdom and it is located at the northern third of the island of Great Britain with population over 5.4 million. Core industries in the region include oil and gas, renewable energy, agriculture, fishing, textiles and food and drink.

The Scottish Government has been strongly supportive of renewables through innovation, planning and economic support activities. Due to the prevalence of deep water off the coast of Scotland, it is also supporting the development of floating offshore wind as a key plank of its energy and industrial strategy. It has also championed and supported marine energy development in the region through innovation funding and infrastructure development. It can be a considered a world-leading region in both floating wind and marine renewables.

The oil and gas sector is a key economic driver and the Scottish Government are looking to support the transition of the oil and gas sector towards a low-carbon economy. Given the importance of these two sectors in Scotland, it is likely that there will be a high-level of political support for initiatives that integrate these two areas. Scotland also has a high level of relevant skills, both in the oil and gas and renewables sector, with three of the most relevant national R&D centres OGCT, EMEC and ORE Catapult located in the region.

Activity on integration of power sources at sea to date in Scotland

World-leader in offshore generation technology development

The world's first commercial floating wind farm, Equinor's 30MW Hywind project (comprising 6 x 5MW spar buoys), is located off the Scottish coast. This project is not integrated with O&G assets; however it has enabled the progression of the 88MW Tampen project. It should be noted that this project is outside the ADMA regions, located between two O&G fields in the Norwegian Continental Shelf (NCS) (see section 4.1.1). Scotland is also considered a world leader in marine energy development and has supported the development of a number of marine energy companies. It hosts EMEC in Orkney, which has hosted testing of several of the wave energy devices under development globally.

Key R&D projects addressing integration of power sources to date

The OGTC and ORE Catapult, both of which are leading programmes supporting this technology are based in Scotland (see section 4.2). A number of devices for integration of power sources at sea have been tested in Scotland, including the EC-OG subsea power hub for O&G applications, that underwent testing in Shapinsay Sound.

Opportunities for economic benefit to Scotland

The opportunities for economic benefit for Scotland from development come from two potential sources, deployment in the region, benefitting companies in the region and the ability for regional companies to supply to regional project or export products and technology.

Deployment	Supply chain development/diversification
The extensive oil and gas assets in Scottish waters provide opportunities for offshore platform powering projects across the North Sea and UKCS. Project identification and development are likely to be driven by the O&G majors, and they already have a strong presence in Scotland. The oil and gas assets also provide potentially significant opportunities for projects involving wave and tidal-based continuous power supply systems for small to medium-power seabed applications. The technology is generally being developed by small entrepreneurial companies, some of which (EC-OG & Mocean) are based in Scotland. There are also reasonable opportunities for wind-powered local water injection projects to support EOR across the Scottish wasters O&G asset base.	There are opportunities for the Scottish supply chain in both floating OSW and marine energy devices and system integration with oil and gas assets. There are no Scottish-based floating wind platform developers, but it is anticipated that the Scottish supply chain will be in a good position to build floating platform structures (in former O&G fabrication yards, such as Nigg), and provide moorings (e.g. Viking Moorings, Gael Force, existing Aberdeen O&G industry etc.), dynamic umbilicals (e.g. Oceaneering) and installation and O&M vessels and services. A similar situation exists for the wave and tidal energy devices. The wide range of O&G engineering, fabrication and O&M companies in Scotland should have the capability in supporting the O&G majors in deploying this technology on UK and assets and potentially exporting products (particularly for the smaller standalone applications). There is also a significant technical consultancy sector in both oil and gas and offshore renewables that can support the deployment of the technology both in UK and overseas

4.5.2 MEMBER: EMILIA-ROMAGNA: Overview of region

Emilia-Romagna in north-eastern Italy has about 4.4 million inhabitants. The region is a cultural and tourist centre and is also a centre for agriculture, oil food and automobile, motor and mechanics manufacturing.

Emilia-Romagna has a strong oil and gas sector supporting activities in the Adriatic Sea. Offshore activity around Italy has until now mostly been limited to the northern quadrant of the Adriatic, off the coasts of Ravenna and Venice. In these regions gas wells have produced substantial volumes of natural gas for domestic Italian consumption.

There has been limited deployment of offshore renewables in the region, particularly due to a lack of natural resources, there is some wave resources but very low level of wind and tidal resource. However, there is a strong push within regional agencies to support diversification of oil and gas companies into the global renewable offshore energy market.

Activity on integration of power sources at sea to date in Emilia-Romagna

The main activities relevant to this study is the Ravenna offshore test site, located just off the coast of the province and city of Ravenna, and operated by ENI. In 2019 ENI Central Northern District installed and activated the 50kW Inertial Sea Wave Energy Converter (ISWEC) production unit, capable of converting energy generated by waves into electricity, and integrated it into a hybrid smart grid system featuring photovoltaics and energy storage. ENI plans to commercialise this technology both for medium power subsea applications, and higher power (100kW+) general platform power applications (OIWEC) In October 2019 ENI signed a deal with three Italian partners for the development of the ISWEC technology with the intention of ultimately establishing a wave energy manufacturing plant.

More broadly, there is a significant amount of activity in development of wave energy devices in Emilia-Romagna through research groups at universities such as the University of Bologna and the Politecnico di Torino. The University of Bologna also has a wave-current basin relevant for further early stage development of offshore technology.

Opportunities for economic benefit to Emilia Romagna

The opportunities for economic benefit for Emilia Romagna from development come from two potential sources, deployment in the region, benefitting companies in the region and the ability for regional companies to supply to regional project or export products and technology.

Deployment

The most likely deployment opportunities in the region relate to the small-power subsea powering of the adjacent domestic O&G assets. The wind resource is low to modest, and floating wind is therefore unlikely to be adopted for general rig powering. The opportunities for water injection are not known, although likely to be small given the predominance of gas rigs.

Supply chain development/diversification

Emilia-Romagna has no offshore renewable device manufacturers at present but some companies within the region have developed and supplied components. However, there are around 800 companies supplying into the oil and gas sector, most of which have experience of working in or designed for the marine environment. This constitutes around 5000 FTEs. This industry is dominated by a small number of major oil and gas multi-national and large number of SMEs. There is potential for diversification of these companies into development of integrated offshore energy systems for powering oil and gas assets, once the commercial case is proven. Whilst the challenges of attracting oil and gas companies into the offshore renewables sector should not be underestimated, this technology area has the natural advantage of having the oil and gas sector as end-users. This removes many of barriers to market entry for the oil and gas supply chain companies.

In addition, there are three industrial clusters active in offshore renewable energy, with much of the activity focused on wave energy. This presence of competence in both oil and gas operation and wave energy in the region, presents a strong opportunity for development of integrated devices.

Due to the presence of local market, activity to date and the potential ease of export, there is potentially a good opportunity for Emilia-Romagna to develop a supply chain in development of wave devices for powering small-mid scale oil and gas operations.

4.5.3 Summary of opportunities

Opportunities for demonstration in Scotland

The level of opportunities for demonstration was assessed according five criteria:

Suitable geography and infrastructure	Good
Political support	Good
Presence of potential supply chain companies	Reasonable
Potential market in region	Good
Access to relevant skills	Good

The presence of substantial oil and gas assets, strong political support and high level of capability in both oil and gas and offshore renewables in Scotland suggest that there are potentially good opportunities for demonstration projects in Scottish waters for all three technology areas.

Opportunities for demonstration in Emilia Romagna region

The level of opportunities for demonstration was assessed according five criteria:

Suitable geography and infrastructure	Reasonable
Political support	Good
Presence of potential supply chain companies	Reasonable
Potential market in region	Reasonable
Access to relevant skills	Good

The opportunities for demonstration focused around using wave energy to power small-mid scale oil and gas operations, are well aligned to Emilia Romagna's skills, environmental conditions and future potential markets.

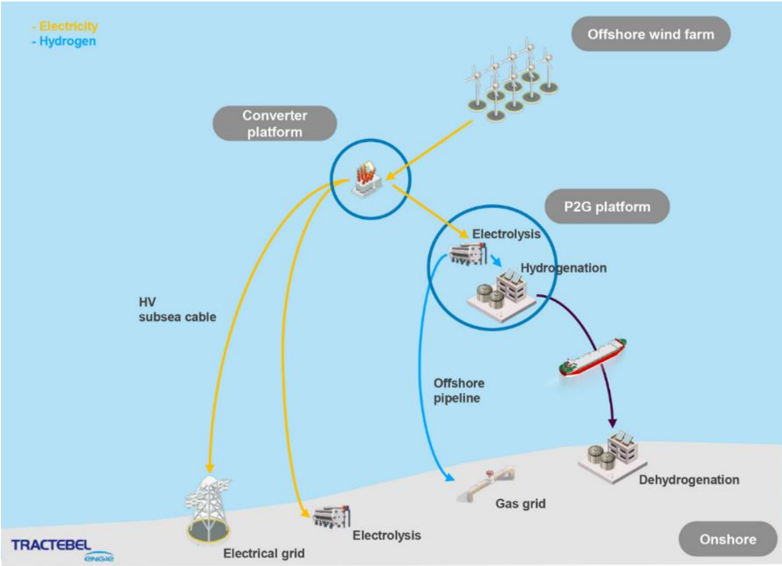
5. Technology Area 2: Production of alternative energy vectors

5.0. Background to H2 technologies

For H2, before reviewing current activity and technology, it is necessary to define the alternative energy vectors systems of interest more tightly.

There is currently a huge level of global interest from many parties in the production of hydrogen (H2) using renewable electricity, and in the downstream synthesis of H2 into so-called e-fuels (carbon-free liquid fuels like Ammonia and Methanol). Applications are potentially widespread, including the powering of heavy transport (shipping, railways, aviation, trucking, agriculture) and industrial (steel making and chemical processes).

Many routes and technologies are proposed or under active consideration for producing and using hydrogen and e-fuels, and in order to understand which technologies are relevant for this project it is first useful to consider the wider picture and the various options. Broadly, there are three options to consider when describing H2 systems are; production route, downstream synthesis of e-fuels and whether production is onshore or offshore. The various H2 pathways are illustrated below:



Source: https://tractebel-engie.com/en/news/2019/400-mw-offshore-hydrogen-production-takes-system-to-new-levels

5.0.1 H2 production routes

There are three main production routes for H2:

- **"Grey" H2** – currently the method used for 96% of global production. It uses a steam reforming process to extract H2 from methane and is thus fossil-based. It is a carbon emitting process unless the CO2 is captured and stored (CCS). Grey H2 is not a low carbon technology and is not considered further here.
- **"Blue" H2** – captures and stores the H2 from "Grey" H2 production; it still uses a fossil fuel base, but if powered by renewable energy it is carbon neutral (although this is disputed by some observers when the extra energy needed for CCS is taken into account, as well as any long-term CO2 leakage from the natural underground storage reservoirs). Large-scale uptake of blue H2 requires the parallel development of large-scale CCS.
- **"Green" H2** – uses renewable energy to produce H2 by direct electrolysis from water. Seawater can be the feedstock, provided it is pre-filtered and treated, hence the application can work offshore. Green H2 can be used in fuel cells or direct combustion engines, and in many industrial processes where it can replace the current grey H2.

A 2018 study by DNVGL "Hydrogen as an Energy Carrier[2]" concluded that:

- Offshore production of blue H2 is only cost-effective compared with onshore production of blue H2 if the platform is more than 300km offshore (based on considerations of HVDC and pipeline transmission costs).
- The cost of producing green H2 onshore by electrolysis could become lower than steam reforming with CCS by 2030, assuming the capital costs of electrolyser technology reduce significantly (which is in-line with the currently expected trajectory when assuming volume uptake).
- The cost of producing green H2 by electrolysis using offshore wind energy requires a high H2 price, driven by the cost of the wind farm. This option becomes increasingly attractive as the cost of offshore wind reduces.

This report therefore focusses on the offshore production and storage of green hydrogen (H2), using seawater electrolysis, powered by (predominantly floating) offshore wind plants.

5.0.2 Downstream synthesis of e-fuels

In addition to H2, downstream processes can be implemented to produce other energy vectors:

- ***Direct injection of H2 into the gas network***; this can only be done in relatively small concentrations without upgrading the infrastructure, although there is disagreement amongst experts as to the exact fraction that can be safely injected (estimates ranging from <1% to ~15%).
- ***Ammonia synthesis*** – this uses a nitrogen reaction process that incurs an ~8% additional energy loss, but creates a carbon-free fuel that is liquid at ambient temperature and pressure, and which despite some safety and toxicity concerns, is generally easier to store and handle than H2 (which requires either very large high pressure tanks or cryogenic storage systems).
- ***Power-to-gas (P2G)*** – the Sabatier process is used to combine H2 with the C from CO2 to produce methane that can be directly injected into the existing natural gas infrastructure. (O2 is produced as a useful side product). The CO2 can come from biogas plants, but this would only be done onshore in plants located close to the source of the biogas, and this route is not therefore considered further here.

All three of the above energy vectors are relevant to this current project.

5.0.3 Drivers for offshore production as opposed to onshore

There are three potential opportunities drive the consideration of H2 and e-fuel production plants offshore:

(i) ***Overcoming grid constraints.***
In areas where there are strong grid constraints, this poses potential curtailment problems for rolling out significant capacity of offshore wind. In Scotland, where long-term planned capacity is in the tens of GW range, this is a particular problem, and using the energy offshore to produce gaseous or liquid fuels that can be transported by pipeline or ship, offers an opportunity to avoid such constraints. (More generally, however, where onshore grid connection is not such a problem, it will generally be cheaper to transmit the power to shore and electrolyse onshore, unless the wind farm is located far offshore and the costs of HVDC transmission to shore exceed the O&M costs of the extensive offshore process plant).

(ii) ***Re-use of O&G assets.***
There is currently great interest in offshore H2 as a means of re-using existing Oil and Gas infrastructure. Around UK waters alone, there are over 600 platforms, many of which are connected to shore via pipeline, and/or have depleted O&G reservoirs that could be used for storage; these rigs offer potential re-use opportunities for offshore H2 and other energy vector production and storage. It has to be recognised, however, that many of these rigs will be unsuitable for accommodating the necessary process plant, and many others will be life-expired and life extension safety cases may not be feasible. Each project is likely to be highly bespoke,

[2] https://www.dnvgl.com/oilgas/download/hydrogen-as-an-energy-carrier.html

making it somewhat difficult to envisage a generic industry; in many cases it may be technically easier and more cost-effective to construct new-build process platforms, taking the place of a conventional offshore substation within a wind farm. Re-use of pipelines and storage reservoirs, however remains a genuine potential opportunity.

