Assessment of Economic Opportunity Report

North Sea Solutions for Innovation in Corrosion for Energy

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The NeSSIE project (2017-2019) seeks to deliver new business and investment opportunities in corrosion solutions and new materials for offshore energy installations. The project aims to draw on North Sea regional expertise in traditional offshore sectors (i.e. oil and gas, shipbuilding) in order to develop solutions for emerging opportunities in offshore renewable energy sources (wave, tidal and offshore wind energy).

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Acronyms

ASTM	American society for testing materials
ACP	Active Cathodic protection
ACS	Anti-corrosion Solution
CP	Cathodic Protection (general)
DNV	Det Norske Veritas
EEA	European Economic Area
EMEC	European marine enter centre
ESME	Energy Systems Modelling Environment
ETI	Energy Technology Institute
FRP	Fibre reinforced plastic
FRC	Fouling release coatings
GRP	Glass reinforced plastic
IMS	Inspection and monitoring systems
ISO	International Standards Organisation
LCOE	Levelised cost of electricity
MIC	Microbially influenced corrosion
NACE	National association of corrosion engineers
NPV10	Net Present Value with discount rate of 10%
NSB	North Sea basin
O&M	Operation and Maintenance
OEM	Original equipment manufacturers
OPEX	Operating expenditure
OWF	Offshore wind farm
OWT	Offshore Wind Turbine
PCP	Passive Cathodic protection
R&D	Research and Development
SHM	Structural health monitoring
SME	Small to Medium Enterprise
TEC	Tidal energy converter
TRL	Technology readiness levels
TSA	Thermally sprayed aluminium
VC	Value Chains
WEC	Wave energy converter
WP	Work Package
VARTM	Vacuum assisted resin transfer moulding

1. Executive Summary

This deliverable assesses the potential economic opportunity in Europe that could be delivered if novel anti-corrosion solutions found in traditional marine sectors are applied in the offshore renewables sector. The report grew beyond the original work scope to provide a firmer foundation to NeSSIE. Additions to the original scope will better support project decision making around the future WP3 Roadmap and WP4 Demonstration project selection process.

The issue of marine structure corrosion was found to be a common one amongst a diverse set of offshore users and established industry supply chains. Corrosion mechanisms, rates, management, standards application, manufacturing and fabrication supply and applied solutions were all briefly listed and explained. To understand offshore marine device corrosion studies to date, new materials and direct corrosion solutions case studies were analysed. The findings provide context and relevancy to NeSSIE demonstration candidates.

Four key supply chains were identified from research:

1. Protective layerings including environmentally benign paints, sprays and coatings;
2. Cathodic protection;
3. New materials and their associated fabrication, manufacturing and assembly processes;
4. Corrosion monitoring, assessment and repair services.

A non-exhaustive and project-relevant filtered dataset of supply chain companies delivering these solutions to established industries across the NSB region was then constructed. It is clear amongst consortium partners that the supply chains required to collaborate with the demonstration projects can originate outside the NSB region, and that NeSSIE will create a case study which can be copied and applied elsewhere across Europe with the common goal of stimulating regional industrial growth. NeSSIE personnel approached these identified supply chain companies during the 2017 Offshore Europe conference, in Aberdeen, to better assess their relevance and interest in collaborating. 95% of companies interviewed were interested in the opportunities to diversify presented by NeSSIE.

Additional lists were made of the other relevant key stakeholders required to make NeSSIE a success and will help to formulate the characteristics of possible demonstration project candidates. These include research collaboration, standards bodies, test facilities, developers and legal statutes.

To calculate the economic worth of anti-corrosion solutions to developers and solutions Vendors, a number of assumptions taken from the oil and gas, maritime and offshore renewables sectors were made. Capital expenditure (CAPEX), operational expenditure (OPEX) and performance impacts of applying corrosion solutions were calculated separately for new materials and their associated processes, and direct corrosion solutions such as cathodic protection or coating systems. The calculations covered the UK and wider EU, and utilised projected capacity taken from various renewables roadmaps. The scenarios investigated ranged from the reduction of offshore renewables project CAPEX to increased CAPEX with the application of novel anti-corrosion solutions, yet in all cases considered the reduction of OPEX and contribution towards maintaining device performance.

Reducing CAPEX leads to developer savings of up to £9.2bn in the UK and £32.7bn in the wider EU by 2030, increasing to £12.8bn and £74.6bn respectively by 2050. On the other side of the spectrum, in the case of an increase in CAPEX through the introduction of novel anti-corrosion solutions in comparison with the business-as-usual case (BAU), there can be a cost to the developer of £0.04bn and £1.6bn in the UK and wider EU, respectively, by 2030. In this scenario, there is a notable turnaround for the UK, when a tipping point is reached and the reduction in OPEX outweighs the increased CAPEX cost, whereby a developer saving is possible of £0.5bn by 2050. Such a tipping point is not encountered in the wider EU, where the additional cost in the wind energy sector is significant.

Considering the results to anti-corrosion solution Vendors, the different scenarios result in a range of value chain availabilities between £17.3bn and £43.5bn in the wider EU, by 2030; with these numbers more than doubling to £33.6bn and £83.3bn by 2050. The future market size of the UK and wider EU anti-corrosion solutions were shown strongly positive and aligned well with existing market sizes in established oil and gas, and marine supply industries.

			TOTAL WAVE & TIDAL			TOTAL FIXED & FLOATING WIND			TOTAL OFFSHORE MARKET		
			Capacity	Developer Saving	Vendor Value	Capacity	Developer Saving	Vendor Value	Capacity	Developer Saving	Vendor Value
			MW	NPV10 £M	NPV10 £M	MW	NPV10 £M	NPV10 £M	**GW**	**NPV10 £bn**	**NPV10 £bn**
Scenario 1	UK	**2020**	350	208	283	8,060	2,507	3,043	**8.4**	**2.7**	**3.3**
		2030	6,000	1,538	1,984	19,477	7,703	9,181	**25.5**	**9.2**	**11.2**
		2050	15,000	2,345	2,907	45,000	10,486	11,459	**60.0**	**12.8**	**14.4**
	EU	**2020**	350	206	307	23,493	10,276	13,146	**23.8**	**10.5**	**13.5**
		2030	25,282	5,949	10,311	66,488	26,831	33,218	**91.8**	**32.8**	**43.5**
		2050	188,000	14,219	22,403	460,000	60,353	50,891	**648.0**	**74.6**	**83.3**
Scenario 2	UK	**2020**	350	6	118	8,060	266	1,154	**8.4**	**0.3**	**1.3**
		2030	6,000	114	829	19,477	913	3,506	**25.5**	**1.0**	**4.3**
		2050	15,000	364	1,224	45,000	1,493	4,397	**60.0**	**1.9**	**5.6**
	EU	**2020**	350	5	130	23,493	730	4,979	**23.8**	**0.7**	**5.1**
		2030	25,282	445	4,463	66,488	2,570	12,810	**91.8**	**3.0**	**17.3**
		2050	188,000	2,431	9,712	460,000	6,296	23,881	**648.0**	**8.7**	**33.6**
Scenario 3	UK	**2020**	350	-25	161	8,060	-22	1,566	**8.4**	**-0.05**	**1.7**
		2030	6,000	-102	1,130	19,477	67	4,753	**25.5**	**-0.04**	**5.9**
		2050	15,000	49	1,662	45,000	444	5,957	**60.0**	**0.5**	**7.6**
	EU	**2020**	350	-27	176	23,493	-712	6,756	**23.8**	**-0.7**	**6.9**
		2030	25,282	-617	5,981	66,488	-968	17,343	**91.8**	**-1.6**	**23.3**
		2050	188,000	128	13,006	460,000	-2,578	32,261	**648.0**	**-2.5**	**45.3**

Table I – Summary Economic Opportunity Anti-Corrosion Solutions for Offshore Renewables

Finally, for all resource types - strong UK and wider EU support to their continued growth were demonstrated, with the key challenges to their growth coinciding with the mitigations, which corrosion solutions and new materials offer. An accompanying Scottish Enterprise diversification study was further able to illustrate just how established supply chains can diversify their business model to deliver the cost reductions that offshore renewables developers are desperately seeking.

2. Introduction

The intention of this WP2 deliverable was to evaluate the anti-corrosion expertise employed by other industries outside the offshore renewables industry as well as the economic opportunity for anti-corrosion solutions within the marine renewable energy sector. The subtasks of this deliverable include the following:

- Identifying key companies, research organisations and regional collaborations, test facilities, standards and regulatory bodies in the North Sea basin region (Chapter 5);
- A State of the Art assessment was undertaken to determine the status of novel materials and direct corrosion solutions usage (Chapter 5 and 6);
- An assessment of the economic opportunity relating to novel materials and direct corrosion solutions in the North Sea basin was then made (Chapter 7);
- Existing roadmaps and assessments were analysed and evaluated in terms of making an estimate of economic opportunity using market data from the UK & Europe (Chapter 8).

NeSSIE (North Sea Solutions for Innovation in Corrosion for Energy) is an EU-funded research and development project primarily focused on the research and translation of cross industry anti-corrosion technologies in the North Sea basin (NSB) to the offshore renewable energy sectors. The project commenced in spring 2017 and will run for two years, with the interim target in spring 2018 of identifying potential investable demonstration projects in the NSB to promote to industry at later stages.

The NSB region was defined using the European Atlas of the Sea [1] and is illustrated in Figure 1. The NSB region includes the following EU members; the UK, Belgium, Germany, Netherlands, Denmark, but also Norway, which, though not being an EU member is a member of the European Economic Area (EEA) and in possession a wealth of offshore expertise and experience. The end goal of the project is to promote to the wider EU the identified project supply chain opportunities that could similarly benefit communities outside the NSB region. Hence, the project initially characterises an offshore anti-corrosion NSB pilot project, with research methods, templates and lessons learned allowing other European basins to follow a similar roadmap to capture similar Small to Medium Enterprise (SME)[1] manufacturing growth opportunities in the offshore renewables energy generation sector (see Table 13, Annex I for full SME definition).

The NSB region in this study refers to offshore and onshore activities, and industries. Marine Exclusive Economic Zones determined by territorial water boundaries and median lines divide each country's offshore North Sea sovereign segment. The NSB offshore region is best known for its oil and gas industries, which have been around since drilling began in the 1960s and form major economic backbones to the UK, Norwegian, Dutch and Danish economies - collectively contributing 3.5% and 5.8% of the world's oil and gas daily production respectively in 2016 [2]. Maritime fishing activities are also a vitally important regional resource. Norway alone in 2015

[1] European definition of SME's; category of micro, small and medium sized enterprises which employ fewer than 250 people and an annual turnover < 50million Euros and/or annual balance sheet total <43 million Euros (EU recommendation 2003/361 (See Annex I).

landed a total catch of 2146 kilotonnes, with the other five identified NSB countries' landing 2212 kilotonnes of live fish stock, i.e. 30% and 31% respectively of that year's total EU catch [3]. Fishing activities provide just one window into the region's large maritime sector, which also includes shipbuilding and shipping. More recently, the renewable energy sector in this offshore region has seen rapid commercial expansion, especially in offshore fixed foundation wind power due to strong prevailing winds and shallow waters – each of the NSB region countries has some installed offshore wind contribution to electrical generation.

The report focus is on analysing existing in situ anti-corrosion solutions employed in these three established offshore industries within the NSB region. The overall target of NeSSIEis to translate this knowledge and value chain expertise into anti-corrosion solutions for all offshore renewable energy systems.

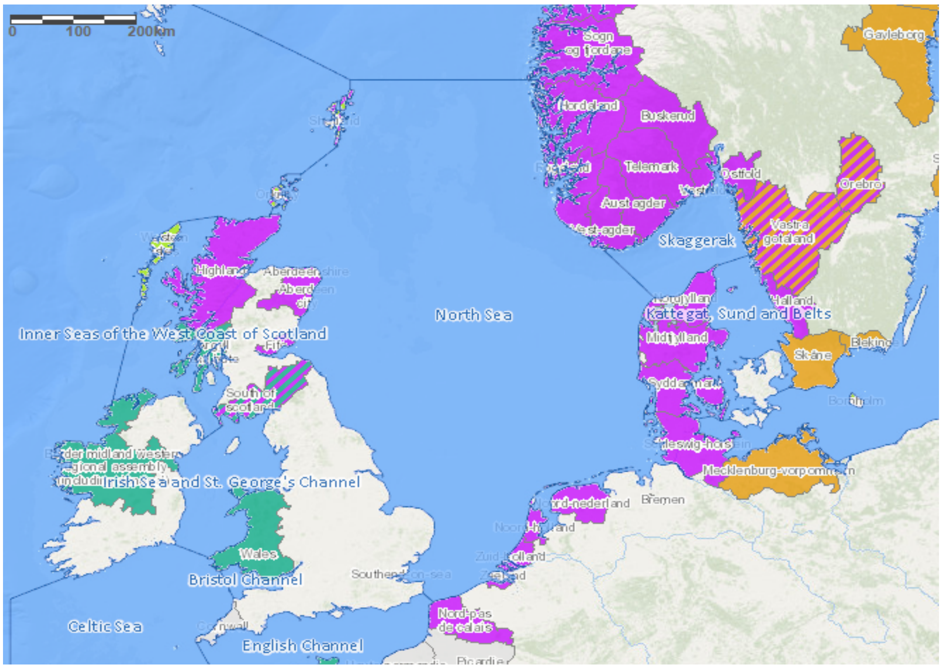


Figure 1 – North Sea basin as defined by European Commission [1]

Deliverable 2.2 fits into the overall NeSSIE WP2/WP3 scheme as illustrated in Figure 2. It is an important contribution towards identifying the economic potential for cross industry anti-corrosion solutions and products in the marine renewable energy NSB region and wider EU areas. It also concentrates its findings on supporting early demonstration project definition and funding.