(iii) ***Offshore refuelling of vessels***
Offshore H2 or e-fuel platforms could potentially provide offshore refuelling points for vessels, rather than delivering the products to shore via pipeline or tanker. Everoze considers, however, that this route is unlikely to be pursued because most vessels are likely to refuel in harbours. This applies to vessels of all sizes and types from small fishing and leisure craft, to Ro-Ro ferries, coastal freighters right up to trans-oceanic vessels This is primarily for safety reasons (refuelling at sea is hazardous), but also logistical ones in that it is easier to build large-scale onshore fuel storage and handling infrastructure. (In much the same way, battery electric vessels such as short-passage Ro-Ros and some leisure craft, will recharge in harbours where the charging infrastructure can easily be built). This option is not therefore considered further here.

5.0.4 Summary of technologies to be considered

In the light of the above, this report will focus only on the following technology options:

- Green H2 produced offshore by electrolysis using offshore wind energy
- Energy vectors synthesised offshore from H2 such as Ammonia and P2G
- Opportunities for making use of existing O&G assets (platforms, pipelines and storage reservoirs).
- Bespoke H2 (& e-fuel) process platforms located within new offshore wind farms.

5.1 Current activity in developing or deploying this technology

5.1.1 Demonstration projects

No demonstration projects (comprising either offshore H2 production powered by offshore renewables, or offshore H2 production on its own) have been identified. There are some early stage research project underway, however related to on-turbine H2 production which could have potentially both onshore and offshore applications.

Area: Alternative Energy Vectors	**Location: N/A**	**Project dates: Feasibility 2018-2019**
HYGRO	Funded by HYGRO and ECN	

The world's first hydrogen wind turbine became a reality in the Wieringermeer area at the start of 2019. This is the objective of a partnership formed between initiator and sustainable hydrogen supplier HYGRO, wind turbine manufacturer Lagerwey and research institute ECN. The wind turbine will be producing hydrogen for the Duwaal project, the initiative of a wind-ranging consortium in the North Holland region led by HYGRO. The consortium's aim is to implement the chain of sustainable hydrogen production, distribution to at least 5 hydrogen fuel stations and 100 hydrogen trucks simultaneously.

The 4.8 MW Lagerwey wind turbine will be converted to allow it to incorporate electrolysis technology. Integration of both proven technologies will enable many components to be omitted, making the hydrogen production cheaper, more efficient and more robust.

The hydrogen wind turbine, the first of its kind, is to be demonstrated on ECN's wind turbine testing field at Wieringerwerf. In the future, wind turbines will ideally be connected up to a hydrogen gas network rather than an electricity grid. Transporting hydrogen by pipeline is significantly cheaper than transporting electricity by cable. Furthermore, pipelines serve as an inherent buffer, as a result of which significantly less harmonisation of supply and demand is required, one of the challenges that 'regular' wind and solar energy face. The sustainably produced hydrogen will be used within the compass of the Duwaal project in so-called fuel cell electric trucks. In addition to preventing CO2 emissions, this will also dispense with noise nuisance and emissions of NOx- and particulate matter. Hence the project will show how future energy infrastructure could take shape

https://www.lagerwey.com/blog/2017/10/18/de-eerste-waterstofmolen-voor-duurzame-brandstof-komt-in-nederlan

5.1.2 Development projects

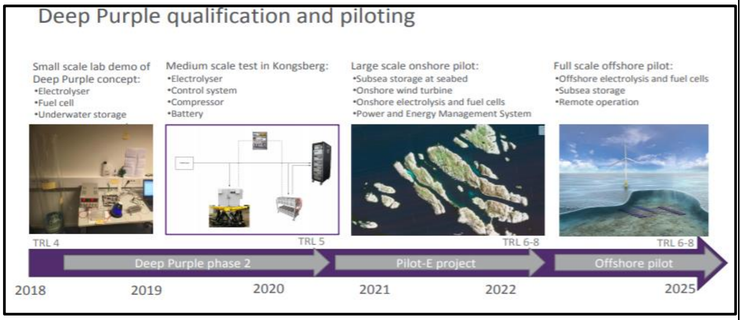
This section provides examples of development projects. These have been categorised as projects which are under development, typically the front-end engineering having been substantially completed for a specific site/project. Projects may have secured construction finance but may still be seeking it.

Area: Alternative Energy Vectors	Location: N/A	Project dates: Feasibility 2018-2019
Tractebel development project	Self-funded by Tractebel	
Power consultancy Tractebel, part of Engie, is developing a 400MW offshore platform that is intended will produce environmentally friendly hydrogen from offshore wind energy at an industrial scale. The proposed platform uses electrolysis to deliver 400 MW, which Tractebel say exceeds the output of previous technologies, and is ready to put into practise in areas like the North Sea.  The company is confident the role of hydrogen is gaining importance in the energy mix, because the proportion of "green" hydrogen or H2 derived from renewable sources can be increased on a carbon-neutral basis. In addition, the method effectively stores energy and the multiple transportation options of hydrogen provide relief for the electricity transmission grid, the capacities of which are limited. Furthermore, hydrogen can balance out seasonal fluctuations in renewable energy sources.		
https://www.power-technology.com/news/company-news/tractebel-hydrogen-wind-offshore//		

Area: Alternative Energy Vectors	Location: Dutch North Sea	Project dates: July 2019 – 2020 COD
Neptune Project	Funded by NexStep and the Dutch TNO	
In July 2019, Neptune Energy, a UK O&G independent, announced it has been formally selected to participate in a pioneering pilot project to create the first offshore hydrogen plant in the Dutch sector of the North Sea. The pilot was commissioned by NexStep, the Dutch Association for Decommissioning and Re-Use, and TNO, the Netherlands Organisation for Applied Scientific Research in close collaboration with the industry. Both wind energy and natural gas are abundantly available in the North Sea, and it seen as the perfect testing ground. Neptune's Q13a platform, illustrated, has been selected. The platform was the first in the Netherlands to be fully electrified, making it an excellent fit for this important pilot.  A megawatt electrolyser will be placed within a sea container and installed on Neptune's Q13a platform, located near the Dutch coast, 13 kilometres from Scheveningen. The hydrogen produced by the electrolyser on the Q13a platform will be transported via an existing pipeline to an offshore structure where it will be used to generate electricity. The pilot – due to begin production later in 2020 – will provide the participants with the opportunity to develop their experience of producing hydrogen in an offshore environment, and will create a testing ground for innovative technologies and integrated systems		
https://www.neptuneenergy.com/news/neptune-energy-selected-for-offshore-hydrogen-pilot/		

Area: Alternative Energy Vectors	Location: N/A	Project dates: Feasibility 2018-2019
***'Deep Purple'* Project**	Funded by Technip and industrial partners	

The Deep Purple project was conceived in June 2016 by partners including TechnipFMC, research institution SINTEF and Bergen-based technology cluster Energy Valley.



The project is coordinated by oil services company TechnipFMC, and aims to convert windfarm-generated electricity to hydrogen which can be stored on the seabed and supplied to offshore facilities on the Norwegian continental shelf. TechnipFMC has appointed hydrogen power consultancy Hyon to deliver engineering services including technology qualification and subsea energy storage. The proposed development road map is illustrated
In addition to powering offshore oil and gas installations, the hydrogen produced can also be used for zero-emission power onboard ships.

Hyon's scope of involvement also includes contributing its expertise in electrolysis, storage, and fuel cell technologies, as well as competencies within naval architecture and the design of hydrogen processes and power facilities for marine structures.

Developing technology that can store hydrogen offshore would remove challenges associated with storing the fuel on land -including perceived safety concerns - and pave the way for the use of the clean fuel at sea.

https://energyvalley.no/wp-content/uploads/2019/04/Deep-Purple-.pdf

Area: Alternative Energy Vectors	Location: UK (Desk study)	Project dates: Feasibility Oct 2019 – April 2020
***'Gigastack'* project**	Funded by £500k grant from BEIS's £20m Hydrogen Supply programme	

The Gigastack project is a feasibility study led by offshore wind developer, Orsted, along with hydrogen specialist ITM Power and consultancy Element Energy. The aim is to dramatically reduce the cost of green hydrogen by manufacturing 'stackable' 5MW electrolysers in gigawatt-scale factories and then deploying them at very large scale to exploit synergies with gigawatt-scale offshore wind farms.

The deployment of Polymer Electrolyte Membrane (PEM) electrolysers on such a large scale has not been possible to date, as it requires low-cost stack modules which are easily integrated into larger electrolyser systems, and much larger automated manufacturing facilities. In this initial phase, ITM will develop the designs for a low-cost 5MW electrolyser and a semi-automated electrolyser manufacturing facility with an annual production capacity of 1GW; Orsted will investigate how offshore wind farms can provide enough energy to allow economic operation of the electrolysers (a higher load factor increases the efficiency and therefore lowers the cost of green hydrogen production); while Element Energy "will conduct market analysis of potential end users, explore business models for the operation of large electrolysers in the energy system and define a roll-out strategy for the first 100MW electrolysers".

The implementation phase, which would require further funding, would see the 5MW stack being built and tested, the start of construction of the manufacturing facility and the refinement of the business case for large electrolysers, which would help to commercialise the technology.

https://www.itm-power.com/news-item/gigastack-feasibility-study-with-orsted

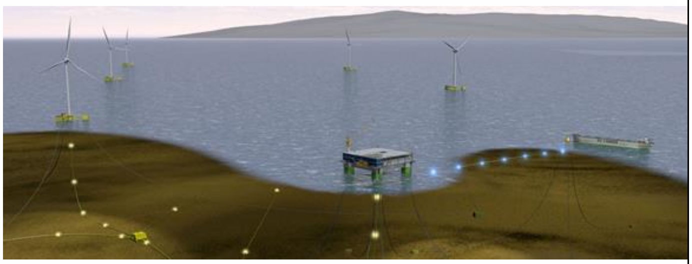
5.1.3 Research projects

Research projects are categorised as activities looking at early stage research. There is extensive research being carried out within universities industrial companies and universities, looking at various components of on- and offshore H2 and e-fuel production. Examples of projects looking at the integration of offshore energy and H2 are outlined below.

Area: Alternative Energy Vectors	**Location: N/A**	**Project dates: Feasibility 2015**
DNVGL JIDAI research project & others	Funded internally by DNVGL	

DNVGL prepared an internal desk study on the use of floating offshore wind off the Japanese coast to produce green H2 by electrolysis.

Hydrogen production requires water with very high purity, and seawater is therefore desalinated using stacks of polymer exchange membrane (PEM) electrolysers produce high-purity hydrogen and oxygen from water.



This gives the plant enough capacity to match the maximal power output of the wind farm. PEM electrolysis is at the heart of Jidai, and the electrolysers are compact and flexible, responding to intermittent power supply on a second to second basis. Hydrogen gas is then compressed to 700 bar in an ionic compressor to reduce storage volume. High-pressure H2 is stored in a module-based tank system. By using lightweight composite tanks, both weight and cost are reduced. The storage capacity is 400 tonnes of hydrogen at 700 bar, equivalent to three days of average production.

All system components have been specifically chosen to withstand the intermittent power supply from the wind turbines as well as frequent start-stop cycles without undue delay or wear. In addition, a combined battery and fuel cell backup system provides the necessary power for keeping critical equipment in operation when wind power is unavailable.

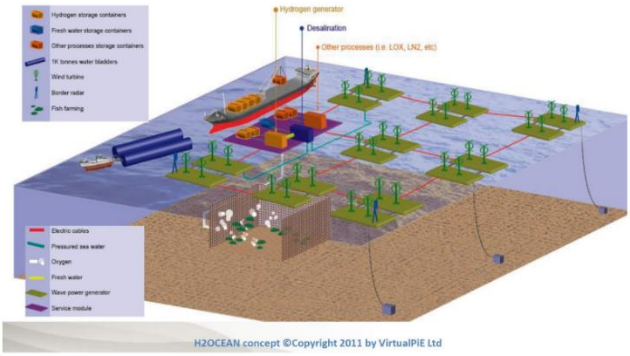
Even though the technologies in Jidai already exist, they need to be commercialized further before the concept is applicable. According to calculations, Jidai may be cost-efficient by 2030. It is not known how DNVGL proposes to progress the outputs of the project; the Japanese government, however, has made significant commitments to towards developing an H2 economy in japan post-Fukushima, and it is not coincidental that Toyota is developing hydrogen cars there (one of the few global manufacturers to be bucking the EV trend). A flavour of the activities underway is given in a March 2019 conference presentation: https://www.fch.europa.eu/sites/default/files/210-MI_Antwerp-H2_Valleys-Japan%20%282%29.pdf

In addition to the Jidai project, DNVGL is actively appraising the global energy transition as part of its future business strategy, it has prepared several research reports and position papers investigating the technical and commercial aspects of H2 within the energy transition, including in relation to its future use in shipping.

https://www.dnvgl.com/news/a-new-era-for-hydrogen-energy-unveiled-by-summer-students-at-dnv-gl-33379

Area: Alternative Energy Vectors	Location: Multiple Eu partners	Project dates: Feasibility 2012 - 2014
H2OCEAN	Funded by EU FP-7 CORDIS programme	

H2OCEAN (*Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy*) is one of the other 2 projects on multi-use offshore platforms that were selected for funding by the European Union in response to Ocean 2011 (*FP7-OCEAN.2011-1 "Multi-use offshore platforms*").



H2OCEAN aimed to develop an innovative design for an economically and environmentally sustainable multi-use open-sea platform. Wind and wave power were intended to be harvested and part of the energy was to be used for multiple applications on-site, including the conversion of energy into hydrogen that can be stored and shipped to shore as green energy carrier and a multi-trophic aquaculture farm.