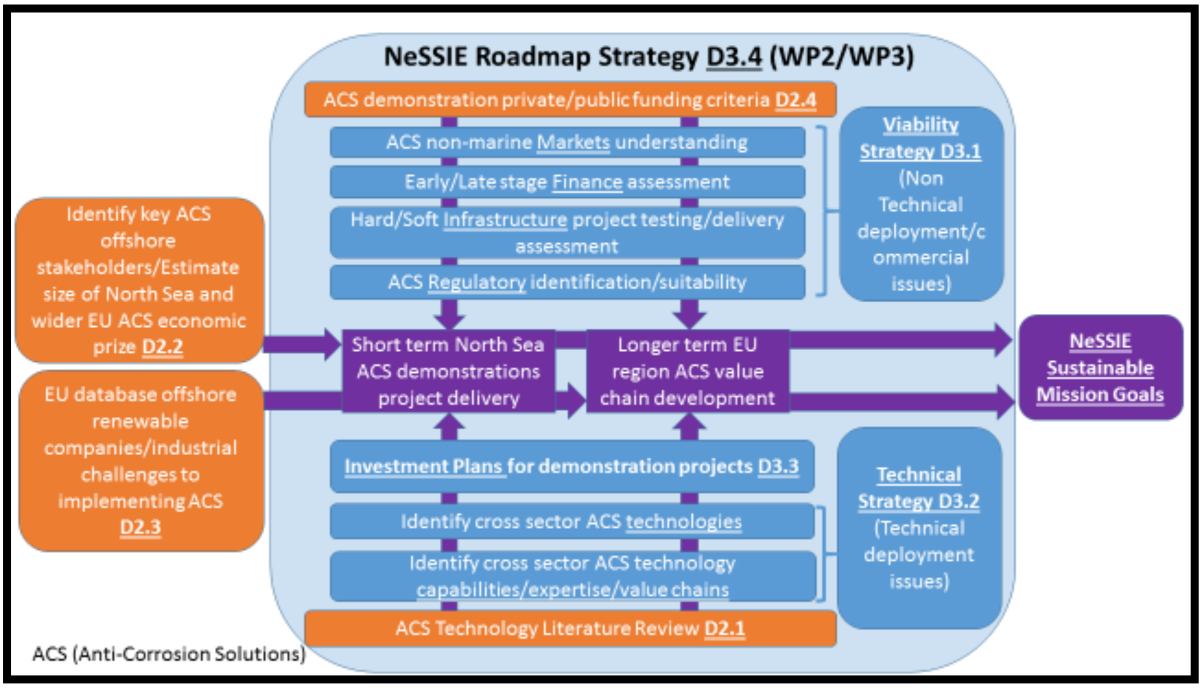


Figure 2 – D2.2 position in the wider WP2/WP3 NeSSIE project (UEDIN, Laurie 2017)

The report is divided into nine, structured, chapters:

- **Chapter 3** – Introduction with report context, objectives and layout;
- **Chapter 4** – Brief recap of earlier literature reviews on existing utilised offshore materials, corrosion mechanisms and employed solutions;
- **Chapter 5** – Evaluation of the materials expertise and innovative solutions employed by industries operating in the NSB offshore sector by identifying relevant value chains, including the identification of key private companies (service, provider, and manufacturers), research organisations/collaborations, testing facilities and applicable standards/regulatory bodies. In addition, a short list of planned wind, tidal and wave projects operated, or planned to operate by Developers within the NeSSIE timeframe were identified;
- **Chapter 6** – Case studies in applicable new marine materials landscaping investigations and lessons learned from existing marine energy project biofouling and corrosion testing. These case studies will provide real world context of the practicalities of applying corrosion solutions to marine devices;
- **Chapter 7** – An assessment of the potential economic opportunity of applying novel materials and direct corrosion services/products to offshore renewables across the NSB region;
- **Chapter 8** – Review and summary of offshore renewables industry development roadmaps from the UK/EU region to summarise to the wider audience the technology barriers and challenges, as well as highlight the support for the emerging sector;
- **Chapter 9** – Concluding remarks.

The overall NeSSIE impacts, of which D2.2 forms the initial foundation for were established within the following context:

- Three bankable/investment-ready demonstration projects in the North Sea basin that involve a transnational public/private consortium. The projects will be planned and investment identified at the completion of NeSSIE. The demonstration projects will deliver high value manufacturing opportunities to the supply chain in the North Sea Basin and the wider EU supply chain;

- New transnational business and investment opportunities and value chains in high potential blue growth domains across the North Sea;
- The Roadmap will serve as a model for other sea basins and consortia to address common technical challenges and develop bankable/investment-ready demonstration projects.

3. Summary of key corrosion issues offshore

Key messages

Corrosion is a common mechanism in the marine environment, with typical forms of corrosion being: general corrosion; pitting corrosion; crevice corrosion; galvanic corrosion; stress-corrosion cracking; corrosion fatigue; and MIC.

Current methods to prevent corrosion are cathodic protection as well as protective paints and coatings. Innovations in the latter are investigated, as well as the application of polymers and aluminium (which has been applied previously). In addition to these anti-corrosion measures, monitoring and assessment are a part of corrosion management.

The authors' own research and preceding project deliverable D2.1 formed the knowledge base in marine environment technical corrosion for this report. D2.1 was a research-based task looking at the identification of corrosion mechanisms and analysis of existing anti-corrosion solutions (ACS) currently used in North Sea offshore cross sector industries, i.e. corrosion solutions/standards/systems and new materials. The review also highlighted materials fabrication methods and products available on the current market in the North Sea.

- **Corrosion analysis:** the most prevalent marine energy device component materials in use today are steel alloys and composites. Corrosion solutions for these components present the largest opportunity for NeSSIE to translate cross-industry value chain expertise to the marine renewables sector. The wealth of other, less prevalent offshore component materials corrosion issues, such as elastomers and plastics corrosion were alluded to briefly in later chapters, as their usage below the splash zone within submerged environments is relatively new and less well understood.
- **Corrosion definition:** (in traditionally used marine metals): metals traditionally used in most offshore structures are metastable and liable to electrochemical corrosion. Fundamental thermodynamics states that they have an innate potential to revert to lower energy, more stable levels through entropy – the rusting of carbon steel (commercial iron containing less 2.1% carbon by weight [2]) is the best-known example of this offshore. Carbon steel and steel alloys of different grades (strengths) include additional elements, and are both widely utilised as a construction material offshore because of their relatively low cost, ease of fabrication, moderately good mechanical properties and ease of transport (see Table 16, Annex I for offshore metallurgical descriptions). Metal corrosion offshore can be defined and controlled using the corrosion triangle and removal of at least one of components contributing to corrosion - Figure 3 [3].

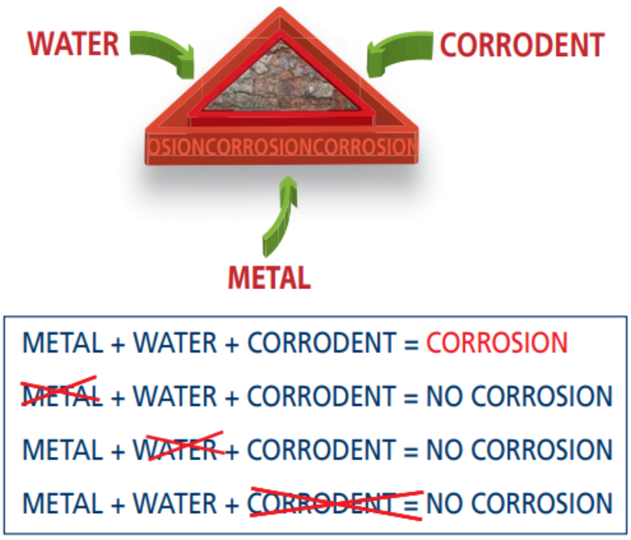


Figure 3 – Metallic structure in water corrosion triangle *[3]*

- **Physical corrosion rates:** the corrosion of metals in seawater is well understood given its historic deployment [4]. The most appropriate rate variables influencing marine energy device corrosion rates include dissolved gas concentrations in seawater (oxygen ions), seawater salinities, relative velocities and seawater temperatures, all of which have a proportional impact on metal corrosion and vary themselves as a function of location and depth. Two other important corrosion rate variables for marine energy devices exist, namely hydrogen ion concentrations, with similar corrosion rates observed between pH 4-10 (normal sea water having a pH of 8), and sulphate-reducing bacteria corrosion – recognised as being the most important type of corrosive micro-organism occurring in micro-habitats in anaerobic pockets beneath biofouling (although a wealth of other microbial organisms will exist as corrosive agents) [5]. Steel structures immersed in seawater in the atmospheric, highly corrosive zone, if unprotected, will corrode typically between 80-200um per year due to extended periods of wetness and high chloride concentrations, as well as UV light exposure. Splash zone corrosion rates are even higher – typically between 200-500um per year, and for continually-immersed zones rates between 100-200um per year are typical [8]. Figure 4 shows a typical offshore oil and gas structure corrosion profile, with corrosion highest in the splash zone.

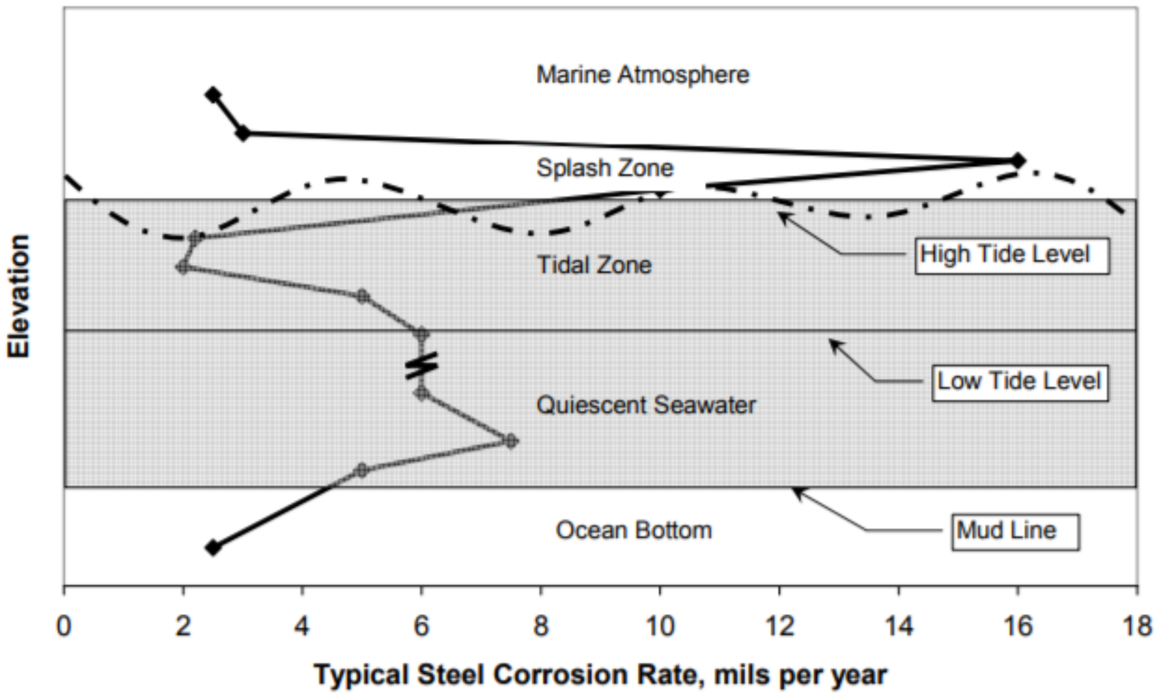


Figure 4 – Typical steel corrosion profiles for an offshore structure (1 mil = 25um) *[9]*

- **Corrosion degradation mechanisms:** metal corrosion mechanisms in offshore structures are displayed in Figure 5. For marine energy devices especially, microbially-influenced corrosion (MIC) is very relevant and has been observed as a pitting attack, via organisms attaching themselves to structures and forming a corrosive biofilm [6]. Evidence of bio-fouling on wave energy devices was investigated during Pelamis WEC trials [7].
  Although traditionally used metals are the most widely used material offshore, thermoplastic and thermoset (depending upon the matrix resin used) reinforced fibre composites have also been employed. Whilst they do not corrode, they do suffer from varying degrees of mechanical degradation when exposed to seawater (refer to Table 17, Annex I for comparable plastics matrix properties). Moisture diffusion within the composite can degrade the fibre-matrix interfacial bonding causing swelling, micro-cracking, plasticizing and hydrolysing. Water absorption for thermoplastics depends upon their chemistry and morphology, and their volume fraction versus fibres in the composite. Under conditions of moisture absorption and elevated temperatures, polymer chains relax and micro-crack formation occurs from residual stresses which weakens the fibre/matrix interface causing brittle failures. Certain types however performed better in seawater environments like POM and PP [8].