The H2OCEAN consortium aims at developing an innovative design for an economically and environmentally sustainable multi-use open-sea platform. The H2OCEAN platform will harvest wind and wave power, using part of the energy on-site for multiple applications – including a multi-trophic aquaculture farm, and convert on-site the excess energy into hydrogen that can be stored and shipped to shore as green energy carrier.

http://www.vliz.be/projects/mermaidproject/project/related-projects/h2ocean.html

5.2 Overview of organisations active in this area

5.2.1 Technology developers, providers and installers

There is a vast number of organisations currently involved globally in the development, provision and installation of H2 and associated e-fuel production plant and end-use application technologies, too many to list within this document. Instead, the leading organisations currently involved in the offshore production of H2 and e-fuels and the integration of hydrogen with offshore wind and O&G assets are summarised below:

DNVGL	Tractabel / Engie	Neptune Energy
DNV·GL	TRACTEBEL ENGIE	NEPTUNE ENERGY
Norway / global	*Global*	*Global*
Leading global provider of risk management and quality assurance services to the maritime, oil and gas, and power and renewables industries. DNVGL has prepared several position papers on the global Energy Transition, Hydrogen as an Energy Vector and its role as a future shipping fuel, and the place of Hydrogen in the Low Carbon Value Chain.	Tractebel is one of the world's largest engineering consultancy companies with more than 150 years of experience. It provides multidisciplinary solutions for energy, water and infrastructure, and operates across Europe, Africa, Asia, Middle East and Latin America. It is involved in many energy transition projects.	Neptune Energy is an independent exploration and production company with a regional focus on the North Sea, North Africa and Asia Pacific. Our diverse, gas-weighted portfolio and deep industry expertise offer multiple opportunities for growth, both organically and via potential acquisition.
https://www.dnvgl.com/	https://tractebel-engie.com/en	https://www.neptuneenergy.com/

Orsted	ITM Power	ZEEDs consortium
Ørsted	ITM POWER Energy Storage | Clean Fuel	
Denmark/Global	*UK, Europe , Australia, USA & Canada*	*Nordic region*
Ørsted develops, constructs and operates offshore and onshore wind farms, solar farms and energy storage facilities, bioenergy plants and provides energy products to its customers. Headquartered in Denmark, Ørsted employs 6,500. The company vision is a world powered entirely by green energy.	ITM Power specialise in the manufacture of integrated hydrogen energy systems. Founded in June 2001, the company floated on the Alternative Investment Market (AIM) in 2004 and was the first United Kingdom-based fuel cell company to go public. ITM Power operates out of two premises in Sheffield, UK with further offices in Australia, Germany, France, the USA and Canada.	ZEEDs is the Zero Emission Energy Distribution at Sea initiative, led by six Nordic partners: Smart technology provider Wärtsilä is lead, with engineering experts Aker Solutions; Equinor; engineering, procurement and construction (EPC) provider Kvaerner; and on the shipping side by ferry and logistics specialist DFDS and shipowner Grieg Star.
https://orsted.com/en	http://www.itm-power.com/	https://energynorthern.com/2019/06/06/zeeds-consortium-hunts-additional-partners/

5.2.2 Research groups

As per the key active organisations listed in Section 5.2.1 above, there are too many research groups to list, who are involved in various technology aspects of H2 and e-fuel production and downstream applications. No specific research groups for the development of offshore green hydrogen were identified.

5.2.3 Enabling bodies/Working groups

There is a range of both public and private sector enabling bodies and working groups supporting the development of technology for integration of offshore power sources. The key groups are listed below that are known to be actively support this technology areas and relevant to Scotland and Emilia Romagna (ER). (ER is the only ADMA member that expressed an interest in this specific technology area during the survey phase).

Offshore Wind Industry Council (OWIC)	
OffshoreWind IndustryCouncil	UK wide
The Offshore Wind Industry Council (OWIC) was established under the Offshore Wind Sector Deal in 2019. It consists of all the major offshore wind developers and has the remit to deliver industries commitment under the Deal. As part of this commitment, it launched a task force to look for opportunities to 'make the best use of electricity generated by renewable sources, including offshore wind'. This is being realised through the 'Solving the Integration Challenge' project, launched in March 2019. It includes more innovative options such as the use of hydrogen as a vector.	
https://www.offshorewind.biz/2019/05/22/uk-tackles-offshore-wind-power-integration-challenge	

ART-ER	
ART-ER ATTRACTIVENESS RESEARCH TERRITORY	Emilia-Romagna
Formed in 2019 after the merger of two existing organisation ART-ER provides and coordinates access to over 80 regional R&D organisations, to allow access to facilities and capabilities that would be outside the reach of SMEs that dominate the regional industrial base. It has a remit both supporting innovation and R&D and building a sustainable economic development. They are an ADMA Energy member and have expressed interest further supporting development of offshore generation of green hydrogen.	
https://en.art-er.it	

ORE Catapult	
CATAPULT Offshore Renewable Energy	UK focused, active globally
The Offshore Renewable Energy Catapult (ORE Catapult) is a UK based National R&D centre for offshore renewables. It launched it Centre of Excellence in Floating Wind in October 2019. The centre is primarily focused on delivering cost reduction and commercial deployment of floating wind but it is one of its initial workstreams addresses powering of oil and gas platforms using floating wind plan.	
https://ore.catapult.org.uk/	

North Sea Energy	
North Sea Energy offshore system integration	Netherland and north sea basin
North Sea Energy Group is an industry-driven Shared Innovation Program that connects the wind sector and gas industry. North Sea Energy has clear goals focusing on gathering and developing specific knowledge and technology for offshore system integration in the North Sea. It is actively looking at hydrogen generation from offshore renewables.	
https://www.north-sea-energy.eu/	

5.3 Summary of technology status

5.3.1 Tech Summary: PRODUCTION OF ALTERNATIVE ENERGY VECTORS[3]

TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TR9

Level of current activity in this area	None	Few scattered projects	Extensive range of projects	Range of large well-coordinated programmes

Generation of H2 via electrolysis powered by offshore renewables is technically feasible, however there are technical challenges to be overcome in scaling up the present technology for volume production.

Several industrial consortia, research groups and working groups are researching opportunities, in conjunction with O&G majors, offshore wind developers such as Orsted and Vattenfall, and leading energy consultants and EPC contractors such as DNVGL and Tractebel, for the production of alternative energy vectors, and integration with offshore wind farms and existing O&G assets. There is currently no market pull, however, and considerable disagreement exists amongst industry players as to the extent and timing of the take-up of H2 and e-fuels. This means there are, as yet, no large-scale demonstration projects.

For offshore H2 production, the challenge is to produce de-salinated water and introduce efficient new technologies such as PEMs to produce the required H2 output. Further technical challenges include:

- matching the H2 and e-fuel rates with the variable wind farm output.
- Upgrading existing gas pipeline network for high-concentrations of H2 injection
- Integrating storage reservoirs and ensuring suitable storage conditions for compressed gaseous products

Offshore H2 production will always be in competition with onshore production, which doesn't require the system integration of de-salination plant, PEMs/electrolysers, compressor/refrigeration units. Offshore production overcomes the issue of onshore grid connection constraint (a genuine issue in Scotland if large volumes of offshore wind are to be rolled out as planned) and avoids the need for transmission cabling to shore. However, onshore plant is easier to build since it doesn't have to be integrated onto an offshore platform, and is easier to maintain, plus the product can be fed directly into land-based distribution networks (gas pipelines and port refuelling, road tankers to industrial applications etc.).

There are strong regional differences in the prospects for H2; Japan for example, appears heavily committed to developing an H2 economy post-Fukushima, and is investing heavily in R&D, including in floating offshore wind farms that could be used for H2 production.

This report does not address the end user applications, which are key to the uptake of the H2 economy. This is a much broader issue which is being researched by many organisations, however detailed analysis of the H2 market lies outside this current project.

5.4 Barriers to market entry

The barriers to deployment for integration of power sources at sea are outlined in the section below.

5.4.1 Challenges to market entry for production of alternative energy vectors

Level of challenge		
TECHNICAL	**Moderate**	There are still significant technical challenged in developing commercially viable offshore hydrogen production. The main technical challenges are: • Scaling up PEM technology for volume production • Cost reduction • Bespoke engineering for re-use of ageing O&G assets • Upgrading pipelines for high concentrations of H2 • Ensuring storage reservoir suitability for offshore storage • Lack of scale demonstration projects for system integration • System integration of de-salination plat, PEMs/electrolysers, compressor/refrigeration units etc. None of these are expected to be insurmountable, should the market drivers be in place.
COMMERCIAL	**High**	There are some significant commercial challenges in the deployment of offshore green H2 product. The two key challenges are: **1. Lack of near-term market for H2 -** It is fair to say that despite the level of interest in H2, there is currently considerable uncertainty in the extent and timing of its uptake and the development of the H2 economy. This is due to factors that include: (i) The high current cost of H2 electrolysis technology; (ii) The low Round Trip Efficiency (RTE) of hydrogen as a transport fuel (when considering the losses in the chain from electrolysis, compression or liquefaction, and transport through to final fuel cell / combustion); (iii) The competition to H2 (in terms of domestic and industrial heating) from electric-driven heat pumps; (iv) Difficulties in storing and handling H2, which requires either ultra high-pressure tanks, or ~~cyrogenic~~cryogenic systems. The UK Climate Change Committee, for example, considers that H2 is likely to remain fairly niche[4] whereas the North Sea Energy Project takes the view that the costs, both of the electrolyser technology and of offshore wind, are coming down rapidly and that this will drive an earlier and much more widespread adoption .Within the shipping industry, a market that is widely promoted as providing a potentially large future market for H2, there are similar disagreements and uncertainties; a balanced presentation of both sides of the argument can be found here: https://www.motorship.com/news101/fuels-and-oils/cutting-through-the-hydrogen-hype. **2. The cost of green hydrogen compared to other alternatives –** Large-scale deployment of electrolysers has not been possible to date as green hydrogen is currently 5-10 times more expensive than grey hydrogen, which is mainly produced by cracking natural gas and results in 830 million tonnes of CO_2 being released into the atmosphere each year, according to the International Energy Agency. The largest electrolyser factories to date are capable of producing less than 30MW of electrolysers each year. This is expected to change over the long-term. This conclusion is supported by a later 2019 paper by DNVGL "Hydrogen in the Electricity Value Chain", which concluded: *"In 2050, the combined effect of lower investments for electrolysis, availability of more low-to-zero priced electricity and higher carbon cost will make electrolysis the option with potentially the lowest levelized hydrogen production cost".* [5]

[4] https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf
[5] https://www.dnvgl.com/publications/hydrogen-in-the-electricity-value-chain-141099

FUNDING	Medium	Development and feasibility projects for hydrogen production are led by oil and gas and offshore wind majors currently. Demonstration will demand large investments to deliver system integration projects for companies with a mid to long term view. There is currently limited public funding for demonstration stage technology, excluding large funds specifically set up to fund innovative offshore renewable energy projects (e.g. the EU Innovation fund). There is however minimal commercial demand for this currently because the market for hydrogen fuel is not well established. At the development stage, both at the EU level and UK level, smaller technology companies could apply directly to calls that provide funding to early stage development for SMEs (e.g. the EU's EIC Accelerator or Innovate UK's SMART Grants). Innovate UK has also previously hosted theme specific calls for Hydrogen and it is expected that there will be more of these in the future from its work on the Industrial Strategy Fund. The Oil and Gas Technology Centre or the Offshore Renewable Energy Catapult would also be able to support later stage companies to develop their technology with indirect funding or via their accelerator programme TechX. Current EU funding calls that may be appropriate to this area are those that focus on the production of liquid fuels: RES-3-2020 - International Cooperation with USA and/or China on alternative renewable fuels from sunlight for energy, transport and chemical storage (RIA) and RES-25-2020 - International cooperation with Japan for Research and Innovation on advanced biofuels and alternative renewable fuels (RIA). Both of these calls would require a collaboration to be formed with USA and/or China or Japan respectively. Cost reduction and market facilitation are required before demonstration projects are delivered. Whilst it is outside the scope of this particular ADMA work stream, extensive support and funding is needed to create a short-mid term market pull for e-fuel, despite extensive on-going work, globally. Support for this through the wider ADMA Energy activities could stimulate the market for production of alternative energy vectors offshore.
ACCESS TO TEST AND DEMO	Low	Main players are O&G and offshore wind majors, hence access to test sites for demo at the appropriate time should be available

CONCLUSION ON BARRIERS TO MARKET ENTRY

The man challenges are the current weak commercial case and the lack of end market pull for the technology. No clear timescale or certainty for development of the H2 economy, not helped by the disagreement between the main industry players as to the extent and timing.

The poor Round Trip Efficiency of electrolysis as an energy vector for transport fuel means that there is some way to go to make it competitive.

There is also competition with heat pumps, for example, for de-carbonisation of domestic and industrial heat – direct powering by renewable electricity gains a factor of 3 of free energy whereas conversion to H2 and methane involves considerable losses.

5.5. Opportunities for ADMA members

An opportunities review was carried out for member regions that expressed an interest in technology for providing at-sea power. The only ADMA member region expressing interest was Emilia-Romagna.

4.5.2 MEMBER: EMILIA-ROMAGNA: Overview of region

RegioneEmilia-Romagna

Emilia-Romagna in north-eastern Italy has about 4.4 million inhabitants. The region is a cultural and tourist centre and is also a centre for agriculture, oil food and automobile, motor and mechanics manufacturing.

Emilia-Romagna has a strong oil and gas sector supporting activities in the Adriatic Sea. Offshore activity around Italy has until now mostly been limited to the northern quadrant of the Adriatic, off the coasts of Ravenna and Venice. There has been limited deployment of offshore renewables in the region, particularly due to a lack of natural resources, there is some wave resources but very low level of wind and tidal resource. However, there is a strong push within regional agencies to support diversification of oil and gas companies into the global offshore energy market.

Activity on integration of in Emilia-Romagna

There has been no significant activity in the region to date on development of green hydrogen offshore. The region has been actively developing the onshore hydrogen market through development programmes.

Opportunities for economic benefit to Emilia Romagna

The opportunities for economic benefit for Emilia Romagna from development come from two potential sources, deployment in the region, benefitting companies in the region and the ability for regional companies to supply to regional project or export products and technology.

Deployment	Supply chain development/diversification
Despite the presence of the oil and gas major (who are driving the offshore hydrogen market), there is little opportunity local deployment due to a lack of wind resource in the region. Large scale offshore renewable deployment will be needed to make an economic case for offshore hydrogen production and the only source of generation for this is likely to be offshore wind, for the foreseeable future. Potentially, in the future, wave energy may reach this scale, but it is some way off.	The capability of the local supply in hydrogen production technology was not reviewed in this study, so there may be potential opportunity with the region for this. However, without a local market driver, slow market development and no clear cluster of activity in this area, it seems likely that the opportunities for companies within the region for supporting the development of hydrogen offshore are likely to be niche and some way off emerging.

Opportunities for demonstration in Emilia Romagna region

The level of opportunities for demonstration was assessed according five criteria:

Suitable geography and infrastructure	Low
Political support	Reasonable
Presence of potential supply chain companies	Low
Potential market in region	Reasonable
Access to relevant skills	Reasonable

Despite a strong skill base in offshore engineering in Emilia-Romagna, the lack of wind resource is likely to limit the regions ability to host a demonstrator until wave energy is commercially deployable at scale comparable to offshore wind.

6. Technology Area 3: Providing at-sea power solutions

6.1 Current activity in developing or deploying this technology

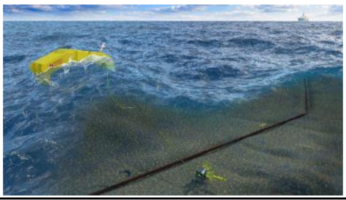
There is a trend towards increased use of both Remotely Operated Vehicles (ROVs) and Underwater Autonomous Vehicles (UAVs) in both the oil and gas and offshore wind sectors. ROVs/AUVs enable more cost effective and, in some cases, more comprehensive data collection and they are used to carry out light intervention and repair of subsea assets. This removes the need for high-risk diving operations. The development of sub-sea charging and/or docking of these autonomous vehicles would allow them to cover bigger areas or stay submerged for longer, delivering both cost and operational benefits. Therefore, development of sub-sea charging technology is a key focus for R&D within the sub-sea autonomous vehicle sector.

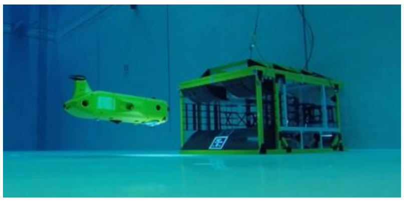
This section provides examples of key projects within the field of providing at-sea power solutions for ROVs/AUVs which have an element addressing the development of offshore or subsea docking and recharging. They have been broadly split into: Demonstration projects, Development projects and Research projects. This is not an exhaustive list of activity in the area but aims to provide an overview of the current technology development landscape.

6.1.1 Demonstration projects

There are projects demonstrating integrated technology systems and technology at TRL 5-8. Demonstrations have focussed on proving subsea docking technologies and autonomous systems.

Project: **Eelume Åsgard Residency**	Location: Norway	Project dates: 2019
	Funded Commercially	
The Eelume Åsgard Residency is a project developed by Eelume, Equinor, Kongsberg, Norwegian university of Science and Technology (NTNU). Eelume robots are designed to be permanently installed on the seabed and perform planned and on-demand inspections and interventions. A joint venture between the project partners formed in 2016 and since then, the project partners have worked together to deploy the robots on the Ågard oil field in Norway, proving their subsea docking and induction charging functionality.		
	https://eelume.com/	

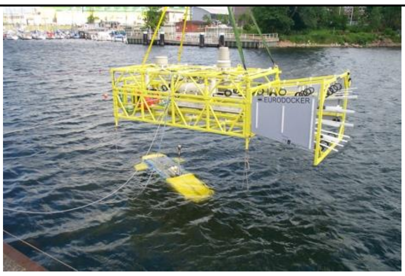
Project: **Blue Horizon Demonstration**	Location: Scotland	Project dates: 2019
	Funded by WES Wave Energy Converter Programme	
Blue Horizon is a wave energy converter developed by Mocean Energy. It is designed to power AUVs and is one of only two technologies to reach the scale prototype stage of Wave Energy Scotland's competition. The company received £3.3 million support to fund the design, manufacture and deployment of a half-scale machine to be deployed in Orkney in 2020. The prototype will utilise a purpose-built power take-off generator, C-GEN, designed and built by Edinburgh University.		
https://www.mocean.energy/wave-energy-converter/		

Project: **Flatfish**	Location: Germany	Project dates: 2013-2017
	Funded by EMBRAPII (Embresa Brasileira de Pesquisa e Inovação Industrial)	
The commercial deployment of the Flatfish is currently led by Shell, following successful demonstration. The original project aimed at designing an AUV for repeated inspections of oil & gas subsea structures whilst being submerged for extended periods of time. Its main innovation is that it is subsea-resident, as it is hosted within a docking station underwater. The project partners are: Shell, German Research ~~Center~~Centre for Artificial Intelligence (DFKI), the Brazilian Institute of Robotics (BIR) and BG Group		
https://robotik.dfki-bremen.de/en/research/robot-systems/flatfish.html		

Project: **ENDURUNS**	Location: Greece / EU wide	Project dates: Nov 2018 – Oct 2022
	Funded by EU **H2020-EU.3.4.**	
The ENDURUNS project is implementing a novel hybrid design powered by hydrogen fuel cell. It is lead by Altus SA and Birmingham University and has a wide consortium of 16 others organisations. An Unmanned Surface Vehicle (USV) will support the operation of the AUV, providing geotagging and data transmission capability to and from the Control Centre on shore. The USV will have docking capability to aid re-charging the AUV battery when the hydrogen onboard has been exhausted.		
https://cordis.europa.eu/project/rcn/218347/factsheet/en		

Project: **Autonomous Vehicle for Inspection of offshore wind farm Subsea INfrastructure (AVISIoN)**	Location: UK	Project dates: Oct 17 - Sep 19
	Funded by Innovate UK	
AVISIoN delivered a demonstrator of a low cost, fully autonomous subsea inspections and survey system for offshore wind farms. It is being developed by Modus Seabed Intervention, ORE Catapult and Osbit Power. The key optimisation was delivered by Osbit, who developed an innovative subsea docking station to allow the permanent residency of the AUV offshore. ORE Catapult tested and demonstrated the AUV hardware developed in the project off the UK coast. A report is due from ORE Catapult on the potential lifetime savings on a wind farm that could be realised by the technology.		
https://gtr.ukri.org/projects?ref=103894		

Project: Open source Subsea Docking Station (SDS) Development	Location: Norway	Project dates: 2019
	Funded by Equinor	
Based on Equinor's Underwater Intervention Drone (UID) standard interface definition, Blue Logic produced the world's first universal, open-standard subsea drone docking stations. There are three types of connectors on the docking station: 2kW, 250W, and 50W. All supply both power and data transfer and communication. The latest version of the UID Subsea Docking Station (SDS) lands all currently available drones. Blue Logic has performed interface checks with SAAB Seaeye, Oceaneering, Saipem and Stinger. Standardisation is a big step forward for the sector, however the dock is designed for inspection class AUVs typically used in offshore wind and O&G. It is likely too costly in design to suit smaller AUVs used in industries such as scientific research.		
https://www.bluelogic.no/news-and-media/subsea-docking-station-sds-		

Project: **EURODOCKER**	Location: Germany / EU-wide	Project dates: Dec 1997 – May 2001
	Funded by FP4-MAST 3	
The project was of the earliest demonstrator projects for demonstration of the technology necessary to accomplish automatic docking of an AUV to a docking station that is either lowered from a surface ship or mounted to an unmanned underwater platform on the seabed. The project lead was the University of Hannover. The other project partners were: The Danish Technical University (DTU), Studio 3 Ingegneria, Orca Instrumentation, Maridan Gisma Steckverbinder.		
https://cordis.europa.eu/project/rcn/38893/factsheet/en		

6.1.2 Development projects

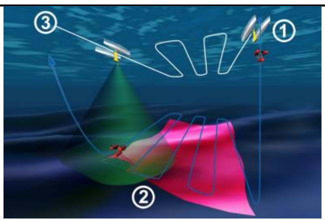
This section provides examples of demonstration projects. These have been categorised as projects which are under development, typically the front-end engineering having been substantially completed for a specific project. Development projects are focussed on less advanced AUV technology such as swarming (multiple AUVs controlled simultaneously) and upscaling ASVs.

Project: **Oceanid™**	Location: Norway	Project dates: 01/05/2016 – 31/08/18
	Funded by EU H2020-EU.2.1.1, H2020-EU.2.3.1	
The Oceanid™ is a product designed for sea bottom data acquisition in deep water (e.g. 3000m) across large areas. The developer is Abyssus Marine Services. The project developed the ability to connect an Ocean Bottom Node (OBN) with "swarms" of AUVs to quickly covering large areas and exploring of the ocean floor. The AUV is novel because it is powered by gravity and ballast shift only. The concept relies on the development of the ability to recharge and dock on a ship.		
https://cordis.europa.eu/project/rcn/204237/factsheet/en		

There is a large amount of development activities being carried out on providing at-sea power solutions. Examples of additional demonstration projects are outlined in Appendix 2.

6.1.3 Research projects

Research projects are categorised at activity on technology within TRL 1-3. The following section outlines examples of projects looking at early stage technology for at-sea power solutions.

Project: **TRIDENT**	Location: Spain / EU-wide	Project dates: Mar 2010 – Feb 2013
	Funded by FP7-ICT	
Development of a concept for multipurpose underwater intervention tasks with applications such as underwater archaeology, coastal and ocean observatories, oceanography and offshore industries. The TRIDENT project brings together research skills specific to the marine environments in navigation and mapping for underwater robotics, multi-sensory perception and a range of control techniques relating to intelligent control architectures, vehicle-manipulator systems and dexterous manipulation. Partners in the projects were all Universities: Herriot Watt in Scotland, Universitat de les Illes Balears and Universitat de Girona in Spain, Universitat Degli Studi Di Genova and Alma		

Mater Studiorum-Universita di Bologna and Graal Tech SRL, and Instituto Superior Tecnico in Portugal.		
https://cordis.europa.eu/project/rcn/93968/factsheet/en		
Project: **EXCELLABUST**	Location: Croatia / EU-wide	Project dates: Jan 2016 – Dec 2018
	Funded by **H2020-EU.4.b.**	
EU funded project to support University of Zagreb Faculty of Electrical and Engineering (UNIZG-FER) in Croatia to increase its capabilities in marine robotics, focussing on: 1) mapping and perception, 2) advanced navigation, guidance, and control, and 3) autonomy and cognition		
https://cordis.europa.eu/project/rcn/199363/factsheet/en		

6.2 Overview of organisations active in this area

6.2.1 Technology developers' providers and installers

Demonstration of at-sea power solutions for AUVs has been largely been driven, to date, by Oil and Gas end-users (e.g. Equinor, Shell) and small-medium sized companies (e.g. Modus Subsea Intervention). Companies that are developing the technology typically have a subsea services background or in some cases have emerged as technology spinouts from universities (e.g. Eelume). There is a particularly strong level of activity in Germany, Norway and the UK. Key developers, providers and installers are outlined below.

Eelume	**Kongsberg Maritime**	**Modus Seabed Intervention**
Eelume SUBSEA INTERVENTION	KONGSBERG	MODUS
Norway, Scotland	*Global, HQ in Norway and robotics arm represented in Aberdeen, UK*	*UK*
Spin out from Norwegian university of Science and Technology, commercialising the Eelume AUV in partnership with Kongsberg and Equinor.	Norwegian technology company, established in1814. Company delivers systems for dynamic positioning and navigation, marine automation, safety management, cargo handling, subsea survey and construction, maritime simulation and training, and satellite positioning.	Specialist global provider of modular subsea vehicles and managed services for inspection, intervention, trenching, survey and construction support.
https://eelume.com/	https://www.kongsberg.com/maritime/	https://www.modus-ltd.com/

Oceaneering	**Saab Seaeye**	**Blue Logic**
OCEANEERING	SAAB	
Global	*Global, HQ in UK*	*Norway*
A large applied technology development and subsea services organisation, it offers remotely operated vehicles, built-to-order specialty subsea hardware, deepwater intervention and manned diving services, non-destructive testing and inspection,	Saab Seaeye manufactures ROV systems for a wide range of professional applications. It is the manufacturer of the Seaeye Falcon, used and adapted by AUV innovators for use in subsea docking demonstration projects.	Subsea product development firm and leading developers of inductive subsea connectors. Blue Logic are heavily involved in taking forward subsea docking and charging technology. Blue Logic produced the universal, open-standard subsea drone docking stations with Equinor.

and engineering and project management services.		
https://www.oceaneering.com/	https://www.saabseaeye.com/	https://www.bluelogic.no/home

6.2.2 Research groups

Robotics and subsea research groups are the key bodies contributing to the development of at-sea power technology development. They collectively have a global reach and are generally well-established organisations.

ORCA Hub	Edinburgh Centre for Robotics	NSRI
UK	*Scotland*	*UK*
ORCA Hub is part of the UK Government's £93m R&D funding on "Robotics and AI for Extreme Environments" through the Industry Strategic Challenge Fund (ISCF). The fund is delivered by UK Research and Innovation (UKRI) and managed by the Engineering and Physical Sciences Research Council (EPSRC).	The EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems (CDT-RAS) is hosted at the Edinburgh Centre of Robotics. The organisations aim to realise the industrial potential of robotics, by producing highly skilled researchers, trained to take a central role through technical skill coupled to industry and market awareness.	The National Subsea Research Initiative (NSRI) facilitates academia and industry, enabling market acceleration of technology and commercialisation of products for subsea sectors within the UK.
https://orcahub.org/	https://www.edinburgh-robotics.org/	http://www.nsri.co.uk/

SINTEF	Deepstar	Jamstec
Norway	*Global*	*Japan*
Research Organisation with research teams on subsea power and power electronics. It has laboratories, equipment and expertise to test and develop materials and components for demanding environments.	DeepStar is a joint industry technology development program focused on advancing Deepwater Oil and Gas technologies, including playing a role in standardisation of subsea docking technology.	Japan Agency for Marine-Earth Science and Technology (JAMSTEC) supports academic research for improvement of marine science and technology, including funding a number of AUV developments.
https://www.sintef.no/en/subsea/#/	https://thedeepstar.com/	https://www.jamstec.go.jp/e/

6.2.3 Working groups/Enabling bodies

Enabling bodies that offer support to the at-sea power sector solutions support from the key industry sectors where these technologies are utilised; O&G, offshore wind and subsea. The only working group, that this study uncovered, specifically focussed on the at-sea power sector was the Subsea Wireless Internet Group (SWiG).

Subsea UK	**Offshore Renewable Energy Catapult**	**The Carbon Trust Offshore Wind Accelerator (OWA)**
Location: UK	Location: UK	Location: UK
Subsea UK is a not-for-profit member-supported industry body that promotes the UK's underwater supply chain companies.	The UK's leading technology innovation and research centre for offshore renewable energy. Involved in multiple AUV R&D projects for use in offshore wind.	The OWA programme involves nine offshore wind developers, accounting for 76% of Europe's installed offshore wind capacity. The group have conducted multiple studies and projects on powering of AUVs.
https://www.subseauk.com/	https://ore.catapult.org.uk/	https://www.carbontrust.com/offshore-wind/owa/

Society for Underwater Technology (SUT)	**Oil and Gas Technology Centre**	**Oil and Gas Innovation Centre**
Global	Scotland	Scotland
A multidisciplinary society that brings together organisations and individuals with a common interest in underwater technology, ocean science and offshore engineering.	Established in October 2016 with £180 million from the Aberdeen City Region Deal, the OGTC aims to be the go-to technology centre for the oil and gas industry - both in the UK and internationally. It supports companies via it's accelerator and at-sea power or docking station solutions would be within its scope.	OGIC supports and funds innovation in the oil and gas industry. It focusses on industry challenge-led demand by providing innovation support.
https://www.sut.org/	https://theogtc.com/	https://www.ogic.co.uk/

Subsea Wireless Internet Group
UK
The SWiG members are working together to define standards that facilitate interoperability between users' subsea wireless technologies (acoustic, radio frequency, free space optics, etc). SWiG engages with relevant standards bodies, and promote best practices across the industry.
https://subseawirelessgroup.com/

6.3 Summary of technology status

4.1.3 SUMMARY OF STATUS OF TECHNOLOGY								
TRL 1 [6]	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TR9
Level of current activity in this area			None		Few scattered projects		Extensive range of projects	Range of large well-coordinated programmes
Providing at-sea power for AUVs is a hotbed of activity globally and commercialisation of this key area is required in order to enable AUVs to cover larger areas or stay submerged for longer. The market is well advanced, and many are competing in this space. A wide range of docking o charging technologies been developed as part of AUV/UAV R&D programmes, although the most advanced technologies are those deployed in O&G. While concepts have reached demonstration, there is still a significant amount of technology development needed to adapt it for use in industries both inside and outside of O&G. Providing power for AUV technology is a key part of the development of the sector.								