Form of Corrosion	Description	Illustration
Uniform or general corrosion	Uniform corrosion on hot-dip galvanized steel components with significant section loss	
Pitting corrosion	Pitting corrosion in stainless steel piping components	
Crevice corrosion	Crevice corrosion in steel structural elements of flush mounted manhole with pooling water	
Galvanic corrosion	Galvanic corrosion on steel components in atmospheric zone due to improper material selection	
Stress-corrosion cracking (SCC)	Illustration of SCC	
Corrosion fatigue	Corrosion fatigue in steel components subject to cyclic loading	

Figure 5 – Typical corrosion forms in marine environments (Power Principle Inc., USA)

- **Current corrosion solutions:** Submerged metallic offshore wind turbine (OWT) structures have largely employed protective paints and sprayed coatings (thicker covering acrylic, alkyds, epoxy, polyurethane and others coatings) and some form of cathodic protection below the waterline (passive galvanic for OWT). For the proper consideration of coating systems performance, it is critical to understand fundamental parameters in coating selection; type/condition of substrate, the operational environment, surface preparation techniques, quality of coatings, coating system selection criteria, their application and finally a quality control procedure [8]. These corrosion mitigations are in addition to design allowances for structural corrosion, with inspection and monitoring systems (IMS), materials design and weld design considerations [6]. Pre-coating application surface preparation techniques on the variously used metal substrates including cleaning, phosphate and silane pre-coats are used to improve adhesion and long-lasting corrosion protection. These optimised systems of corrosion solutions were largely taken from well understood lessons learnt in the oil and gas sector in corrosion monitoring and maintenance procedures (Figure 6).

  The use of composite materials for offshore infrastructure and equipment are employed because of their physical property advantages. The blades of offshore wind and tidal turbines are the primary applications for glass and carbon reinforced composites. The requirements for high strength and stiffness, resistance to moisture, anti-corrosive to seawater properties, fatigue degradation and ability to mould the material into slender shapes for turbine blades for minimal mass mean that composites out-perform traditional, cheaper metals in all areas of performance (Figure 7 [9]). The oil and gas industry has been conservative in its take up of thermoplastics and composites (combinations of plastic resin and fibre material). They have mainly been used for low-risk topside weight reduction applications, such as aqueous pipework (heavy flange connected lengths), platform walls, handrails, floors, corrosion protective lining for steel pipes and steel pipework repair (Figure 8). For these functions, it is easier to overcome regulatory concerns and technical challenges in replacing steel components and there is little need to scale up fabrication processes. Cross-industry relevant performance information is also well-established for these materials [8]. For higher risk equipment applications such as oil and gas subsea facilities, the regulatory requirements are more stringent, technical challenges more difficult and intervention costs higher if failure occurs [10]. However, the rise in deepwater oilfield developments has placed further emphasis on the use of composites for weight reduction in subsea platforms to seabed tethers, subsea risers and subsea control umbilicals [11].

THREAT #9 – EXTERNAL CORROSION: (A) COATINGS, (B) FASTENERS AND (C) SUBSEA

CAUSES	OCCURRENCE	SUSCEPTIBLE SYSTEMS	INSPECTION / MONITORING METHODS	MANAGEMENT
– Coatings degradation/ damage (e.g. lack of fabric maintenance) – Inadequate surface preparation prior to coating – Deposit build-up on pipework / vessels – Incorrect materials selection, e.g. carbon steel bolting on stainless flanges – Inadequate cathodic protection (Subsea)	– Field applied coatings especially susceptible to degradation – Carbon steel bolting / fasteners – Pitting corrosion of stainless steel – Stress corrosion cracking of stainless steel	– All coated topsides pipework, vessels – Structures – Bolting and fittings – Gratings and walkways – Subsea structures and components	– Visual inspection – Subsea - video inspection by ROV – CP potential monitoring and survey (Subsea)	– Fabric maintenance – Materials selection, e.g. galvanised bolting – Coat hot stainless steels – Avoid deposit build-up – Cathodic protection (Subsea) – Risk based inspection – See EI Guidance document Appdx B, Sections 9, 14 and 15

DEGRADATION MORPHOLOGY


Coating degradation


Corroded bolting, e.g. carbon steel bolting in stainless steel equipment


Deposit build-up leading to under-deposit corrosion

Figure 6 – External corrosion in the oil and gas industries subsea equipment *[3]*

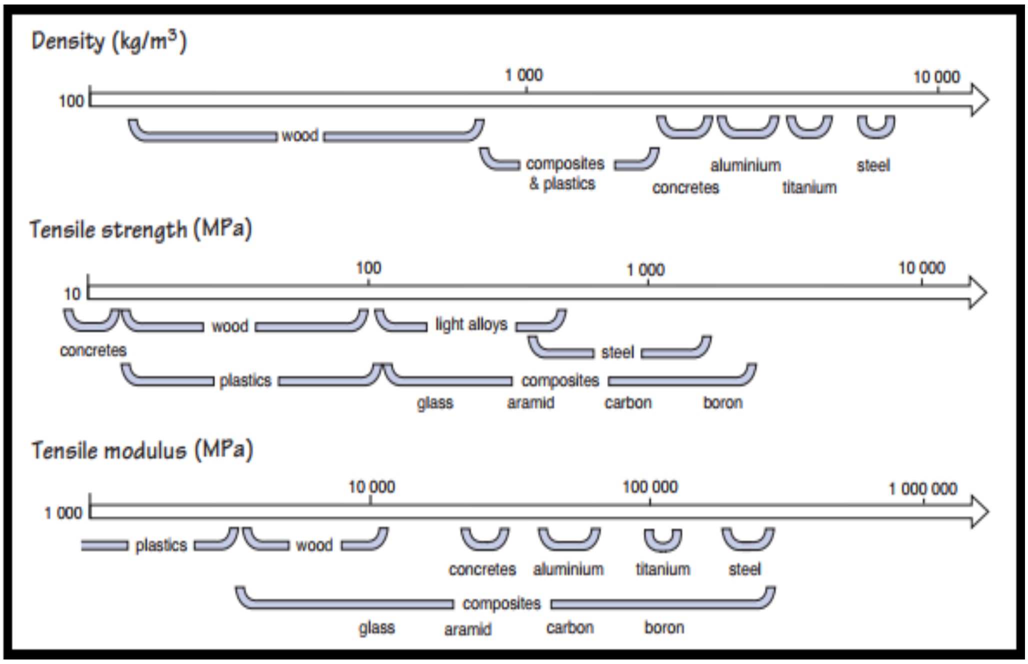


Figure 7 – Properties comparison of various structural materials *[9]*

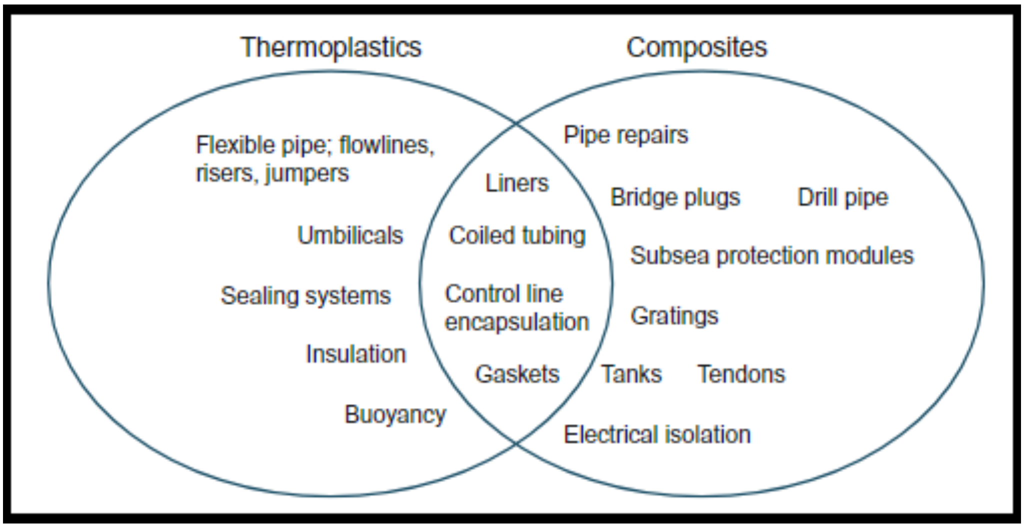


Figure 8 – Some thermoplastics and composites used in Oil and Gas industry *[9]*

- **Corrosion Management:** Achieving device design live corrosion management is essential. A combination of passive coating protection and active corrosion rate reduction to damaged areas is optimal for metallic structures. The cost of coating activities offshore are five to ten times higher than onshore [6]. 'Best practices' in offshore oil and gas processing consultations have been well captured and documented, for example by UK Health & Safety Executive [17] and Energy Institute [18]. These corrosion management policies provide a structured framework for the identification of risks associated with corrosion and the development of suitable control measures. A general corrosion management strategy could be translated and scaled to offshore renewables (Figure 9) as a commercial service along with the inspection and monitoring technologies already employed such as ultrasonic pipe corrosion sensors. Structural Health Monitoring (SHM) systems in offshore wind farms (OWF) are an emerging example of this, and provide an effective corrosion monitoring framework, allowing the planning of inspection and maintenance schedules [6]. The EU-funded TidalSense project investigated the use of ultra-sonic waves to assess submerged composite blade damage [19]. The SmartFiber project used a network of embedded wireless transmission fibre optic cables to monitor marine devices structural health and integrity [20].

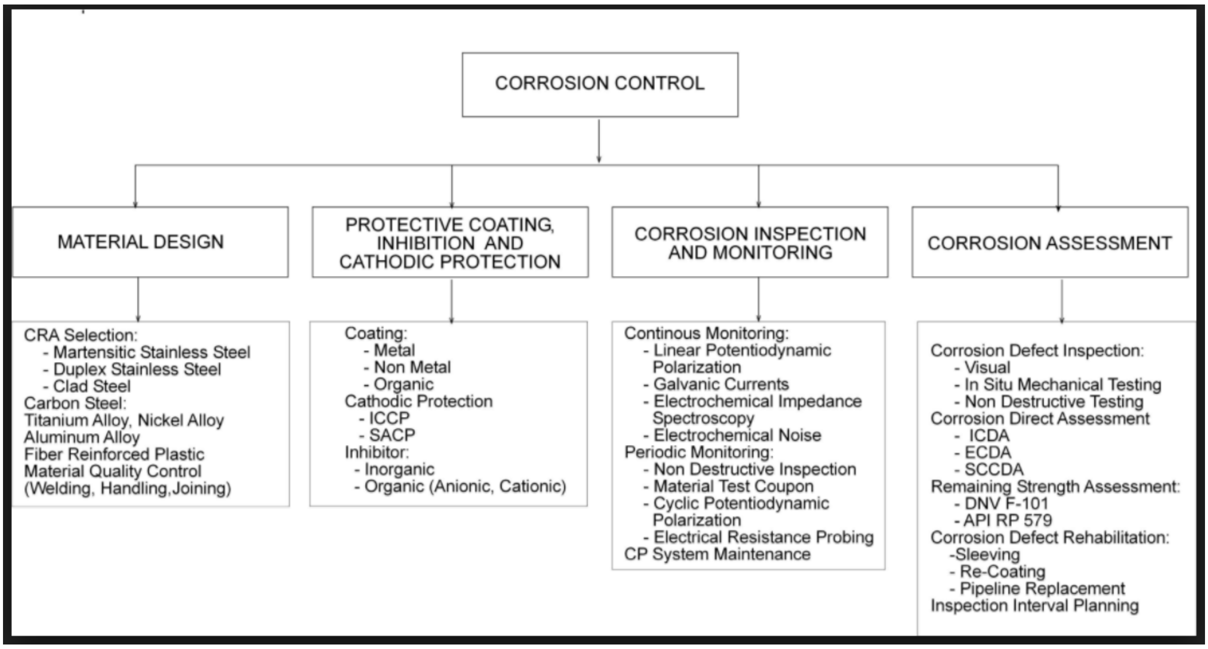


Figure 9 – Oil and Gas example of a basic corrosion management process *[18]*

- **Standards** (consensus document detailing qualification criteria for a product/activity): For the material selection of mainly steel alloys in the offshore oil and gas construction and installation sector, standards, guidelines and certifications are well-defined, given their importance to health, safety and the environment. However, there is no single universal standard applied by all companies in the oil and gas industry on all project phases in the North Sea basin, and it is the end-user's responsibility to implement them [17]. Given the region's long history of offshore oil and gas operations this is surprising, but could be an indication of how future marine offshore renewables standards and certifications will be applied. Examples of issued offshore anti-corrosion standards include;
    - ISO 21457, which is the only standard covering all issues related to materials selection and corrosion control for oil and gas production systems (although was only published in 2010) [21]. Table 1 illustrates a suggested project planning approach for materials selection used within this ISO standard.
    - NORSOK M-DP-001 standards for materials selection have been applied in the North Sea oil and gas sector specifically [22]. Other NORSOK standards, for example Norsok M-501 - used for surface preparations and protective coatings [23] have equal applicability to NeSSIE.
    - ASTM standards cover corrosion and wear, steel manufacture, metallic coatings and composites manufacturer and have been used in the OFW industry [24].
    - DNV standards appear to be the most progressive for the marine offshore renewables industry. DNV-OS-B101, for instance, covers metallic material qualifications for subsea