6.4 Barriers to technology market entry for at-sea power solutions

The barriers to market must be considered when identifying the need for intervention in the development of technology. The barriers to deployment for technology providing at-sea power solutions are outlined in the section below. They can be broadly split into technical, commercial (including funding and access to testing and demonstration opportunities.

6.4.1 Challenges to market entry for technology providing at-sea power solutions

Level of challenge		
TECHNICAL	Low	Key technical challenges include: • **Subsea power transfer technology -** The lack of well-developed solutions for the transfer of power from a docking station to the vehicle. While some have made progress, solutions are still not cost effective for all applications. • **Shallower water applications -** Most activity to date has been on deep-water AUV docking technologies. Docking stations for shallower water such as for offshore wind may be challenging to deliver due to the manoeuvrability of the AUV (e.g. near the surface of the sea) or because the current products are over specified for shallow water deployment. • **Larger spatial areas -** The area covered by an offshore wind farm or a scientific site investigation is typically greater than for an offshore oil and gas installation. This means that the range of the AUV must increase or the number of docking stations (i.e. to reduce the distance between charging) must increase in order to deploy the technology into other sectors. • **Standardisation for low cost industries -** Enabling the standardisation of docking and charging facilities beyond the oil and gas industry, where it currently may be over specified or too costly if directly translated to other industries.
COMMERCIAL	Medium	Key commercial challenges include: • **Lower margin industries -** The margins and challenges offered by the oil and gas industry are useful in driving forward the technology, but the price point will need to shift when moving to more cost sensitive industries like offshore wind. • **Space/cost trade off -** Increasing the number of docking stations to cover larger areas may increase costs to a point where it becomes unviable to deploy. In this situation, an ASV/AUV combination should be considered.

[6] TRL scale based on EU Horizon 2020 TRL scale https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/support/faq/2890

<table>
<tr><td>FUNDING</td><td>Low</td><td>Demonstration stage technology development of marine technologies typically suffers a public funding gap, as the leap to commercial develop can be deemed too risky by industry to take on. For charging and docking solutions for powering UAVs and AUVs in Oil and Gas, the private sector has stepped in to fill the gap. The industry is led (and funded) by larger oil industry corporates, like Equinor, and smaller technology developers, which face a number of options for funding technology development publicly.
On both the EU level and UK level, smaller companies could apply directly to calls designed to provide funding to late stage development for SMEs (e.g. the EU's EIC Accelerator or Innovate UK's SMART Grants). Innovate UK has also previously hosted theme specific calls that fit the sector well and some technologies have been funded through (e.g. Technology for Harsh Environments from Innovate UK). The Oil and Gas Technology Centre would also be able to support later stage companies to develop their technology with indirect funding or via their accelerator programme: TechX.
Where it is less clear that the private sector is active in taking the technology forward is in other sectors that would utilise at-sea power for UAVs and AUVs; including offshore wind, aquaculture and science and research missions . These are sectors where profit margins are lower and the technology must be more cost effective/fit for purpose. Similar public funding calls to those available to O&G technology developers would be available to companies in other sectors. There are also a number of offshore wind specific funding calls available in the last stages of the Horizon 2020 funds e.g. RES-19.2020 Demonstration of innovative technologies for floating wind farms, closing 11 December 2019. The Horizons Europe programme is also expected to offer continued effort to these sectors.</td></tr>
<tr><td>ACCESS TO TEST AND DEMO</td><td>Medium</td><td>Key test and demonstration challenges include:
• Demonstration in offshore wind - Lower cost solutions for the Offshore Wind industry are further behind in development than those for the oil and gas industry. Further demonstration projects with offshore wind and aquaculture end user buy in should be delivered next in order to progress the technology.
Autonomy - The oil and gas industry are the furthest ahead with AUV and docking technology asset owner acceptance, where demonstration projects have shown pilot-less AUVs to work. Younger industries like the offshore wind industry are further behind with accepting un-piloted AUVs go near critical subsea infrastructure. While not strictly related to the provision of at-sea power, it is a barrier to the uptake of AUV technology more broadly.</td></tr>
<tr><td colspan="3">CONCLUSION ON BARRIERS TO MARKET ENTRY</td></tr>
<tr><td colspan="3">The technical challenges to development of the technology AUV range (or number of charging points) and shallower water depth restrictions are not insurmountable for well-funded initiatives such as those in O&G. Test and demonstrations outside of O&G are proceeding but would most likely benefit from some form of support, including increased R&D&D funding.</td></tr>
</table>

6.5. Opportunities for ADMA members

An opportunities review was carried out for member regions that expressed an interest in technology for providing at-sea power. The only ADMA member region expressing interest was Scotland.

4.5.1 MEMBER: SCOTLAND Overview of the region

Scotland is part of the United Kingdom and it is located at the northern third of the island of Great Britain with population over 5.4 million. Core industries in the region include oil and gas, renewable energy, agriculture, fishing, textiles and food and drink.

There is strong political support and a range of programmes to encourage diversification of the oil and gas supply chain into the offshore wind sector. Advancement of the UAV sector provides a good opportunity to do this and is therefore likely to get strong political support.

Activity on on at-sea power solutions to date in Scotland

Many O&G majors that have a presence in Scotland, such as Chevron, Equinor and Shell are actively working to enable rapid development and to address the various technology gaps and challenges around subsea/surface charging and docking. Local offshore wind farm owners are also beginning to see the potential for delivering AUVs with offshore charging platforms, with trials already completed by Modus Seabed intervention (in Australia and potentially soon in the Moray Firth) and soon to begin with ROVCO in the UK. A key part of these tests is proving subsea docking and charging capabilities.

There is a hotbed of underwater robotics expertise in Scotland. The Orca Hub, EMEC and ORE Catapult (all have ongoing R&D projects related to underwater robotics technology, largely focussed on the inspection and intervention in offshore wind energy assets. There are a number of Scottish-based power-at-sea technology developers such as Mocean, which has received significant funding from WES to develop its wave energy generator for powering AUVs (see the Blue Ocean Demonstration project in section 6.1.1).

Opportunities for economic benefit to Scotland

The presence of local high-growth technology companies and large corporates offers a clear case for increased jobs and economic benefit should the sector continue to be supported.

Deployment	Supply chain development/diversification
The Scottish government is strongly supporting the development of offshore wind and there is already a high level of O&G activity in the region. As such, the local market provides a fertile ground for technology developers to deliver demonstrations to customers and prove the business case for providing at-sea power for AUVs. The previously mentioned O&G majors and local technology developers would be the starting point for securing this value locally.	Scotland has a reasonable strong base of UAV developers and power electronics companies and large base of sub-sea inspection companies. For many of these companies the next technology step will be development of sub-sea charging platforms and the potential to integrated with renewables adds another potential competitive advantage. Beyond the indigenous market, the export market for these technologies is global and the physical size of the technologies means that manufacturing can logistically remain in Scotland and target a global export market.

Opportunities for demonstration in Scotland

The level of opportunities for demonstration was assessed according five criteria:

Suitable geography and infrastructure	Good
Political support	Good
Presence of potential supply chain companies	Good
Potential market in region	Reasonable
Access to relevant skills	Good

Scotland's seas are home to many native offshore assets, where AUV technology will no doubt proliferate in the future. The established O&G industry in Scotland is a strong political and economic pillar for the country and offers a well-matched and qualified skill-base for the development of at-sea power technologies, and a number of companies are already delivering into this market.

7.Technology Area 4: Providing power for aquaculture

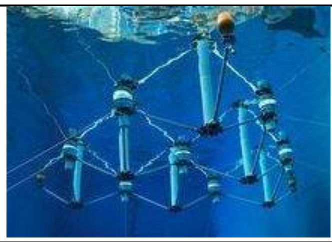
7.1 Current activity in developing or deploying this technology

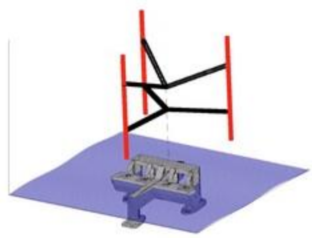
There have been a number of demonstration projects to date that have begun to prove that providing offshore renewable power for aquaculture sites is potentially both technically commercially feasible. Wave power has been successfully demonstrated and commercial integrated wave to aquaculture projects are in planning. There is significant interest from end users in using wave energy and offshore wind energy to power sites.

This section provides examples of key projects within the field of providing power for aquaculture, largely focussed on removing the hurdle of demonstrating the wave energy generator and balancing energy demand and supply.

7.1.1 Demonstration projects

There are projects demonstrating integrated technology systems and technology at TRL 5-7. Many EU-funded projects and programmes have focussed on delivery of multi-use offshore platforms that combine renewable energy, aquaculture or other offshore assets into a single platform. As part of these projects, a number of renewable power for aquaculture concepts were designed or demonstrated.

Project: Albatern demonstration	Location: Scotland	Project dates: 2015
	Funded by Wave Energy Scotland	
In 2013 Albatern installed 3 WaveNET SQUID devices at Marine Harvest's salmon farm off the Isle of Muck. A further pilot was deployed near Ardnamurchan, in conjunction with Scottish Salmon Company, which used a hybrid power management system. The pilot aimed to validate the use of Albatern's device for powering fish farms.		
https://www.waveenergyscotland.co.uk/news-events/wave-energy-first-for-scottish-aquaculture/		

Project: H2OCEAN	Location: Spain / EU-Wide	Project dates: Jan 2012 – Dec 2014
AWS Truepower + 18 others	FP7-TRANSPORT	
Although the project focussed on development of technology for conversion of offshore renewable energy to Hydrogen, the project developed a multi-use open-sea platform that included a multi-trophic (growing finfish, shellfish and marine plants together) aquaculture farm. The unique feature of the H2OCEAN project was the integration of different activities into a shared multi-use platform, and the transmission of offshore-generated renewable energy through hydrogen.		
https://cordis.europa.eu/project/rcn/102016/factsheet/en		

Project: PowerModule	Location: Finland	Project dates: Oct 2017 - Sep 2019
	Funded by H2020-EU.3.3, H2020-EU.2.1.1, H2020-EU.2.3.1	
The project centred on demonstrating the Wello wave energy converter concept at full scale and in an operational environment, resulting in a 300kW ocean energy generator. The aim was to develop a system for small scale offshore power users like fish farms and algae cultivation systems. Although a reference to Wello actually integrating the system into aquaculture could not be found, it is assumed the company's partnership in China[7] is most likely driven by the local Shandong region's drive to connect the blue economy.		
https://cordis.europa.eu/project/rcn/212502/factsheet/en		

Project: Inertial Sea Wave Energy Converter (ISWEC)	Location: Italy	Project dates: 2019
	Assumed to be commercially funded	
Eni installed the Inertial Sea Wave Energy Converter (ISWEC) production unit in collaboration with Politecnico do Torina and Wave for Energy S.r.l. The pilot plant was installed at the Ravenna offshore site by Eni's Central Northern District and has been integrated into a hybrid smart grid system featuring photovoltaics and energy storage. It reached a peak power output of over 51 kW, or 103% of its nominal power. The technology is suitable for powering medium and large offshore assets. Eni plans to convert mature offshore platforms into renewable energy generation hubs.		
https://www.eni.com/en_IT/media/2019/03/eni-starts-wave-power-energy-generation-at-the-ravenna-offshore-site		

OceanDEMO (2019)	Location: UK / EU-wide	Project dates: 2019 - 2022
	Funded by EU: Interreg North West Europe	
An Interreg funded project, led by EMEC in Orkney to overcome commercial barriers to ocean energy. The project runs open calls for applicants so this is also an opportunity for funding potential projects identified by ADMA regions. The main objectives are to prove the business case of wave energy devices for investors, develop an active supply chain and create a supportive policy environment. It will achieve this by demonstrating and de-risking the most promising offshore renewable energy generating technologies in multi-device farm configuration. It is delivered by EMEC, Foundation Dutch Marine Energy Centre, SmartBay Ireland, Ecole Centrale de Nantes, Ocean Energy Europe		
http://www.oceandemo.eu/		

4.4.1.2 Development projects

This section provides an example of a development project in wave power to aquaculture. Limited projects at this stage have been uncovered by this study. Development projects are categorised as projects which are undergoing early design or options engineering work. It typically takes a concept from TRL 4-5.

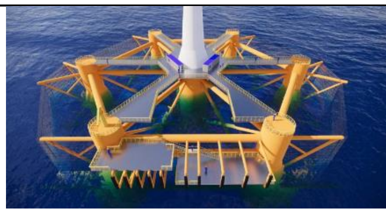
[7] https://www.hydroreview.com/2018/02/13/finland-company-wec-optimization-with-conglomerate-could-lead-to-demonstration-site-in-china/

<table>
<tr><th rowspan="2">Project: eForcis</th><th>Location: Spain</th><th>Project dates: Aug 2016 – Dec 2016</th></tr>
<tr><td colspan="2">Funded by H2020-EU.3.3, H2020-EU.2.1.1, H2020-EU.2.3.1</td></tr>
<tr><td colspan="2">EForcis is an autonomous, off-grid power generation system adapted to the aquaculture sector, targeting lower wave height sites, which is well-matched to the preferred location of aquaculture sites. It is developed by Smalle Technologies. The project sought to analyse the techno-economic feasibility and optimisation routes of the different eForcis equipment and to explore the aquaculture market potential of the current eForcis generator. As a result, a marketing strategy was developed to commercialise the products with end-users (specifically identifying aquaculture companies, oil and gas facilities, fish farms and Port authorities).</td><td></td></tr>
<tr><td colspan="3">https://cordis.europa.eu/project/rcn/205142/factsheet/en</td></tr>
</table>

4.4.1.3 Research projects

Research projects are categorised as activity on technology within TRL 1-3, typically focussing on overcoming engineering challenges with integrating aquaculture and renewable generators. Projects typically undertake early stage engineering options studies or are softer desk-based regional collaboration/cohesion projects.

<table>
<tr><th rowspan="2">Project: The Multi-Use in European Seas (MUSES)</th><th>Location: Scotland/ EU-Wide</th><th>Project dates: Nov 2016 - Oct 2018</th></tr>
<tr><td colspan="2">Funded by H2020-EU.3.2.5, H2020-EU.3.3.2, H2020-EU.3.3.6.</td></tr>
<tr><td colspan="2">The MUSES project is a Horizon 2020 funded project that explored the opportunities for Multi-Use in European Seas across five EU sea basins (Baltic Sea, North Sea, Mediterranean Sea, Black Sea and Eastern Atlantic). It is led by Marine Scotland and has 9 other partners.
The MUSES project participants analysed different opportunities and options, presenting practical solutions on how to overcome existing barriers and minimise risks associated with Multi-Use development.</td><td></td></tr>
<tr><td colspan="3">https://cordis.europa.eu/project/rcn/205970/factsheet/en</td></tr>
</table>

Project: Offshore Platform for Energy Competitiveness (OPEC)	Location: UK	Project dates: Oct 17 - Dec 18
	Funded by Innovate UK Feasibility study	
A feasibility project to assess the technical and commercial use case for combining commercial fish farms into floating offshore wind farm foundations. The aim was to achieve a 20% reduction in the cost of energy produced by these systems. Although the technical feasibility aspect had a positive outcome, OPEC's final report concluded that the economic viability of such joint platforms remains challenging. Partners include; Blue Tech Ventures, ORE Catapult, Houlder, Marine South East, Stellenbosch University and Beckett Rankine		
https://gtr.ukri.org/projects?ref=132944		

Project: MERMAID	Location: Denmark / EU-Wide	Project dates: Jan 2012 - Dec 2015
	Funded by FP7-TRANSPORT	
The consortium, led by DTU, tested design concepts in four example test sites in the Atlantic Ocean, Baltic Sea, the Mediterranean and the southern North Sea / Wadden Sea that experience different environmental, social and economic conditions. Project partners developed new concepts, including the combination of structures for energy generation, aquaculture and platform-related transport. They also investigated the accumulated effects of large-scale structures on the environment and the best strategies for their installation, operation and maintenance.	MERMAID	
https://cordis.europa.eu/project/rcn/101743/factsheet/en		

Project: MARIBE	Location: Ireland, EU-wide	Project dates: Mar 2015 - Aug 2016
	Funded by H2020-EU.3.2	
A coordination project, lead by the University of Cork to identify areas across the blue economy with high potential for Europe. The project assessed the blue economy, delivered socio-economic studies and mapped existing business models to best practice methodologies. The project also sought to assess the technical and non-technical challenges of the areas. Plans were developed to take forward two wave energy to aquaculture developers: Wave Dragon (Wales) and Albatern (Malta)[8]. Plans were also developed to take forward two offshore wind and aquaculture developers: Cobra/Besmar (Gran Canaria) and the outcomes of the MERMAID project (Belgium)[9].	MARIBE Marine Investment for the Blue Economy	
https://cordis.europa.eu/project/rcn/194797/factsheet/en		

There are other examples of research projects in Appendix 2.

[9] https://maribe.eu/blue-economy-growth-science-research-aquaculture-floating-offshore-wind-2/

7.2 Overview of organisations active in this area

7.2.1 Technology developers, providers and installers

A range of companies are actively developing wave energy generators for use in aquaculture farms. These companies include both wave device developers (generally startups) and established aquaculture companies.

Resen Wave	**Gael Force Aquaculture (formerly Fusion Marine)**	**InnovaSea**
Denmark	*Scotland*	*USA*
Developing a range of modular units from 0.3kW to 5kW, designed to provide power for various offshore applications including aquaculture. Power outputs generally lower than required in aquaculture sites so would need multiple devices.	Cage supplier, working with top Salmon farmers to develop complete offshore solutions.	Leaders in offshore cages in the Americas. Also working on a complete single platform solution.
http://www.resenwaves.com/	https://www.gaelforceaquaculture.com/	https://www.innovasea.com/

Akva Group	**AWS Ocean Energy**	**Wave Dragon**
Norway / Scotland	*Scotland*	*Denmark*
Cage supplier, working with top Salmon farmers to develop complete offshore solutions.	AWS has tested a half scale AWS-3 wave energy generator with the intention of developing it for various applications, including offshore fish farms. Testing has taken place in Orkney.	Developing a wave energy generator. Involved in the MARIBE project, developing a wave energy to seaweed farm solution with SeaWeed Energy solutions and BELLONA.
https://www.akvagroup.com/home	http://www.awsocean.com/	http://www.wavedragon.net/

Other developers, providers and installers worth mentioning include:

- Aqualine
- Polygen
- Resolute Marine
- Salmar
- Seaweed Energy Solutions

7.2.2 Research groups

Everoze is unaware of formal research groups that focus on power for aquaculture as a sector (outside of university departments or special interest groups). The following research groups are either focussed on offshore wind energy or the aquaculture sector and have been active on power for aquaculture projects.

DTU Wind Energy	**ARCH-UK**	**ORE Catapult Floating Wind Centre of Excellence**
Denmark	*UK*	*UK*
Major contributors to the Mermaid project and leaders in wind energy, DTU are active in offshore renewable energy to aquaculture platform research. Erik Damgaard Christensen is a key contact in this area.	ARCH-UK is an aquaculture network for the UK. The primary function is to highlight aquaculture research to funders (UKRI) and facilitate knowledge exchange of the latest advancements in aquaculture research to its members.	ORE Catapult launched its Centre of Excellence in Floating Wind in October 2019. The centre is primarily focused on delivering cost reduction and commercial deployment of floating wind and one of it's initial workstreams addresses integrating aquaculture into floating wind foundations.
https://www.vindenergi.dtu.dk/english	https://www.aquaculturehub-uk.com/	https://ore.catapult.org.uk/press-releases/new-multi-million-pound-floating-wind-centre-of-excellence-launched/

7.2.3 Working groups and enabling bodies

Although not exclusively focussed on power-to-aquaculture as a sector, the following enabling bodies and working groups have had a role to play in R&D projects in the sector.

Seaweed Forum Wales (SFW)	**Aquaculture Industry Leadership Group**	**ORE Catapult**
Wales	*Scotland*	*UK*
Set up privately to drive interest in benefiting economically from seaweed production in Wales. Known to be working with Wave Dragon although no active project has been identified.	Seeking to deliver the industry's growth strategy by 2030. The strategy aims to: • Double the economic contribution of the sector from £1.8 billion in 2016, to £3.6 billion by 2030 • Double the number of jobs to 18,000 by 2030	The Offshore Renewable Energy Catapult (ORE Catapult) is a UK based National R&D centre for offshore renewables. It has test facilities appropriate for use by power for aquaculture technology developers and related marine engineering expertise.
http://seaweedforumwales.org.uk/	https://aquaculture.scot/	https://ore.catapult.org.uk/

FAO: Fisheries and Aquaculture	**EMEC**	**BELLONA**
Global	*Scotland*	*Norway + global*
The FAO holds workshops to work on greenhouse gas (GHG) mitigation in fisheries and aquaculture food production systems. It actively explores strategies and practical options for ways of working in the sector.	The European Marine Energy Centre is a test and research centre focusing on wave and tidal power development based in the Orkney Islands, UK. The Centre provides demonstration space for developers of wave energy generators for use in power for aquaculture applications.	Independent not-for-profit organisation that aims to meet and fight the climate challenges, by identifying and implementing sustainable environmental solutions. Engaged in the MARIBE project with Wave Dragon.
http://www.fao.org/state-of-fisheries-aquaculture	http://www.emec.org.uk/	https://bellona.org

7.3 Summary of technology status

4.1.3 SUMMARY OF STATUS OF TECHNOLOGY								
TRL 1 [10]	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TR9
Level of current activity in this area			None		Few scattered projects		Extensive range of projects	None
There is significant end user interest in providing renewable energy to aquaculture sites. The concept is worthy of further investigation and could potentially be commercialised in the next 5 years. There has been some successful demonstration of technology and commercial projects are in planning but are not yet deployed. There is a wide range of activity driving both through research groups, SMEs and large aquaculture farms and collaboration between stakeholders appears to be widespread.								

7.4 Barriers to technology market entry for providing power to aquaculture

The barriers to market must be considered when identifying the need for intervention in the development of technology. The barriers to deployment for technology providing power to aquaculture are outlined in the section below. They can be broadly split into technical, commercial (including funding and access to testing and demonstration opportunities).

7.4.1 Challenges to market entry for technology providing power to aquaculture

Level of challenge		
TECHNICAL	Low	Key technical challenges include: • Reliability of wave technology is still not fully proven. • Reliability of multi-use platforms for combining renewable energy and aquaculture are still not fully proven. • Aquaculture farms are often located in sheltered areas, away from significant wave or wind resource. • It is unlikely that wind/wave generation can viably fully replace diesel, even with the use of a storage technology, due to the misalignment of the end demand and energy use profiles • Solar could potentially offer a more cost-effective energy source in some areas, but less effort has been made on this to date

[10] TRL scale based on EU Horizon 2020 TRL scale https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/support/faq/2890

Level of challenge		
COMMERCIAL	Low	Initial feasibly studies suggest that powering aquaculture platforms using wave and solar devices is very close to be economically viable, despite the high cost of wave generation. This provides a potential route to market for the wave sector, as well as potentially reducing costs for aquaculture operators. There are few commercial barriers but these are not considered insurmountable. Key commercial challenges include: • Relatively long licensing/consenting process for fish farming, which may be increased through addition of novel wave or wind energy device. • Insurance and liability for integration of the aquaculture farm and wind or wave generation devices may also be a concern. This is routinely managed for diesel generation, but wave devices, for example, have less of a proven track record. The barrier is likely to be surmountable. • Installation may require an amendment to existing Town & Country Planning consents and an additional Marine Licence. • Willingness of aquaculture owners to accept higher risk.
FUNDING	Medium	The industry for combining renewable energy and aquaculture is still at a nascent stage of development and typically research projects or feasibility projects have been well funded to date. However, a number of demonstration projects that were planned to lead into full scale demonstration have not yet been funded, indicating there may be a gap in support, both publicly and privately in the demonstration stage. The main commercial interest in wave energy to aquaculture sites is from wave device developers to prove their generation technology (and end users to power their sites). Typically wave energy focussed funding, such as that from Wave Energy Scotland, has served this market but a number of projects go unfunded currently. These projects in limbo, there may well be a gap in both public and private funding to push these projects through to demonstration. It is unclear whether the OceanDEMO Interreg programme alone is enough to fill this gap. Rather than a focus on power for aquaculture, the provision of funding will be more about the strategic choice to back wave energy, an earlier (and potentially higher reward) industry, indigenous to Scotland and Emilia-Romagna. Although the EU Innovation Fund may apply to commercial sites, there may be a case for localised public funding to prove enabling technologies that may not be eligible alone for the Innovation Fund (e.g. energy demand/supply balancing, marinisation of storage technologies). On both the EU level and UK level, smaller technology companies could apply directly to calls designed to provide funding to late stage development for SMEs (e.g. the EU's EIC Accelerator or Innovate UK's SMART Grants).
ACCESS TO TEST AND DEMO	Low	Key test and demonstration challenges include: • Aquaculture operators needing to be provided with evidence that the renewable energy generation technology is viable, the risk of operating is low, and any potential benefits can be realised. • Companies developing devices for small scale wave generation are likely to require investment to bring their product to full commercialisation. This investment will also likely be time limited. With Aquaculture sites taking a long time to reach consent, these dynamics could be at odds with progress. However, there are extensive potential sites for testing, the cost of test and demonstration is relatively low and engagement with end users to date has been good.
CONCLUSION ON BARRIERS TO MARKET ENTRY		
The main barriers to deployment are technical. Primarily these are reliability of wave devices and alignment of generation and demand. However, there is a strong market pull for this technology, assuming licencing and regulatory barriers can be overcome, and good commercial case. Smart prioritisation of which technologies to take forward first, leading to a series of demonstration projects, could initiate rapid development of the sector. This would also encourage technology acceptance by all sectors involved.		

7.5. Opportunities for ADMA members

An opportunities review was carried out for member regions that expressed an interest in technology for the provision of power for aquaculture. The only ADMA member region expressing interest was Scotland.

7.5.1 MEMBER: SCOTLAND Overview of the region

Scotland is part of the United Kingdom and it is located at the northern third of the island of Great Britain with population over 5.4 million. Core industries in the region include oil and gas, renewable energy, agriculture, fishing, textiles and food and drink.

Scotland has one of Europe's largest aquaculture industries and a world-leading marine energy sector. There is a wide range of experience and opportunities for both demonstration and deployment of marine energy and it boasts some of Europe's best marine renewable resources. There is, as might be expected, strong political support for both sectors.

Activity on development of technology for provision of power aquaculture to ~~to~~ date in Scotland

To date, projects utilising wave power have been initiated where the direct supply of energy (and removal of the requirement for shore connection) renders the technology cost-effective at a small scale. Demonstrators have been developed in Scotland. EMEC has been a key facility for testing wave generators before they are deployed and Scotland is currently home to the largest commercial floating offshore wind farm, with plans for many more in the future. There is a dedicated body for enabling wave energy development, Wave Energy Scotland, established by the Scottish Government to ensure progression of the industry.

The Scottish Government has already funded a feasibility and optimisation study into the combination of aquaculture and floating wind foundations, delivered by the ORE Catapult Floating Wind Centre of Excellence. A follow on to this project is likely to include projects that seek to demonstrate integration of aquaculture and floating wind foundations at commercial scale.

Opportunities for economic benefit to Scotland

The presence of local wave energy generation technology developers (along with strong enabling bodies like Wave Energy Scotland) and large end users offers a clear case for increased jobs and economic benefit should the sector continue to be supported.

Deployment

There is both a large aquaculture market and strong wind and wave resource in Scotland. Scotland is well placed to deploy combined use aquaculture and floating wind platforms. Development of the power for aquaculture sector potentially provides a good opportunity for positive marine stewardship as well as providing commercial benefit for Scotland.

Ongoing research at the ORE Catapult should help identify optimal scenarios for aquaculture technology deployment. Early findings suggest that certain niche technologies will be more cost effective to deploy as a starting point for leading into full combined use platforms. The next round of demonstration wind farms and the EMEC facility based in Orkney could be a good place to trial these technologies.

Supply chain development/diversification

Given the high number of wave energy generator developers in Scotland, it not only provides a route to market for generator technology but also a chance to diversify into the aquaculture supply chain.

As with at-sea power technologies, Scottish companies that provide power electronics, or mid-scale fabrication of offshore O&G components would be well placed to diversify into power for aquaculture. Companies that provide marine engineering solutions to other sectors would also be well placed.