systems, marine operations and wind turbines [25]. More specifically DNV-OSS-312 covers certification of TEC/WECs [26].
  - The European Marine Energy Centre (EMEC) has published a large range of draft guidelines for different aspects of marine renewables design and development [27].
  - The National Association of Corrosion Engineers (NACE) provides a long list of well-developed standards for a wider range of specific corrosive materials topics [28].

The cross-sector translation of corrosive standards to offshore renewables is highly viable and is already employed to some degree in offshore wind farm developments [6], for example DNV-GL's OS-C401 offshore standard for the fabrication and testing of offshore structures [29]. A more extensive list of applicable standards to any NeSSIE demonstration project is provided later in this D2.2 deliverable.

Material Discipline Deliverables at Various Project Phases

	Feasibility Phase	Concept Selection Phase	FEED Phase
Materials Selection Philosophy	By operator or by contractor	Updated	Updated
Materials Selection Report	Optional	By contractor	By contractor
Design Report for Surface Protection			By contractor
Design Report for Pipeline Coatings			By contractor
Design Report for CP			By contractor

Table 1 – Project phase documentation for material selection decisions ISO21457 *[21]*

- **Anti-corrosion solutions fabrication**: these_include materials manufacturing and fabrication for metal and composite materials currently used in offshore infrastructure:
  - For the manufacturing of steel alloys used in offshore structures, the demanding environment requires a wide range of alloy compositions – carbon, micro-alloyed, high strength, stainless steel and chemically-resistant alloys as specified by the Norsok M-001 (see Annex I) standard and steel materials selection for different purposes and operating environments [22]. Steel alloys incorporate different combinations of the base metal iron and in addition to carbon, and other elements like nickel, chromium, and manganese alter strength and corrosive resistance for different end uses. Fabrication guidelines for all metal and composite offshore structures are subjected to DNV standards - DNV-GL-OS-C401 [24]. Fabrication planning involves the instructions and information requirements to identify procedures, testing, work instruction, acceptance criteria, hold points and documentation for the range of offshore structural engineering activities. These would include weld joining procedures for different metals/materials, fabrication tolerances, corrosion protection systems and materials certifications.
  - For marine turbine composites manufacturing, early prototypes have used predominantly manual processes with high total manufacturing costs, whilst the first full-scale devices relied solely on manual layup of pre-impregnated (Prepreg) processes which have been

around in other industries since the 1980s [9]. For a review of Prepreg processes, an excellent summary resource is provided by Hexcel [12]. There exists however, a wide range of composite manufacturing processes available to vendors with varying performance versus production volume criteria (Figure 10). Increasing focus is now being placed on reducing manufacturing costs by resin infusions, innovative turbine-moulding processes like IntegralBlade [30] for wind turbines and VARTM processes for tidal blades [31], reduced part counts and increased automation. Typically, tidal turbine blade structural design integrity follows a pyramid scheme; level 1 – material property data, level 2 – design detailed testing, level 3 – testing of structural elements, and finally level 4 – full scale structural testing, which are all driven by the need for materials' long term exposure to immersion and extreme fatigue load [9].

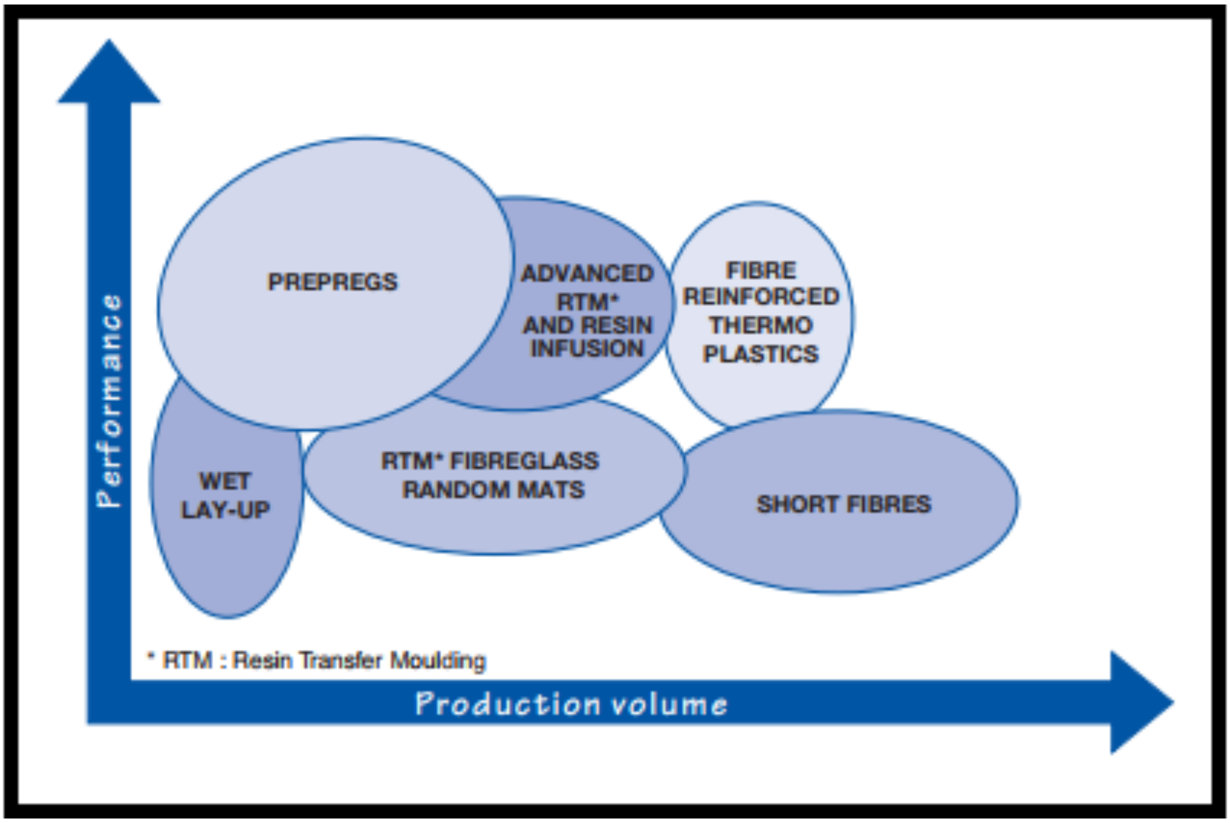


Figure 10 – Composite fabrication processes *[12]*

- **Anti-corrosion innovations:**_Different innovations are_being researched, tested and_under application, including:
  - **Anti-biofouling coating control**. Current anti-fouling control products fall into two categories, chemically active anti-fouling paints or non-stick fouling release coatings. In addition, the wide array of anti-corrosion coating technologies and processes are designed to form either a corrosive barrier (non-porous metal surface protection), a sacrificial coating (a layer that corrodes in preference to the substrate) or a fluoropolymer coating (thicker coating application for more aggressive environments) [32]. The critical factors deciding coating type include: substrate type; offshore environment; exposed stresses;

surface preparation techniques; coating quality; coating systems selection; and quality control - although importantly the laboratory performance of a coating is no guarantee of real life performance [8]. The future of anti-biofouling coatings is to remove the more traditional, environmentally-harmful ingredients of copper, zinc and other organic compounds used in the maritime sector, and replace them with environmentally-friendly and chemical neutral coatings [33], although most of the anti-fouling market today still uses these harmful biocidal coatings. Research is focusing upon modifying these coatings' chemistry, i.e. environmentally-friendly coatings applied to ships' hulls with anti-fouling capabilities [34], coatings with pre-emptive healing abilities [35], multi-layer coating systems to reduce corrosion [36], as well as composite coatings [37].

- **Composites** also constitute a thoroughly-researched and field-applied material given their higher specific strengths and better anti-corrosive properties compared to metallic materials in seawater. Composites are made from a strong fibre 'reinforcement material' component – like fibreglass/carbon – and a plastic 'matrix' that binds the fibres together, e.g. fibre-reinforced plastic (FRP). FRP offers near-free design shapes or wall thickness distribution in addition to the simple integration of metallic fittings, no weld joint weak points, variable conductivity design (glass fibre insulator or carbon conductor elements), as well as lower relative weight and energy consumption during manufacturing life cycles compared to metals [38]. The use of composites in marine energy applications is widespread. Interestingly, the designers of the Pelamis WEC decided to make the main structural elements in early devices out of steel, to simplify structural analysis. Proven equipment/materials were used because they formed the major proportion of structural spend - alternative materials (glass fibre reinforced plastics) were investigated later on as part of an optimisation strategy [39]. Composites are already used in tidal stream energy converters systems; there is no significant distinction between onshore and offshore wind turbine design but there is however significantly different design and material demands for tidal turbine given the greater density of water to air and resulting greater thrust loading. Exposure to extreme static and fatigue loads over lifetime in seawater, required lower maintenance interventions, slender hydrodynamic profiles of blades, biofouling resistance and root joint fitting to metallic hubs are a few considerations [9]. Atlantis Resources Seagen TEC employs carbon fibre and glass fibre composite blades as well as glass reinforced plastic (GRP) fairings on the cross-arm turbine supports [40]. Figure 11 illustrates a typical turbine composite blade construction – ply drop region is prone to cracking due to high through-thickness forces making design and manufacturing critical for blade longevity. The simulation of failure mechanisms has advanced from simple cycle failure counting to numerical modelling techniques – the latter is also being heavily-used to holistically optimise the trade-off between hydrodynamic efficiency and structural strength requirements. The long-term degradation of marine composites has been researched [41], and blade manufacturing cost reductions and reliability improvements identified (Figure 12), which trade expensive carbon and glass off against material and labour costs [42]. Research into maintaining hydrodynamic blade efficiency is aimed at ensuring the blade stays free of biofouling, which would also reduce blade degradation from cavitation effects – the use of anti-fouling coatings has been researched by Plymouth

Marine laboratory as part of the Energy Technology Institute's (ETI) two-year ReDAPT project (Figure 13). Using the DEEP-GEN IV turbine testing at EMEC, investigation found hard biocidal SPC coatings performed best overall, however they are designed for five-year re-application cycles on maritime vessels with coatings regularly replaced, and not the seven years for tidal interventions as modelled. ReDAPT also developed a coating scheme to match other component applications for the device [43]. The ReDAPT testing post 2015 achieved a three-year funding extension for testing at EMEC and will prove a valuable project framework for any future anti-corrosion demonstration product.