There is also a potential market for O&M for these devices once installed, building on the existing capability for aquaculture and marine O&M.

Opportunities for demonstration in Scotland

The level of opportunities for demonstration was assessed according five criteria:

Suitable geography and infrastructure	Good
Political support	Good
Presence of potential supply chain companies	Good
Potential market in region	Good
Access to relevant skills	Good

The presence of significant wave and wind resource, strong political support and a high level of indigenous wave energy and aquaculture end users puts Scotland in a good place for offering demonstration opportunities to grow a local market.

It should be noted, Emilio-Romagna did not express an interest in developing power to aquaculture solutions. However, this is potential route to market, via export, for their emerging wave energy sectors, so should be considered by the region

8. Overall conclusions and recommendations

The following section summarises the conclusions identified for the four priority technology areas within this report. It also outlines where the technology is in its development process and the level of opportunity it presents for the two ADMA members which expressed an interest in the technology (Scotland and Emilia-Romagna). It also outlines where ADMA intervention could potentially beneficial and potential types of intervention that could deliver this benefit.

8.1 Overall technology review conclusions for integration of power sources at sea

There are three separate technology areas to be considered here, each at a different stage and having different drivers and support needs:

8.1.1 Overall General powering of surface platforms									
TRL	1	2	3	4	5	6	7	8	9

Key question	Status SE	Status ER	Conclusion / Commentary
Long-term economic opportunities for ADMA members	**High**	**Low**	Scotland offers good opportunities for deployment and potentially manufacturing, given the present widespread O&G assets in the region. Opportunities for floating wind in ER likely to be much less given low wind energy resource in the gas fields off Ravenna.
Need for intervention by ADMA	**Medium**	**Low**	Intervention will need to be driven by the large oil and gas majors so financing and end user access are not a problem. There is likely to be benefit from external intervention to coordinate asset owners to ensure cooperation, in order to realise the additional benefits of basin wide strategic planning for deployment of this technology. ADMA member support is likely to be beneficial where it is focussed on supporting the general development of floating offshore wind in the respective regions.
Suitability of region for demonstration	**High**	**Medium**	Scotland has deep water resources and widespread O&G assets, plus supply chain partners for several key parts of the installations. Conditions within ER are similar, but fixed offshore wind industry is much less developed so floating is further behind. Offshore wind resource around Italy (considering a broader region than just ER) is generally low, making the commercial case less secure than in Scotland.
Opportunity for ADMA partner collaboration	**Medium**	**Medium**	Both SE and ER have interests and opportunities in this area within their supply chain.

Whilst there are no significant technical barriers to deployment, it is fair to say that few of the floating wind technology and farm developers (with the exception of Equinor and their Hywind technology), seem to be seeking to actively exploit O&G powering as a major part of their commercialisation plans, since it is a somewhat niche market. On the other hand, there is considerable interest in developing floating wind amongst the big oil & gas majors (Shell, Total and others), driven by the pressure to decarbonise; the oil and gas industry missed out on playing a significant part in the fixed wind industry, but perceives that floating platforms and moorings are a better fit with their existing skills base and supply chain and will form an increasing part of future operations. With the large oil and gas players driving this technology to market and limited technical challenges, there is little need for ADMA intervention.

8.1.2 Local powering of smaller sub-sea plant modules										
TRL	1	2	3	4	5	6	7	8	9	

Key question	Status SE	Status ER	Conclusion / Commentary
Long-term economic opportunities for ADMA members	High	High	There are long-term economic opportunities for both Scotland and Emilia Romagna, where the existing oil and gas assets provides scope for the deployment of continuous power supply systems. There are small entrepreneurial companies based in both regions.
Need for intervention by ADMA	High	High	There is scope in both Scotland and Emilia Romagna for ADMA to facilitate technology development companies through the "valley of death" funding stage. This can be achieved by supporting pilot demonstration projects with the oil and gas majors.
Suitability of region for demonstration	High	High	O&G is a large part of Scotland's economy, and its waters contain extensive O&G operations. It has abundant wind, wave and tidal energy resources. Emilia Romagna is adjacent to the ENI test site at Ravenna, and is close to Italy's Adriatic oil and gas operations. There is wave energy resource in the region (although wind and tidal less so).
Opportunity for ADMA partner collaboration	Medium	Medium	Both SE and ER have interests and opportunities in this area.

There is a potentially huge market for smaller scale powering of remote seabed installations using surface wave buoys or subsea ocean current turbines, integrated with battery storage systems. There are a number of demonstration projects in this area involving companies in the two ADMA member regions who expressed interest here. The challenges are both technical (remote wave and tidal generators with subsea battery storage systems) and commercial. The ocean currents at seabed level are very low (0.1-0.3m/s) which requires large rotors to capture meaningful energy (and indeed there is a question in some cases over the carbon content of heavy foundation and electrical containment structures compared with that of laying cables.

As per the General Platform Powering option above, wave energy is being supported by public bodies, e.g. Wave Energy Scotland (WES) in Scotland, and ADMA member support can most effectively be focussed on enabling pilot and demonstration projects of those systems that are integrated with offshore storage systems for bespoke small to medium power applications. Some of the developers such as EC-OG are in the "valley of death" stage, where ADMA support in facilitating pilot projects with O&G majors would be of great benefit.

8.1.3 Local power and process modules for sub-sea operations									
TRL	1	2	3	4	5	6	7	8	9

Key question	Status SE	Status ER	Conclusion / Commentary
Long-term economic opportunities for ADMA members	Medium	Low	Scotland's economy would benefit from the deployment of cost-effective (and de-carbonised) EOR technology, and the supply chain would benefit from the knock-on benefits of floating wind construction (although at present no floating developers are based in the region). There are few offshore wind or EOR process plant supply chain companies in Emilia Romagna, and few EOR project opportunities.
Need for intervention by ADMA	Medium	Low	Demonstration projects are likely to be led by an oil and gas major, given the high cost and technical risk. However an ADMA region could benefit by facilitating such a project in its region, and by facilitating the early onshore development programme.
Suitability of region for demonstration	High	Low	Scotland has extensive oil fields which could host demonstration projects for EOR. With respect to Emilia Romagna, the wind resource in the Adriatic sea (and around much of Italy) is lower, making project the economics locally more challenging. Also there is a higher concentration of gas fields that wouldn't benefit from EOR.
Opportunity for ADMA partner collaboration	Low	Low	Of ADMA regions, only Scotland's geography really presents and opportunity for deployment of this technology.

There is a reasonable amount of global interest in using offshore floating wind platforms with integrated process equipment for local high-power applications such as water injection for EOR (by local is meant local to the individual wellhead/injection points, but remote from the central receiving platform). There is also a potential application for local gas processing and compression modules, although this concept is some way further behind.
DNVGL is the only major developer identified at present at an advanced stage of developing such a system; their WIN-WIN system has been under development since 2013. Work to date, however, has comprised only feasibility and engineering design, and partners are currently being sought for the prototyping phase. This technology carries high technical risk, as there are numerous systems that have to be integrated onto the platform as a whole, however it offers potentially large benefits to a region should an ADMA member facilitate and support a prototyping and demonstration project.

Recommendations for potential ADMA intervention	
Basin and asset mapping	Assist existing organisations (EMEC, OGTC, OGA and others) with mapping out the economically feasible project landscape for all three technology areas. Specifically, for general platform powering, facilitate wider field / regional mapping of O&G assets and interconnectivity with renewable resources and infrastructure to identify and optimise sites and projects with the strongest commercial case.
Support for companies developing integrated systems	Help small technology companies avoid the "valley of death" by facilitating pilot demonstration projects with the end users and providing funding. This should include raising their profile with end-users.
WIN/WIN type demonstration funding	Assist with project site selection and potential provide funding, with a view to facilitating a pilot demonstration project in the region(s). This is needed for both development of local power and process modules for sub-sea operation and for solutions for general powering if rigs.
Ongoing support to the developments and uptake of floating wind, wave and tidal energy	Continue to support the development of floating wind within the ADMA regions. Particularly with a view to cost reduction.

#

8.2 OVERALL TECHNOLOGY REVIEW CONCLUSIONS FOR ALTERNATIVE ENERGY VECTORS									
TRL	1	2	3	4	5	6	7	8	9

Key question	**Status ER**	**Conclusion / Commentary**
Long-term economic opportunities for ADMA members	Low	Relatively low wind resource in much of the Mediterranean makes the case for offshore H2 production more challenging in the region. Wave-power likely to be cheaper to smaller scale and plants closer to shore than wind, hence onshore H2 production powered by renewable energy is likely to be more commercially feasible.
Need for intervention by ADMA	Medium	Little opportunity for ADMA intervention, other than to facilitate companies in the H2/e-fuel supply chain and foster the wider relationship with ENI for opportunities outside ER.
Suitability of region for demonstration	Low	Little opportunity for EOR demonstration using floating offshore wind in the region.
Opportunity for ADMA partner collaboration	Medium	Opportunities exist for collaboration with Scotland in facilitating onshore technology and integration testing.

Technically, there no major barriers to generation of green hydrogen offshore, however, there are currently major commercial issues. These can be broadly split into two categories:

1. Lack of market pull – Currently there is not enough of a market for hydrogen to attract the companies with capability and finance to invest in demonstrating and deploying this technology
2. Cost – Both the cost of floating wind, transport and electrolysis are too high, at present to produce a commercially viable fuel.

This reflected in the level of activity in the sector. Whilst some feasibility work has been done, there is little evidence that industry is pushing this technology through to demonstration and deployment. Whilst there are interventions ADMA could take to build confidence in the technology and start the cost reduction process, there is little incentive to do this until the market pull is established. There may be a role for the wider ADMA energy group to do this, alongside a range of other initiative that are ongoing global to build a user base for hydrogen.

Should the need arise, Scotland would be a viable place for demonstration and however, Emilia-Romagna lacks the wind resource for large scale demonstration at present. This may change as wave energy becomes deployable at a larger scale.

Recommendations for potential ADMA intervention	
Maintain watching brief on H2 market	From a power integration at sea perspective, there is little that can be done by at present by ADMA until the market pull increases. However, if and when there is confidence in the market for hydrogen, ADMA can play a useful role. Therefore, a watching brief should be kept on the market. ADMA Energy members may choose to play a role in developing the technology needed to stimulate the hydrogen economy, which would create the required market pull.
Support for companies developing integrated systems	Despite the lack of current market for H2, pilot projects will be needed at some point to ensure the technology is ready to meet market needed. ADMA Energy should be ready to engage at the right time to support the development of offshore pilot H2 and e-fuel production projects. It can potentially play a strong role supporting demonstrators. This should be done in collaboration with the oil and gas majors.
Continue to support the development of floating wind within the region	One of the key cost drivers for hydrogen production offshore in the high cost of floating wind. Supporting the demonstration of floating wind would build the confidence required by developers and investors for mass deployment and cost reduction of the technology is likely to follow as a result.

8.3 OVERALL TECHNOLOGY REVIEW CONCLUSIONS FOR AT-SEA POWER SOLUTIONS		
TRL	1 2 3 4 5 **6 7 8** 9	
Key question	**Status**	**Conclusion / Commentary**
Long-term economic opportunities for ADMA members	**High**	Scotland offers good opportunities for deployment and potentially manufacturing, given the present widespread O&G and (soon to be) offshore wind assets in the region.
Need for intervention by ADMA	**Medium**	Technology development will continue to be led by the large O&G majors so financing and end user access are less of a problem for at-sea power solutions designed for oil and gas. There are low technical uncertainties with the technologies. There may be a case for supporting AUV charging technology designed for offshore wind, aquaculture or science and research missions. Particularly for support to SMEs to attract the attention of the end users.
Suitability of region for demonstration	**High**	Scotland has deep water resources and widespread O&G assets, plus a wide range of locally based O&G and offshore wind majors and technology developers. It also has a strong base of commercial research providers.
Opportunity for ADMA partner collaboration	**Low**	Only Scotland expressed an interest in this technology. There is also limited geographical crossover between the ADMA regions and the technology development in the industry activity to date.

There is a strong trend towards an increasing use of AUVs in both oil and gas and offshore wind. Technology is developing fast in this sector, mostly driven by the oil and gas majors. There is a strong presence of innovative SMEs in the sector. There is a clear move towards the provision on at-sea charging both through both sub-sea and surface hubs. Which would allow resident fleets of AUVs to provide round the clock inspection and maintenance without the need for the presence of humans on the site. The market demand for providing at-sea power is clear. Equinor's creation of a free license to its SDS both proves the scale of market demand for a solution (i.e. they need a solution at any cost) and highlights that the oil and gas industry is well progressed and is attempting to push forward with standards. Standardisation of a key (and less competitive) area like docking and charging facilities will enable the industry to develop faster. Working alongside Oil & Gas companies, technology developers have now deployed live trials of long-term resident vehicles. Vehicles range from bespoke designs such as the Eelume snake-like swimming robot and adaptations of established ROVs such as the SAAB Sabertooth.

Much of the RD&D activity is driven by the high margin deepwater Oil and Gas industry. Solutions for lower margin industries like the Offshore Wind industry are further behind in development but progressing with lower cost solutions for shallower water. It is also less clear that at-sea power solutions have been well developed for smaller AUVs, typically purposed for survey or science and research purposes, where reliance on vessels is still a big cost driver for the industry. Localised funding support would be best placed to focus on charging and docking technologies that are being developed for sectors outside of O&G. Given the significant effort already made in development of these technologies, demonstration focussed funding would be well received by technology developers. It is an area where private funding is less active due to higher risk/return of lower profit margin industries.

Recommendation for potential ADMA intervention	
Continued support to offshore wind in the region	Stimulation of local markets like offshore wind is essential to provide a fertile ground for AUV and at-sea technology development companies to continue to grow.
Collaboration with and support for existing subsea support organisations	Continue to collaborate and support existing programmes (EMEC, OGTC. OGIC etc.) that contribute to at-sea power technologies and the subsea sector.
Encourage further relationships between local technology developers and end users	Enabling collaboration between companies and end uses (e.g. larger UAV developers and offshore or aquaculture asset owners) within target regions will support technology developers to enter new markets.
Specialist support to AUV developers targeting lower margin industries	There is a strong case for supporting technology development in smaller companies looking to break into supplying AUVs into the offshore wind, aquaculture or science and research sectors. A core part of their required development is innovative charging systems. AUVs designed for these lower margin sectors would benefit from focussed support, where they don't have the financial support like that found in O&G.