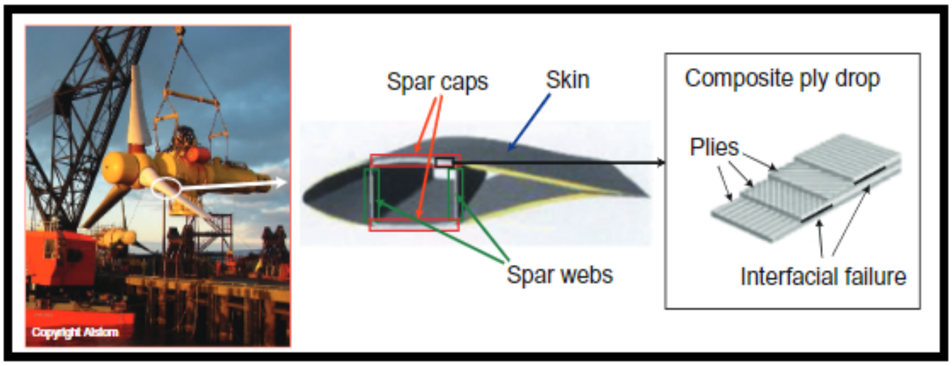


Figure 11 – Typical turbine blade structure using composites *[41]*

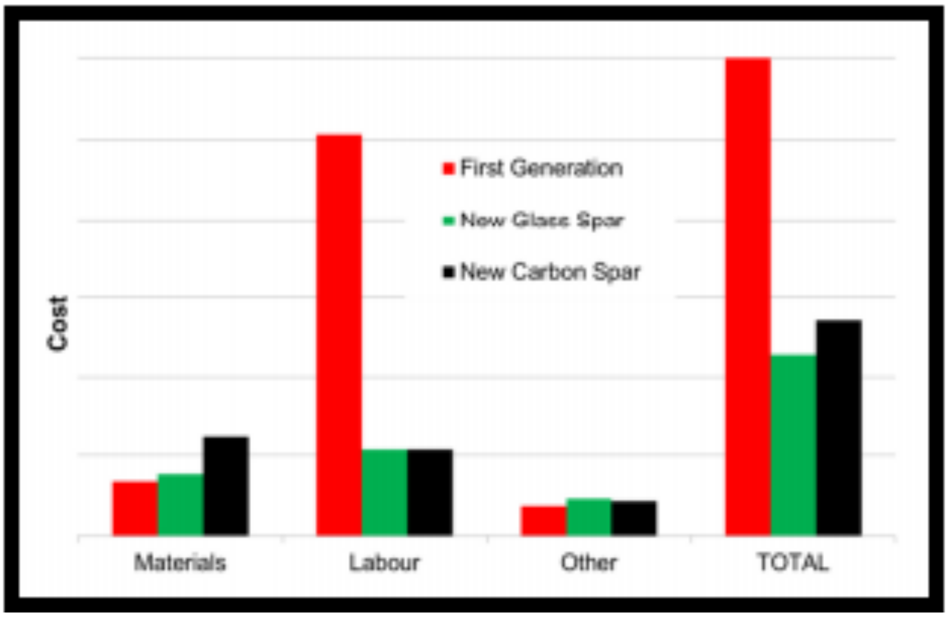


Figure 12 – Comparative cost reductions for composite tidal turbine blades *[42]*

Manufacturer	Brand	Technology Type	Anticorrosive (DFT info supplied by manufacturer)	Tie Coat	Top Coat (DFT info supplied by manufacturer)	Pre-test Total Dry Film Thickness	Notes
Hempel	Hempasil	Fouling Release	Multi-strength 457751-12340 (DFT 250µm)	Nexus 27302-55001	Hempasil Topcoat	~1000µm	Manufacturer applied
International	Not supplied	Fouling Release	Aluminium pure epoxy (150µm x 2 coatings)	Silicone Tie coat 100µm	Flouropolymer Antifouling 150µm	~550 µm	Manufacturer applied
Coppercoat	Coppercoat	Biocidal copper filled epoxy resin	GP120 (DFT 250-300µm)	N/A	Coppercoat (DFT 250 – 300µm)	~350µm	Manufacturer applied
Jotun	Seaquantum Ultra	Self polishing biocidal	Jotamastic 87	Safeguard Universal AS	Seaquantum Ultra	~600µm	Manufacturer applied
International	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied	~550 µm	Manufacturer applied
Plastimo	Plastimo Classic	Self polishing biocidal	Primocon (see below for details)	N/A	Plastimo Classic	~180µm	User Applied
International	Interzone 954	Epoxy	N/A	N/A	Interzone 954	N/A	User Applied
Jotun	Baltoflake Ecolife	styrene free, glass flake reinforced polyester	Jotamastic 87	Safeguard Universal AS	Baltoflake Ecolife	~1200µm	Manufacturer applied
Ecospeed	Ecospeed	Vinyl ester resin base, reinforced with glass platelets	N/A	N/A	Ecospeed (DFT 500µm x2 layers)	~1300µm	Manufacturer applied
International	Primocon	Tar free quick drying primer	This product is an anticorrosive primer and was used as a control coating.	N/A	Primocon	~150µm	User Applied

Figure 13 – ReDAPT ETI project testing anti-fouling coatings on a tidal energy device *[43]*

- The use of **Aluminium** offshore is not a recent phenomenon; it has been used in maritime vessel designs for over 40 years. Aluminium provides advantages for offshore wind such as weight savings on large components, smaller manufacturing carbon footprints, ease of manufacturing manipulation, corrosion resistance (no need for surface treatment since a natural oxide layer protects its surface -as opposed to steel which must be galvanised, heavily-painted or employed as stainless steel forms), non-combustible unlike GRP, non-magnetic,easily welable and can be 100% recycled [44]. Seatricity's Oceanus 2 WEC, currently deployed at the UK's Wavehub testing facility, was largely constructed using Aluminium [45]. Thermally sprayed Aluminium (TSA) coatings used in the oil and gas industry provide long-term protection for steel structures in the splash zone but do not resist biofouling. Traditionally biofouling resistance has used toxic substances harmful to the environment, although more recently a range of more environmentally friendly organic and inorganic substances have been researched and tested in marine conditions [46].

4. NSB offshore across industry anti-corrosion expertise

Key messages

The following value chains are identified with the use of anti-corrosion solutions:

- anti-corrosion coatings;
- anti-corrosion cathodic protection;
- anti-corrosion services;
- anti-corrosion material/ fabrication/manufacturing/assembly;
- anti-corrosion research;
- anti-corrosion standards and regulations;
- anti-corrosion test facilities.

This chapter breaks down the existing NSB anti-corrosion solution state-ofthe-art sector-expertise research into components parts. Firstly, the value chains necessary to deliver various offshore industry identified corrosion solutions are defined. There then follows an identification and summary of private/public companies (SME identifier also used to distinguish company sizes) and research collaborations engaged in anti-corrosion solution value chains in the different sectors. Regulatory and standardisation bodies -with an indication of applicable standards– as well as suitable test facilities required to run an offshore ACS demonstration project are listed. Finally, a scoping review identifying possible NSB offshore renewable energy developers/projects is included at this early stage to narrow down the list of potential demonstration targets (the targets being; offshore wave energy, tidal stream energy and floating wind energy as the most likely NeSSIE demonstration candidates given each one's relative sizes and maturities).

The importance of cross-sector opportunities were recently highlighted in a Scottish Enterprise study analysing Scotland's oil and gas sector [58]. The study identified foffshore wind in particular, and wave and tidal were cited as potential growth zones for companies with existing expertise in subsea facilities and support services. A number of diversification model options illustrated how practical value chain expertise through direct sales, product/service development, targeted acquisitions, partnerships, establishing subsidiaries, sub-contracting, mutual exchange and creating collaborative SMEs could be related between sectors. Understanding value chains and their positioning is key to cross-sector growth.

4.1. Anti-corrosion value chains identified for marine energy projects

The most relevant anti-corrosion value chains (VCs are defined as; the entire range of activities and infrastructure required to bring a product from concept to its end use, i.e., design, production, marketing, distribution and support) within the different offshore industrial sectors in the NSB region active today have been defined. This value chain template approach can be readily applied to other EU regions intending to identify companies and other organisations looking to diversify into the offshore renewables anti-corrosion sector. Direct corrosion solutions include coatings, Cathodic Protection, and services, whilst 'new materials' refer to novel materials other than standard steel alloys, and their fabrication, manufacturing and final assembly. Research, standards, regulatory compliance and testing facilities all form peripheral value chain components for direct corrosion and new materials solutions (Figure 14):

- **Anti-corrosion coating VCs** – This is most applicable to submerged or splash zone steel alloy structures and peripheral components to avoid corrosion and biofouling, but also potentially to submerged composite materials to counter corrosion and blade cavitation effects. The VC includes anti-corrosion coatings, anti-fouling coatings, UV protection coatings and sprayed protective coatings.
- **Anti-corrosion Cathodic Protection VCs** – This is only applicable to submerged metallic alloy components with varying metallic material electrochemical potentials. Equipment deployed includes both passive cathodic protection (PCP) and impressed cathodic protection (ICP) systems. The VC includes installation, operation, monitoring and servicing PCP/ICP.
- **Anti-corrosion Services VCs** – This includes marine offshore corrosion monitoring (SHM),

ACS software design solutions and periodic servicing and intervention systems.

- **Anti-corrosion Material/Fabrication/Manufacturing/Assembly VCs** – This consists of specialist anti-corrosive material solutions that can be used to construct marine device components. Exotic steel alloys, composites, concrete, elastomers, plastics and aluminium materials for both major (e.g. tidal turbine blades) and peripheral marine energy device components (pipework). This also includes fabrication and manufacturing.
- **Anti-Corrosion Research VCs** – These are the available research collaborations and publicly-empowered organisations/projects that facilitate support and encourage the difficult transition of corrosion solutions between R&D to commercial application.
- **Anti-corrosion Standards and Regulatory VCs** – This encompasses the applicable technology verification services through standards and certification for ACS offshore renewables industries. Appropriate regulatory bodies and their main statutes applicable to the North Sea Basin (with a UK example focus) were identified.
- **Anti-corrosion Test facility VCs** – These are the available open-sea NSB testing facilities for potential demonstration projects.

The following section's search forsuitable participating parties in each NSB region relevant to each VC has been wide, but it should be noted was not exhaustive - the identified parties are examples only.

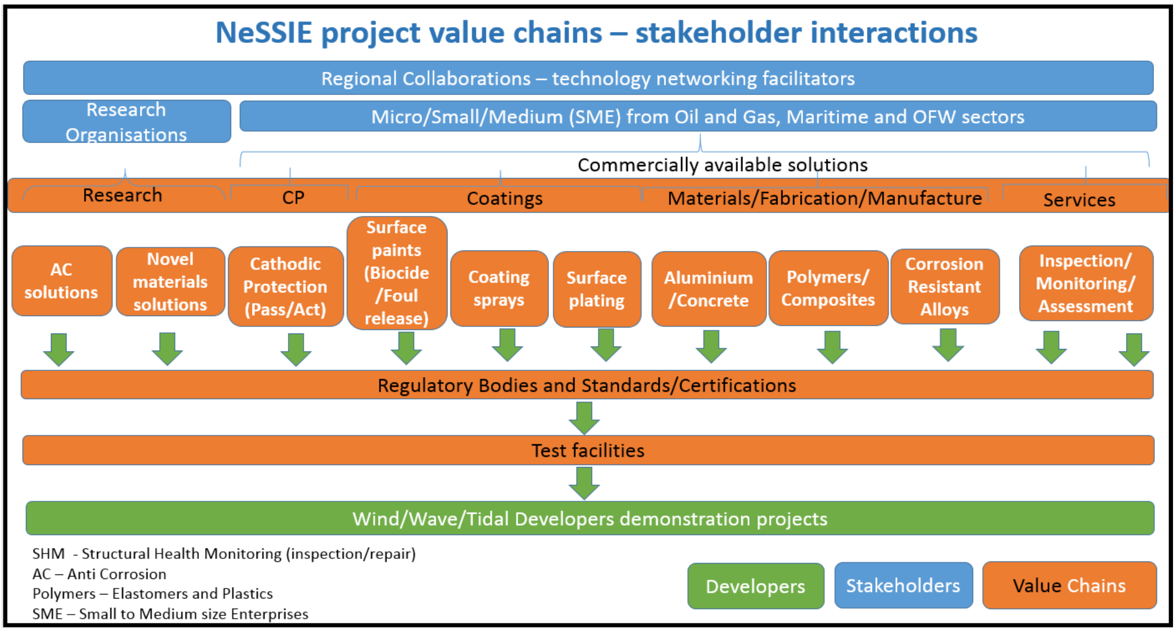


Figure 14 – NeSSIE project value chain interactions with stakeholders

4.2. Key NSB private companies offering offshore anti-corrosion solutions

Using a combination of website research, partner inputs and 2017 oil and gas as well as the offshore renewable energy exhibition vendor attendees, a shortlist of private companies offering various anti-corrosion solution value chain expertise was collected and shown in Table 21, Annex II. Research focused on the NSB region. Within the ACS coatings, CP, new materials, and services value chains, a mixture of larger company and SME expertise exists across different countries. Of particular interest are companies actively advertising their services at the various industry conferences this year – these companies may be particularly favourable to expanding their existing market scope to encourage growth.

The Society of Petrol Engineers (SPE) Offshore Europe September 2017 conference [47] was one such opportunity of which the NeSSIE team took advantage. During the visit, a large number of possible vendors who specialise in supplying and researching novel materials and corrosion products and services to the oil and gas industry were approached and questioned regarding their possible interest in the project. Almost without exception, 14 of the 19 companies interviewed gave a favourable response to further collaboration and contact with NeSSIE via diversification of their existing businesses. Although the transferability between sectors may not have been immediately obvious, the potential use of new materials, existing fabrication supply chains or more direct corrosion services to the marine renewables sector were organically discussed and evident. Most of the companies had already considered diversification at some level, with some already partnering in offshore wind projects and all identifying the lack of translation mechanism between industries as being the main enabler. The recent downturn in the oil and gas industry in the NSB was identified as a key driver to these companies wanting to diversify, whilst perhaps in the past the necessity to do so was less apparent.

The companies approached, as well as those that gave favourable collaboration responses, are listed below, and provide a snapshot of cross industry vendors who could collaborate with NeSSIE:

- Oxifree Global Ltd – a protective thermoplastic coatings provider;
- GCG-Group – A surface treatment and coating specialist (including thermally sprayed aluminium);
- McDuff International – A marine cathodic protection vendor;
- Cactus International Ltd – A ceramic paint coatings and offshore surface preparation specialist;
- Presserv – An asset integrity and preservation services company;
- Rochling – A thermoplastics and composites manufacturer;
- Subsea Power Hub – A small scale Darrius current turbine developer;
- National Composites Research Centre – UK national centre for composites research;
- Bridon Bekaert – A marine steel/plastic braided tension leg rope specialist;
- Rubberatkins – A Norsok standard high performance elastomer manufacturer;
- Motive – A materials and fabrication company;
- Underwater cutting solutions – A decommissioning specialist;
- Oil and Gas Technology Research Centre – A diversification research hub;
- Neptune Offshore Services – A underwater corrosion monitoring provider.

The private anti-corrosion companies who exhibited at the Offshore Wind Energy 2017 conference [48] earlier in the year and thus already actively involved in offshore renewables supply chains included:

- AKZONOBEL – Large coatings supplier;
- Corrosion – Dutch based company specialising in impressed cathodic protection systems;
- Deepwater EU – Corrosion management Services specialist;
- Hutchinson Engineering – Steel fabricator to offshore wind;

- ITW Engineered Polymers – High performance concrete foundation supplier;
- Krebs Korrosionsschutz GmbH – Maritime industry coatings specialist;
- MME Group – Impressed CP and corrosion services;
- CWIND – Corrosion services provider.

The remaining private companies listed in the Annex II Table 21 have been sourced from a collection of inputs; Wave Energy Scotland and Enterprise Technology Partnership referrals, the 2017 Renewable UK Wave and Tidal conference in London, NeSSIE consortium partners and the author of this report's own knowledge and research. The cross-industry sector companies listed all show potential technologies and expertise that would be applicable to a NeSSIE demonstration project and form candidates for the D2.3 industry questionnaire deliverable – the format of which will be heavily influenced by learning from the Offshore Europe conferences attended.

4.3. Key NSB collaborations researching anti-corrosion solutions

Research collaborations are numerous and varied in their structure, locale, timing and funding source. Each, however, shares the common goal of directing funding from public/private budgets into internationally/national/privately targeted strategic technology economic and community development innovation programmes. Table 22 in Annex II lists those NSB regional research collaborations that may be interested in participating in NeSSIE corrosion expertise translation.

An example of a national government funded, regional economic development organisation (REDO) is Wave Energy Scotland [49], a subsidiary of Highlands and Islands Enterprise [50], and which promotes innovation and investment in the wave energy sector in Scotland. This collaboration offers a range of power take off, novel wave energy converter and materials research programs with favourable timings that could coincide with demonstration project selection:

- **Novel WEC programme** – Eight, project gate stage two (small scale engineering and tank testing) WEC devices being researched up to autumn 2018 prior to the next gate selection stage three (scaled prototype in-sea testing).
- **Materials and Manufacturing process programme** – Ten, gate stage one (reduced scale concept proof and iterative engineering performance) materials studies that began in early 2017, stage two selection applications will be decided by early 2018.
- **Power Take off (PTO)** – 17 various stage two and three PTO devices with ongoing research. The CorPower Hi-Drive PTO is the most advanced of all these projects with operational testing planned at EMEC imminently.

Wave Energy Scotland functions on a stage gate process for project development and funding release as represented in Figure 15 [51].

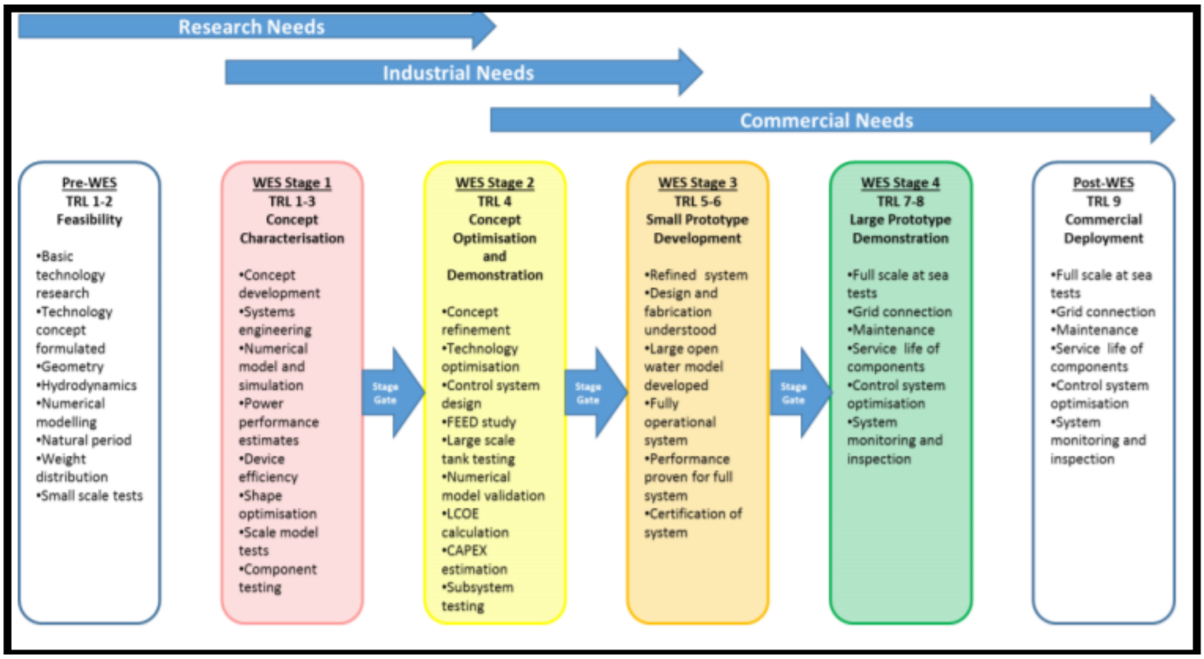


Figure 15 – Wave Energy Scotland stage gate project development [51]

Another attractive R&D collaboration based in the UK is the ORE Catapult - the flagship innovation and research centre dedicated to offshore wind, wave and tidal advancement. The following innovation challenges were identified by the Catapult:

- **For Fixed wind turbine foundations** – Develop improved coatings or corrosion protection methods that protect the structure in the intertidal zone where CP protection is ineffective [52]. This requirement could tally well with a novel materials investigation or new coating methods.
- **For tidal and wave systems** – Develop solutions to improve the monitoring of the condition of tidal and wave energy convertors and arrays [53]. Structural corrosion and biofouling buildup monitoring systems could be translated between industries.
- **For tidal systems** – Develop a cost effective subsea connector that accounts for the dynamic and oxygenated environment of wave and tidal sites, to reduce early failures and to bring down the cost of this significant component [54]. Wet mate connector failures through subsea corrosion initiates early failures of connectors developed for the oil and gas industry.
- **For tidal blades** – Innovative solutions that improve the durability of tidal turbine blades are required. This may include providing levels of self-healing or hardening the leading edges of blades [55]. New composite materials fabrication processes or blade coating research could be applicable to this challenge.

Several relevant research findings have already emerged from the ORE Catapult and may be of use to NeSSIE:

- **Marine growth monitoring and mapping** [53] – Biofouling industry consultation, predictive mapping feasibility study and promising commercial sensor monitoring technology investigation. Key findings:
    - Applied biofouling monitoring technology supply chains are only feasible if services are spread across all offshore sectors. A single technology focusing on marine offshore

devices alone would not be economic unless spread across the wider offshore sector.
- Biofouling monitoring would allow optimisation of expensive vessel/ROV interventions. It will also allow optimisation of routine/regular device corrosion check-ups and device performance efficiencies.
- Biofouling of important measuring devices like Acoustic Doppler Current Profilers and Acoustic Doppler Velocity Meters are often overlooked by developers. A biofouling sensor twinned with these instruments would provide better data quality and maintenance scheduling.
- Macro-fouling monitoring will aid device compliance with incoming legislation based on the EU biodiversity strategy 2020 on 'combatting alien species', which involves compliance monitoring.
- No one technology is suitable for either micro or macro fouling monitoring of renewable marine energy devices.
- CENSIS (Innovation centre for sensor and imaging systems) has ongoing projects with useful networking and knowledge sharing capabilities [56]. For example, the 'Improved NDT for corrosion' study that began in early 2017 by Strathclyde University and TRAC Oil & Gas ltd.

- **O&M key issues in offshore wind 2015/2016** – Analysing the key challenges required for the growing offshore wind industry and related products and services [57]:
  - Unscheduled reactive and proactive activities constitute 65% of O&M incurred costs.
  - ORE Catapult priorities to reduce this fraction relevant to NeSSIE:
    - Improvement in asset management tools – e.g. condition monitoring systems;
    - Reliability improvements.
- **Floating wind technology assessment 2015** – Assessment of floating wind sector in relation to technical development, deployment volume and cost competitiveness [58]. The most technically advanced projects include Statoil's Hywind, Principle Powers Inc. Windfloat and Glosten Associates Pelastar farms. More recent additions to this list include the IDEOL Floatgen demonstration project and the Kinkardine OFW. The key identified technical challenges relevant to NeSSIE are:
  - Support structures for floating wind not yet optimised;
  - Distance offshore limits inspection and maintenance operations.
- **Marine energy component analysis case study 2016** – An EMEC and ORE Catapult kick-off database cataloguing component failures during EMEC testing that impacts device reliability, survivability and O&M cost impacts [59]. Key findings:
  - To successfully move to commercial scale deployments, the sector will need marine components that are fully tested and proven. The cost of field failures is high, especially if the initial component failure leads to cascading failures.
  - Corrosion failure mechanisms for small components and need for higher corrosion grades or corrosion coatings are referred to, along with better high stress component materials selection and more rigorous weld inspection.

Three particular institutions and organisations specialising in specialist materials research and industrial collaboration, which outwith the UK may warrant an approach by the NeSSIE consortium to develop conversations around materials and corrosion value chains. These include; **SINTEF** (Scandinavia), **SWEREA** (Sweden) and **ITMA** (Spain). Each one has direct connections to corrosive solutions research and may best be approached by partners in their respective countries to investigate possible project collaborations with NeSSIE.

Two EU-funded projects that specifically looked at thermally sprayed protective aluminium (TSA) coatings for marine energy devices include ACORN [46] and OCEANIC [60]. The former ended in 2016, but the latter has in-sea tests ongoing. ACORN embedded environmentally friendly anti-fouling substances to the TSA coating with seven-month trials in Northern Spain exhibiting excellent corrosion protection and a predicted twenty-year design life. The ACORN project also developed a corrosion and cavitation resistant coating (cermet HVOF) for tidal turbine blades with a ten-year design life. Both offer high potential innovative ACS that could be incorporated into NeSSIE demonstration projects. Similarly, but perhaps constrained by confidentiality is the EMEC-Whitford ACS coatings investigation project carried out in 2016. Engagement with the University of Highlands and Islands in Scotland, which led the EU-funded FP7 MERIKA [61] marine energy accelerator programme, may also prove profitable, as under this research umbrella a biofouling study on AW-Energy's Waveroller device in Peniche, Portugal was carried out in late 2017 [62].

The Belgium-based collaborative OWI-lab Energy Research Alliance specialises in linking R&D with industry to help realise cost reductions on offshore wind. In particular these include the OWI-project (dedicated innovation projects), VIS-O&M project (smart solutions to OPEX cost reductions) and O&O Parkwind projects (monitoring and assessment offshore foundations) [63]. All will share synergies with novel materials and corrosion solutions for fixed wind turbine systems and provide a valuable linkage between NeSSIE demonstration projects and industry, in a similar way to the UK WES and ORE Catapult organisations.