8.4 OVERALL TECHNOLOGY REVIEW CONCLUSIONS FOR PROVIDING POWER TO AQUACULTURE										
TRL		1	2	3	4	5	6	7	8	9
Key question	**Status**	**Conclusion / Commentary**								
Long-term economic opportunities for ADMA members	**High**	Scotland offers good opportunities for deployment and potentially manufacturing, given the presence of wave energy developers and the (soon to be) floating offshore wind assets in the region.								
Need for intervention by ADMA	**Medium**	The regulatory environment does not currently encourage integration of offshore renewable energy and aquaculture sites. There is a clear role for Scotland to make this process easier or create a "sandbox" for industry to come and trial new ways of working.								
Suitability of region for demonstration	**High**	Scotland has a strong floating offshore wind resource and a large aquaculture sector, with the potential to grow and exports from Scotland. It also has a strong base of commercial research providers that are heavily active in this space.								
Opportunity for ADMA partner collaboration	**Medium**	Only Scotland showed interest in this technology but there is potentially an unrecognised opportunity for Emilio-Romagna.								

Offshore renewable energy generation technology can technically provide a potentially viable alternative source of power for off-grid aquaculture farms. A number of technical challenges including variable generation and large fluctuations between peak and minimum demand must be overcome in order for the technology to progress. A key driver for progress is the opportunity the sector offers the nascent wave energy generator industry to develop in an environment where it becomes economically viable (under high diesel cost scenarios).

If the combination of wave energy generators and aquaculture progresses, significant work will however be needed to develop appropriate insurance, liability and O&M solutions for these devices. Solar could potentially offer a more cost-effective energy source in some areas and it has begun to be explored for use in some demonstration projects.
For both wave energy for aquaculture and offshore wind energy for aquaculture, there is a gap in both public and private funding to push these projects through to commercial demonstration. With wave energy, the focus of funding will be more about the strategic choice to back wave energy, an earlier (and potentially higher reward) industry, indigenous to Scotland. Although the EU Innovation Fund is commercially focussed, it may be too large a fund to fully fill the gap to support wind-to-aquaculture technologies come to fruition. In both wind and wave, there may be a case for localised public funding to prove enabling technologies (e.g. energy balancing, marinisation of storage technologies).

Recommendation for potential ADMA intervention	
Further engagement with the OceanDEMO project	SE could engage with EMEC to discuss whether there is scope for demonstration of power to aquaculture technologies within their OceanDEMO project, which is already funded by Interreg.
Engage the EU Innovation Fund	ADMA members should engage the EU Innovation Fund Expert Group[11] to lobby for the requirements of the ADMA regions and understand the potential of the Innovation Fund to support ADMA activities in power for aquaculture (and potentially other areas).
Networking end users with generators	Intervention measures such as networking initiatives between the offshore wind and aquaculture industry or specific funding to encourage this would be a good low-cost way of catalysing activity in this space.
Consider development of another Interreg NWE programme	ADMA members should consider applying for Interreg NWE funding with its applicable ADMA regional partners. This must however be complementary to the OceanDEMO Interreg project currently being delivered by EMEC. The funding is focussed on exactly the technologies of focus in this report and is open to private or public organisations.
Consider enabling activities that support development of regulations or standards	A coordination project could be initiated that standardises the requirements for power for aquaculture and develops a simpler policy framework for implementing the technology. ADMA members could also consider creating a "sandbox" or specified designated (unregulated) demonstration site where industry can come and trial new ways of working in the sector, without being prohibited by regulatory processes.

[11] https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3593

APPENDIX 1: MEMBERS OF ADMA AND THEIR STATED INTEREST IN POWER TRANSFER AT SEA

The following members indicated an interest in 'power transfer at sea'.

1. Scotland, UK

Scotland is part of the United Kingdom and it is located at the northern third of the island of Great Britain with population over 5.4 million. Core industries in the region include oil and gas, renewable energy, agriculture, fishing, textiles and food and drink.

2. Emilia-Romagna, Italy

Emilia-Romagna in north-eastern Italy has about 4.4 million inhabitants. The region is a cultural and tourist centre and is also a centre for agriculture, food and automobile, motor and mechanics manufacturing.

The following members expressed no interest or did not express and interest in 'power transfer at sea

3. Asturias, Spain

The Principality of Asturias in northwest Spain has a population of just over 1 million. Energy, transport and materials are the main sectors in which Asturias has a specific advantage in advanced manufacturing. Specific areas that could be highlighted include: Marine renewable energy, fabrication of structures and systems, pumps, valves & turbines for onshore and offshore applications, energy efficiency, distribution of electric power, wind turbines and components and smart grids; and Machinery and industrial systems and components for manufacturing processes.

4. Basque Country

The Basque Country is an autonomous community in northern Spain with a population of 2.2 million. The strongest industrial sectors are machine tool; aeronautics; and energy.

5. Navarre, Spain

Navarre is an autonomous geographically diverse region in northern Spain with a population of 650.000. It is one of the richest regions in Spain. Navarre leads Europe in its use of renewable energy technology and is planning to reach 100% renewable electricity generation, consisting of wind farms, small-scale water turbines, and biomass & biogas plants as well as large & small scale photovoltaic power plants.

6. Lombardy, Italy

Lombardy in the northwest of Italy has a population of about 10 million people and about a fifth of Italy's GDP is produced here. It is the leading industrial and commercial region of Italy producing iron and steel, automobiles & trucks, and machinery.

7. Norte, Portugal

Norte or Northern Portugal is the most populous region in Portugal with a population of just under 4 million. Norte is highly industrialised with textiles, footwear, mechanical, electrical, electronics and chemical industries. Energy policies established in 2005 have made Portugal one of the top renewable power producers in Europe where wind power production is massively obtained in the Centre and North regions.

8. Flanders, Belgium

Flanders in the north of Belgium has a population (including Brussels) of 7.9 million. It is mainly flat with a small section of coast on the North-Sea. It is agriculturally fertile. The main exports are automobiles, food and food products, iron and steel, finished diamonds, textiles, plastics, petroleum products, and non-ferrous metals

9. Scania, Sweden

Scania (Skåne) is the southernmost county of Sweden with a population of 1.34 million. Main employment is in services, care, education and trade. Scania has a goal to be 100% free of fossil fuels in energy consumption, public transport and vehicle use by 2020 by use of renewable energy and fuels such as biogas, wind power and hydrogen gas.

10. Dalarna, Sweden

Dalarna is a county in the middle of Sweden with a population of 280,000. The core industries are mining and steel and with 70 percent of its area covered by forests, Dalarna is naturally one of Sweden's strongest bastions of the forestry and paper industries. Dalarna's third industrial base is the supply of electrical power and they also manufacture the world's largest transformers for power networks.

APPENDIX 2: ADDITIONAL RELEVANT EXAMPLES OF PROJECTS

POWER AT SEA DEVELOPMENT PROJECTS		
Precise Positioning for Persistent AUVs (2020)	Aiming to improve the navigational accuracy and power consumption of AUVs helping to further reduce the dependency on offshore infrastructure for wide area surveys of challenging marine environments.	https://gtr.ukri.org/projects?ref=104070
Enabling low cost AUV technology: Development of smart networks & AI based navigation for dynamic underwater environments (2019)	*Overcoming challenges related to deploying small AUVs, including power I.e. they are unable to rely on incumbent technologies for navigation, such as expensive Inertial Navigation Systems (INS), large Doppler Velocity Logs (DVLs) and traditional Long Baseline positioning (LBL)*	https://gtr.ukri.org/projects?ref=104058
Launch & Recovery of Multiple AUVs from a USV (2017)	AUVs were autonomously deployed and powered from a USV, providing science users increased range, spatial sampling resolution and reduced cost versus existing solutions.	https://gtr.ukri.org/projects?ref=102302
Subsea USB (2015)	Qualified a connector system that could transfer large amounts of electrical power, serial communication, and Ethernet data communication through the same interface, with a reported efficiency 98% for the connectors.	https://subseaworldnews.com/2015/06/09/blue-logic-gets-funds-for-its-subsea-usb-project/
ALIVE (2003)	Developed a new autonomous light intervention vehicle that, unlike conventional AUVs, features automatic manipulation capabilities, in addition to autonomous docking and recovery.	https://cordis.europa.eu/project/rcn/54236/brief/en

PROVIDING POWER FOR AQUACULTURE RESEARCH PROJECTS		
Name	*Description*	*Website*
Floating wind to aquaculture opportunity study (2019)	ORE Catapult Floating Wind Centre of Excellence is currently delivering a review of combining aquaculture into floating wind foundations, and builds on work delivered under the OPEC project.	N/A
Risks and Opportunities for Sustainable Aquaculture – ROSA (2017)	ROSA developed a stakeholder-friendly tool to assess, in space and time, the risks and opportunities for sustainable aquaculture. It also investigated relevant information for fisheries & aquaculture energy provision.	https://gtr.ukri.org/projects?ref=BB%2FM026221%2F1

APPENDIX 3: FUNDING REVIEW

Future funding calls to watch:

Country	Funding body	Specific funds	Type of funds	Links	Commentary
EU-wide	EU	Innovation fund	Demonstration grant	https://ec.europa.eu/clima/policies/innovation-fund_en	Starting in 2020 and successor to the NER300 demonstration funding programme. Most likely will total €10bn and reinvests money from the EU Emission Trading System (ETS) and the previous NER300 programme into novel renewable energy sites. The Innovation Fund will support up to 60% of the additional capital and operational costs linked to innovation. It is also open to small-scale projects with total capital costs under €7.5 million, and projects that benefit more than one sector.
EU-Wide	EU	Horizon Europe	Research-Demonstration grants	https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en	Successor to Horizon 2020, the programme is slated to be a €100 billion research and innovation programme. Horizon Europe will incorporate five research and innovation missions. The areas covered in this study cover three of these missions: Adaptation to Climate Change, including Societal Transformation; Healthy Oceans, Seas, Coastal and Inland Waters; Climate-Neutral and Smart Cities

Current and live funding calls:

Country	Funding body	Specific funds	Type of funds	Links	Commentary
EU-Wide	EU	Horizon 2020		https://www.euenergyfocus.co.uk/wp-content/uploads/2019/07/H2020-Energy-Call-summary-2020-July-19.pdf	**11th December 2019** RES-19-2020: Demonstration of innovative technologies for floating wind farms (IA), up to €25M **21st April 2020** RES-1-2020: Developing the next generation of renewable energy technologies (RIA), €2M to €4M RES-26-2020: Development of next generation renewable fuel technologies from CO2 and renewable energy (Power and Energy to Renewable Fuels) (RIA), €3M to €5M **1st September 2020** RES-3-2020: International Cooperation with USA and/or China on alternative renewable fuels from sunlight for energy, transport and chemical storage (RIA), €2M to €4M RES-25-2020: International cooperation with Japan for Research and Innovation on advanced biofuels and alternative renewable fuels (RIA), €2M to €5M **29th January 2020** ES-3-2020: Integrated local energy systems (Energy islands) (IA), €5M to €6M **21st April 2020** LC-BAT-11-2020: Reducing the cost of large batteries for waterborne transport (RIA), €8 to €12M
North West Europe	EU	Interreg North-West Europe (NWE)		https://www.nweurope.eu/apply/who-can-apply/	European Territorial Cooperation Programme funded by the European Commission with the ambition to make the North-West Europe area a key economic player and an attractive place to work and live, with high levels of innovation, sustainability and cohesion. It invests EUR 370 million of European Regional Development Fund (ERDF) in activities based on the cooperation of

					organisations from eight countries: Belgium, France, Germany, Ireland, Luxembourg, The Netherlands, Switzerland and the United ~~Kingdom.The~~Kingdom. The fund covers many of the regions within the ADMA and the current challenges in the fund are very focussed on low carbon technologies.
EU-Wide	EU	Invest EU	Demonstration grants/loans/guarantees/subsidies/prizes/public contracts	https://europa.eu/investeu/home_en	Open to companies of all sizes – as well as local, regional and national organisations and governments. Funding is made available in various ways, including grants, loans and guarantees, subsidies, prizes and public contracts. Example project on Borkum in the North Sea explains how the support can work.
EU-Wide	EU	EIC Pilot: Fast Track to Innovation (FTI)	Demonstration grants	https://ec.europa.eu/research/eic/index.cfm?pg=funding	For relatively mature ground-breaking technologies, concepts and business models which are close to market. Proposals must come from consortia of 3 to 5 legal entities who want to see quick market uptake of new technologies. Grants of up to €3 million may be awarded.
EU-Wide	EU	EIC Pilot: EIC Accelerator Pilot	Demonstration grants	https://ec.europa.eu/research/eic/index.cfm?pg=funding	Builds on the SME Instrument Phase II and provides grant-only support as well as support in the form of blended finance (combining grant and equity). The scheme supports high-risk, high-potential small and medium-sized innovative enterprises willing to develop and commercialise new products, services and business models that could drive economic growth and shape new markets or disrupt existing ones in Europe and worldwide.It has a total budget of more than €1.3 billion for 2019-2020.
EU-Wide	EU	EIC Pilot: EIC Pathfinder Pilot	Research-Demonstration grants	https://ec.europa.eu/research/eic/index.cfm?pg=funding	Offers grants of up to €4 million to promote collaborative, inter-disciplinary research and innovation on science-inspired and radically new future technologies. These grants are for consortia of at least 3 entities from 3 different Members States. The EIC Pathfinder pilot has a total budget of around €660 million for 2019-2020.
EU-Wide	EU	InnovFin Energy Demonstration Projects	Demonstration loans	https://www.eib.org/en/products/blending/innovfin/products/energy-demo-projects.htm	InnovFin Energy Demonstration Projects provides loans, loan guarantees or equity-type financing typically between EUR 7.5 million and EUR 75 million to innovative demonstration projects in the fields of energy system transformation
UK	Innovate UK	Open/SMart	Applied Research-Demonstration grants	https://apply-for-innovation-funding.service.gov.uk/competition/446/overview	Smart is the new name for Innovate UK's 'Open grant funding' programme. £25 million is delivered in tranches to commercially viable innovative or disruptive ideas. All proposals must be business focused. Duration between 6 and 18 months and total eligible project costs between £25,000 and £500,000.
UK	Innovate UK	Innovation loans	Demonstration / scaling loans	https://apply-for-innovation-funding.service.gov.uk/competition/456/overview	£10 million in loans to SMEs. Loans are for innovative late stage projects with game changing and/or disruptive ideas or concepts. There should be a clear route to commercialisation and economic ~~impact.Projects~~impact. Projects should aim to develop new products, processes or services which are significantly ahead of anything similar in the field.
UK	Defence, Science and Technology Laboratory (DSTL)	Various	Applied research – Demonstration grants	https://www.gov.uk/government/organisations/defence-science-and-technology-laboratory	Although focussed on the defence sector, DSTL periodically opens funding calls for technologies that straddle both defence and those mentioned in this report. Examples include remote charging of drones or providing remote power conversion.