Staying with the topic of offshore wind, the Carbon Trust's Offshore Wind Accelerator is a flagship R&D programme set up in collaboration with key developers. The current phase kicked off in 2017, with cost reduction topics split into five categories. The most relevant category to NeSSIE is arguably offshore foundations [64], in particular a new subsea structure inspection competition to enhance inspection strategies – for example grouted joints and welds corrosion preventative maintenance. Whilst the competition itself does not directly lend itself to NeSSIE aims, it does identify a key corrosion weakness that could be addressed by novel materials or ACS, such as a corrosion monitoring system.

R&D into corrosion solutions in addition to the previously mentioned WES studies is widespread across the UK. However, integrating advanced materials research into a 2018 demonstration project is more of a practical challenge than applying a component coating, CP or ACS service. Further investigation into several other advanced materials R&D programmes may be beneficial should confidentiality not be an issue. R&D programmes in the UK include; AEMRI's tidal device inspection methods [65], the University of Manchester's SUSTICOAT and Graphene Oxide coatings [66], Warwick University's DURACOMP study on composites durability [67], Plymouth University's Materials and Structures (MAST) composites research [68] and the University of Cork's MaREI composites fatigue testing [69].

4.4. Key NSB test facilities for demonstration trialling of anti-corrosion solutions

Demonstration project suitability to private test facilities across the North Sea Basin depends upon the testing TRL stage of the projects selected. NeSSIE will specifically be identifying projects at EMEC-referenced TRL standards [70] greater than level five for wave and tidal, i.e., projects that have emerged from conceptual/detailed design and scaled tank performance testing to large-scale/full-scale in-sea testing (see Table 20, Annex II for a description of TRL levels). This TRL convention was also used for offshore wind demonstrations. Table 23 in Annex II lists identified and suitable test facilities/partnerships for each of the technologies.

Given the particular nature of corrosion in seawater for this project, only active open ocean testing facilities have been considered in this listing. The majority of large-scale test tanks around Europe use freshwater facilities for maintenance reasons. The Energy Technology Partnership - mentioned in the R&D collaborations table – is involved in the Scottish Energy Laboratory (SEL) in the UK, a network of research, test and demonstration centres. This partnership grants access to a wide range of wind, wave and tidal test facilities, as well as material-testing facilities that could be made available to a NeSSIE demonstration; these facilities largely cater to projects at TRLs four and below. The last point of note is that most floating wind projects and some start-up tidal array projects in the context of possible NeSSIE demonstration candidates are better covered in the later 'Developers' section of this chapter given their post testing, more advanced commercialisation status.

When describing offshore test facilities, the pre-eminent large-to-full-scale open-sea wave and tidal test facility in Europe is EMEC, in the Orkney Islands of Scotland, which has been attracting wave and tidal developers since 2003. This facility, and projects scheduled for testing in EMEC during 2018, are an obvious target given NeSSIE's criteria. Up to 2015 EMEC was one of the sites funded through the EU-funded MaRINET project, giving selective access to developers to accelerate marine energy development. EMEC will continue to be accessible via MaRINET's daughter project - MaRINET2, which provides access to 57 offshore energy test facilities of varying size, and which runs between 2016-2019 [71]. MaRINET2 recently closed to first call submissions and awarded €1.3M to 34 successful projects. The infrastructure portfolio accessible under the MARINET2 project is shown in Figure 16.

	TRL 1-3	TRL 3-4	TRL 5	TRL 6-7
Tidal	*UCC_MaREI: Lir wave & current flume* FLOWAVE: Ocean Energy Research Facility CRIACIV-LABIMA: Laboratory of Maritime Engineering // IFREMER: IFR WCF University of Strathclyde: Kelvin Hydrodynamics and James Weir Fluids Lab *MARIN: Multiple basins*	CNR-INSEAN: CWC and TWT FLOWAVE: Ocean Energy Research Facility University of Plymouth: COAST IFREMER: IFR WCF // *Oceanide: BGO FIRST Basin // ORE Catapult: Laboratories* *IHCantabria: Coastal and Ocean Basin* *MARIN: Multiple basins*	EMEC: Tidal Scale TTC: Discharge Sluice EMEC: Integrated Monitoring Pod *QUB: Portaferry Tidal Test Site* *ORE Catapult: Laboratories*	EMEC: Tidal Full Scale EMEC: Integrated Monitoring Pod *QUB: Portaferry Tidal Test Site* *ORE Catapult: Laboratories* *TTC: Off shore test side Marsdiep*
Wave	UCC_MaREI: Lir_OOB and Lir wave & current flume // University of Edinburgh: Curved tank // AAU: Basin // CRIACIV-LABIMA: Laboratory of Maritime Engineering // IFREMER: IFR WCF // FLOWAVE: Ocean Energy Research Facility // University of Strathclyde: Kelvin Hydrodynamics and James Weir Fluids Lab // QUB: Portaferry Wide Wave Basin // *MARIN: Multiple basins*	IFREMER: IFR WB // ECN-LHEEA: HOET CNR-INSEAN: TWT // FLOWAVE: Ocean Energy Research Facility University of Plymouth: COAST Leibniz Universitaet Hannover: GWK *Oceanide: BGO FIRST basin* *UCC_MaREI: Lir_DOB* *IHCantabria: Coastal and Ocean Basin* *MARIN: Multiple basins // SSPA: Sweden AB*	SmartBay Ireland Ltd: GB MARETS WavEC: PICO OWC Wave Energy Plant University of Exeter: FaBTest *BiMEP: Biscay Marine Energy Platform* *QUB: Portaferry Wave Test Site* *EMEC: Wave Scale* *Uppsala University: Islandsberg*	EMEC: Wave Full Scale WavEC: PICO OWC Wave Energy Plant ECN-LHEEA: SEM-REV *EVE: Mutriku OWC Plant* *BiMEP: Biscay Marine Energy Platform* *PLOCAN: The Oceanic Platform of the Canary Islands*
Offshore Wind	UCC_MaREI: Lir_OOB University of Strathclyde: Kelvin Hydrodynamics and James Weir Fluids Lab *University of Surrey: EnFlo Stratified Flow Wind Tunnel* *UCC_MaREI: Lir wave & current flume* *MARIN: Multiple basins*	University of Plymouth: COAST // ECN-LHEEA: HOET //*University of Surrey: EnFlo Stratified Flow Wind Tunnel // Oceanide: BGO FIRST Basin // ORE Catapult: Laboratories //* *UCC_MaREI: Lir_DOB* *IHCantabria: Coastal and Ocean Basin* *MARIN: Multiple basins // SSPA - Sweden AB*	SmartBay Ireland Ltd: GB MARETS University of Exeter: FaBTest *BiMEP: Biscay Marine Energy Platform* *Uppsala University: Islandsberg*	ECN-LHEEA: SEM-REV IFREMER: IFR HOMERE DTU: Windscanner NTNU: Skipheia Met-station *CENER: WINDBENCH* *BiMEP: Biscay Marine Energy Platform*
Grid - PTO	UCC_MaREI: Lir_OOB TECNALIA: Electrical PTO Lab	UCC_MaREI: Lir_OOB TECNALIA: Electrical PTO Lab SINTEF: Renewable Energy Lab-Smart grids	WavEC: PICO OWC Wave Energy Plant *EVE: Mutriku OWC Plant* *ORE Catapult: Laboratories*	WavEC: PICO OWC Wave Energy Plant *ORE Catapult: Laboratories* *EMEC: PTO Test Rig* *EVE: Mutriku OWC Plant*
Cross cutting: Material and mooring	IFREMER: IFR Materials UCC_MaREI: Lir_OOB	IFREMER: IFR Materials University of Exeter: DMaC UCC_MaREI: Lir_OOB *NUIG: Galway Large Structures Test Cell* *SSPA: Sweden AB*	TECNALIA: Components & Corrosion Test Platform University of Exeter: FaBTest *University of Limerick – MaREI: MRE ROV* *ORE Catapult: Laboratories* *CTC: Marine Corrosion Test Site 'El Bocal'* *PLOCAN: The Oceanic Platform of the Canary Islands*	TECNALIA: Components & Corrosion Test Platform *EVE: Mutriku OWC Plant* *University of Limerick – MaREI : MRE ROV* *ORE Catapult: Laboratories* *CTC: Marine Corrosion Test Site 'El Bocal'* *PLOCAN: The Oceanic Platform of the Canary Islands*

MaRINET2 Infrastructure portfolio

Figure 16 – MARINET2 infrastructure access portfolio: technologies and TRL levels [71]

Another EU-funded project, FORESEA, grants access to a far narrower range of open sea testing sites - these do however include the larger sites at EMEC in Scotland, SEMREV in France, SmartBay in Ireland and the Tidal Test Centre in the Netherlands. FORESEA runs between 2016 and 2019, with the fifth call for proposals inviting 45 applications, with winners being announced in September 2017 [72]. Accessibility to each of these facilities' testing schedules would aid the identification of wave and tidal demonstration project candidates. Of the other open sea test sites listed, only WaveHub (UK) – with sites in South Pembrokeshire and Cornwall - as well as FaB Falmouth (UK) for WECs, and QUB (Ireland) for TECs have easily traceable, demonstrable records of past project testing, and mention future growth and device testing programmes. The recently-completed PLOCAN test centre in Grán Canaria, which sits outside the NSB region, should however be considered for demonstration projects since it uniquely possesses floating wind test site infrastructure as well as wave site testing.

In the UK, testing facilities starting at earlier TRL stages are available at the ORE CATAPULT's National Renewable Energy Centre (NaREC). These independent and open-access facilities are designed for project access at the TRLs three and higher, with the purposes being the scaling up of projects towards pre-commercialisation. Relevant test facilities include rotor blade structural testing, PTO component testing, HV cable electrical testing, subsea shallow seawater testing tanks and an artificial seabed, as well as a 7MW nearshore wind turbine at Levenmouth in Fife, Scotland. Given the CATAPULT's earlier identified corrosion challenges, a new, previously-validated materials/fabrication process for superior corrosion protection could be tested here, or even a short term scaled prototype using the artificial seabed facility.

A rapidly developing marine energy research centre is to be found in the Marine Energy Hub in North Wales [73]. Nova Innovation, a private tidal turbine array company is building an operational presence at the site to aid development of its Bardsley Sound tidal project. The facility itself has identified West Anglesey as a future tidal demonstration site.

With respect to offshore wind test sites, traditional turbine test sites have been lacking due to the high capital cost of establishing them, in turn encouraging a monopoly for well-funded and independent turbine manufacturers to dominate - Siemens Wind Power supply 96.4% of the EU's current offshore wind turbines [74]. The new offshore wind testing centre (EOWDC), offshore of Aberdeen, is planned to come online for testing access in the summer of 2018. It will look to facilitate entry into the turbine market for smaller players, and improve innovation testing access to existing developers. This facility may provide opportunities to test anti-corrosion solutions to offshore wind structure foundations, or potentially scheduled floating wind testing programmes.

4.5. Key NSB regulatory and standards certification bodies

Regulatory compliance by a NeSSIE corrosion demonstration project would primarily need to refer to national and international health, safety and environmental regulations. The collection of International and European regulatory statutes is shown in Table 24, Annex II. At a national level, and since the UK is at the forefront on offshore renewables installations, the MeyGen tidal stream project's comprehensive environmental impact assessment [75], which was required to outline compliance with all relevant regulations, has been used for the NSB region demonstration projects regulatory reference. The existence of projects and reports like this one do favour the UK for all NSB demonstration projects given the maturity of regulatory and compliance frameworks already in place. The UK Health and Safety Energy (HS&E) division's regulations – to which all UK offshore oil and gas platforms adhere – would also be a reference resource. Any corrosion specialists already working in the offshore oil and gas sector would be aware of the necessary HS&E regulations for their products and services.

Early stage technologies benefit from similar, more established offshore industrial expertise when it comes to countering challenges and incorporating lessons learnt – for wave, tidal stream and floating wind the application and adaptation of certifications and standards can help to guide technology development. For fixed wind, technology standards have already been adopted - ASTM standards covering corrosion and wear, steel manufacture, metallic coatings and composites manufacturing are already used in the OFW industry [24]. For floating wind technologies approaching commercial deployment, developers have benefitted by the adaptation of both the existing oil and gas, and the above-mentioned fixed wind offshore design standards. A 2011-2013 joint industry project by DNV-GL adapted a standard for a floating offshore wind design - DNV-OS-J103,which - when used in parallel to DNV-OS-J101- allows a set of design principles, technical requirements, construction guidelines and inspection criteria to be used [76]. DNV-GL standards are also prominent in European offshore wind farm development.

Regarding standards, guidelines and certification for offshore wave and tidal stream devices, their agreement and application is not as advanced as for offshore wind. EMEC in 2009 coordinated a set of twelve wave and tidal energy draft standards for application (Table 25 in Annex II). An ORE Catapult review of their application in 2014 [77] concluded a variable awareness and take up of these standards and an awareness that further guideline construction was underway. In this workshop, it was also recognised that the development of a clearly distinguishable marine energy certification would help promote the technology. This is led by the International Electrical Commission (IEC), with an IECRE organisation, namely Technical Committee (TC) 114 ‘Marine energy’, established to coordinate the MET-CERTIFIED [78] programme and funded through the EU’s INTERREG-2 Seas programme. The objective is to develop a set of internationally recognised certifications to promote marine renewables, which focus on resource assessment, device performance assessment and electrical power delivery quality.

With respect to NeSSIE, there are a number of well developed, cross-sector, industrially-applied standards and certifications that could potentially be applied to offshore protection . NORSOK design, installation and fabrication standards are heavily applied to design in the offshore oil and gas sector, as are some ISO standards, yet on a variable basis. In addition, the National Association of Corrosion Engineers (NACE) provides a comprehensive list of standards specifically for offshore corrosion treatments. To resolve the question of which standards to use for NeSSIE’s anti-corrosion demonstrations, it is suggested to look to NORSOK standards M-CR-501 and M-DP-001 [22]:

- NOROSK M-DP-001:
    - “The scope of this standard is to provide general principles, engineering guidance and requirements for material selection and corrosion protection for all parts of offshore installations.”
    - “Material selection shall be optimized, considering investment and operational costs, such that Life Cycle Costs (LCC) are minimized while providing acceptable safety and reliability.”
    - External corrosion protection - The external atmospheric environment shall be considered wet with the condensed liquid saturated with chloride salts. Material selection and surface protection shall be such that general corrosion is cost effectively prevented and chloride stress corrosion cracking, pitting and crevice corrosion are prevented. Carbon steel shall always have surface protection to the external environment. Additional corrosion allowance or other means of protection are required for installations in the splash zone.”
    - “Cathodic protection shall be used for all submerged, metallic materials, except for materials which are immune to seawater corrosion. Surface coating shall in addition be used for components with complex geometry and were found to give cost effective design.”
    - “If galvanic corrosion is likely to occur, the dissimilar materials shall either be electrically isolated with an isolating spool or the more noble material shall be internally coated close to the coupling.”
    - “For carbon steel welds - For pipe systems with corrosive service the welds shall be compatible with the base material in order to avoid local corrosion of weldment and heat affected zone. Where weld overlay is used to prevent crevice corrosion in seawater systems, alloys with documented crevice corrosion resistance in the as weld overlaid condition shall be used.”
    - “Design of corrosion monitoring systems shall be based upon criticality evaluations taking appropriate note of probability of failure/damage and the consequences. Such

systems shall at least be evaluated for carbon steel pipelines and flow lines, carbon steel hydrocarbon piping and cathodic protection systems."

4.6. Key NSB developers for demonstration trialling of anti-corrosion solutions

A non-exhaustive and selective listing of European centric wave, tidal and offshore wind energy developers was undertaken to better focus NeSSIE's selected demonstration projects. Companies were only considered, which were known to currently have, or plan in the near future to have, marine technology projects above TRL 5 (full scale testing at sea according to EMEC TRL scale [70]), or fully commercial projects. An illustration using a WEC example of the various TRL stages is shown in Figure 17. Each developer was further filtered by location, i.e., only those either having headquarters in Europe, or those known to be using European test facilities were chosen. In addition, those developers no longer active in the market were also removed and only those with active projects listed for testing in 2017-2018 or beyond were included. The complete search list is shown in Table 24, Annex II. In addition to this filtered search, a more complete, global 2014 referenced list of wave and tidal developers and developments has also been included in Annex II (Tables 26, 27, 28 & 29). In 2014, EMEC listed 170 different wave developers, and 100 tidal developers worldwide, 45% and over 50% of which were developers with an EU base respectively [79].

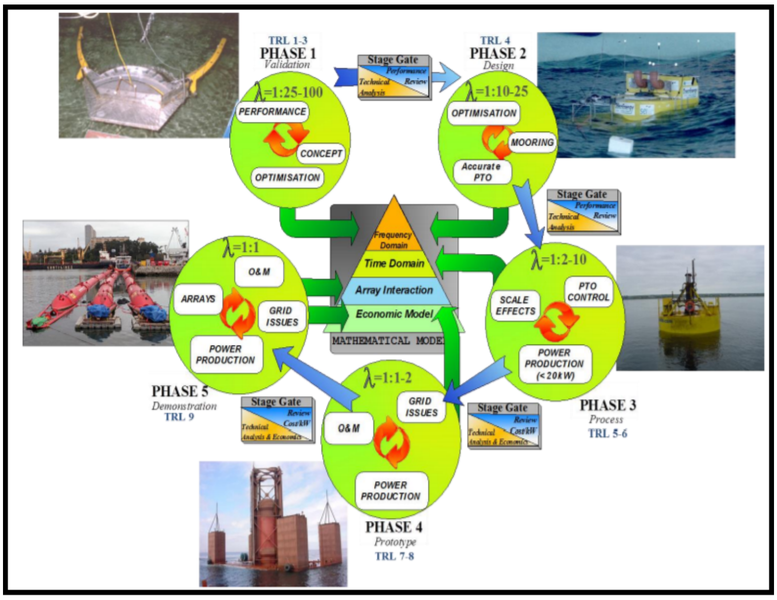


Figure 17 – Guide to various TRL stages for a WEC [70]

The most notable developers recognised to have projects potentially suiting the NeSSIE time frame which will need further networking investigation include:

- WECs:
  - *Carnegie Clean Energy* – CETO WEC device testing at WaveHub 2017 (TRL 7-8);
  - *Wello OY* – Penguin WEC device testing EMEC 2017 (TRL 7-8);
  - *Havkraft* – H-Wec WEC device Hybrid commercial deployment (TRL 5-6);
  - *WaveTricity* – Ocean Wave Roller testing (Pembrokeshire) 2017 (TRL 7-8);
  - *Seatricity* – Oceanus2 WaveHub testing 2017/2018 (if ERDF fund matched only!);

  - *CorPower* – HiDrive PTO/CorPower WEC Device, 2018 EMEC testing (TRL 5-6);
  - *AW-Energy* – WaveRoller, WAVEC testing 2017 (TRL 7-8).

- TECs:
  - *MeyGen Project* – Alstom/Andritz devices operated by Atlantis Resources. Ongoing Phase one commercial development in Scotland (TRL 9);
  - *Tocardo* – InToTidal TEC testing EMEC 2017 (TRL 8-9);
  - *Current2Current* – TEC4 tidal turbine R&D 2017 (TRL 8);
  - *EC-OG* – Subsea Power Hub testing EMEC 2017 (TRL 7-8);
  - *NovaInnovation* – NovaInnovation 30/100 turbines, BlueMill Sound extension Shetland Tidal Array 2017/ EnFAIT EU project 2017-2022 (TRL 9);
  - *Scotrenewables* – SR2000 TEC tested at EMEC 2017 /FloTEC EU project (TRL 7-8);
  - *Openhydro/Naval Energies* – newly taken over (Jan 2017), well resourced marine energy company. Turbines were EMEC test 2014 and a number of tidal array projects are underway; Paimpol-Breht in France, and under consenting; Brimms Head in Scotland (Openhydro/SSE Renewables) (TRL 9);
  - *SME/Schottel Hydro* – SIT tubines/PLAT-O testing deployment EMEC 2017 (TRL 7-8).

- OFW/FOFW:
  - *VanOrd/HVC* – Gemini/Walney fixed OFW Extension foundation installer 2017 (TRL 9);
  - *Hexicon* – Dounreay Tri Floating wind farm approval March 2017, with unit one assembly complete operational July 2018 (TRL 9);
  - *IDEOL* – FLOATGEN floating wind demonstration project at Le Croisic, France SEM-REV test facility evaluation 2017 (TRL 8-9).

There are more viable tidal project developers to approach compared to those developing wave energy devices, given the former's more advanced technology, converged design and commercial maturity. It may also be more productive for the NeSSIE consortium to approach offshore floating wind developers for demonstration partnerships rather than fixed offshore wind projects. Fixed offshore wind projects are large in relative size to NeSSIE, are monopolised by well-resourced owners, turbine suppliers and investment funds in the North Sea sector and have already identified corrosion problems and set up their own, ongoing solution projects. Floating wind, on the other hand, has just begun its first offshore pre-commercial installations, with optimisations ongoing and smaller players potentially valuing a NeSSIE demonstration project association more. As a case in point, the previously referenced Carbon Trust study [58] reviewed the market for floating offshore wind technology and identified the diversification in device designs and rapid growth in deployment beyond 2018 worldwide, as well as corrosion being one of the major sources of failure for steel platforms (22% of CAPEX), concrete moorings (6% of CAPEX) and anchors (2% OF capex), whilst excluding turbine failures.

5. Offshore renewables corrosion and novel materials case studies

Key messages

The following key findings were gathered from the literature research:

- A cost reduction between 20% and 50% could be reached with the introduction of new materials compared to the initial steel prototype, as shown in the Pelamis study [80].
- WES identified four key areas of investigation concerning novel materials in the marine energy sector: construction costs, articulation systems, environment, and performance.
- Both the ETI's ReDAPT project and a tidal project in Nagasaki pointed out the importance of taking into account bio-fouling and its damage on marine structures and

Whilst the earlier D2.1 report gives a good introduction to offshore infrastructure corrosion solutions generally, it is deemed worthwhile in this deliverable to target marine renewable device corrosion studies specifically, to give some context to the targeted demonstration projects. In this way, more focused and relevant attention can be given to the research already applied to testing innovation in the context of marine renewable demonstration devices, as well as value chain recognition, prior to embarking on identifying cross industry value chains in the NSB region. The issue of corrosion effects on offshore energy devices is an important and growing area of interest as device deployment and designs advance, and focus falls on device performance maintenance and lowering costs. Biofouling of tidal energy devices for example can increase drag resistance of tidal turbine blades – reducing performance efficiencies, cumulatively leading to large power generation losses for tidal farm arrays [8]. Corrosion of offshore steel structures in highly corrosive seawater mixtures significantly reduces component life, increases operational and maintenance costs, and consequently impacts project profitability. Corrosion mitigation for offshore devices typically takes place within the earlier design life of the devices on a proactive basis, rather than reactively as witnessed in the evolution of the oil and gas sector.

During the literature research stage of this report, a few highly relevant reports came to light, namely a Pelamis WEC commissioning materials selection study [80], a Wave Energy Scotland marine energy device Materials Landscaping Study [81], Aquamarine's knowledge-sharing reports from its EMEC-trialled Oyster WES devices [82] [83] [84], an Energy Technologies Institute (ETI) ReDAPT anti-fouling field trial on a tidal turbine in-sea test [41], and a peripheral biofouling effects study from a tidal project in Japan [85]. This chapter summarises the findings of each study, developer and industry-led innovation in materials and corrosion for marine energy devices.

5.1. Pelamis WEC materials selection study [80]

The main objective was to optimise the cost efficiency of the primary structural materials used for the WEC main buoyancy elements. The four cylindrical steel elements on the prototype accounted for 50% of the project's structural budget, thus an obvious area for cost saving. The work programme initially considered several materials already employed elsewhere offshore, including rolled steel (as used already on the prototype), glass reinforced plastic (GRP), wood-epoxy laminate and different forms of concrete in single skin shell form.

Each material candidate was then assessed against a number of strength and elastic stability criteria to which each would be subjected offshore, including extreme bending moments, shear force, hydrostatic loading, extreme torsional loads and lifetime bending fatigue. Minimum material requirements versus these loads were then determined and indicated only steel, GRP sandwich form and reinforced concrete with steel post-tensioning (carbon/steel fibres found to bring no real advantage and higher costs than steel) would economically be applicable. More detailed studies on these three materials were then carried out.

The GRP results showed segments could be manufactured with a weight of 10-12 tonnes, using a combination of filament-wound and rolled GRP laminates. The recommended materials are relatively standard isophthalic polyester resin and E-glass, with some more specialised materials incorporated in the inner and outer skins to reduce permeability. In high volume manufacture, a cost price of £32.5k (£2003) is estimated for the GRP segment (10-tonne weight and manufacture in the UK).

A suitable arrangement for a concrete segment was based on 125mm wall thickness and post-tensioning system comprising eight steel tendons in four groups of two –although in principle the material had good fatigue properties, more work was needed at the time within the immersed environment situation. The preferred manufacturing method is horizontal manufacture, using either discrete pre-cast rings or a single-piece construction. The estimated cost of a one-off prototype segment was £47k, and a cost in volume production of £30k per segment (bespoke manufacturing facilities).

For the option of a steel segment with 20mm wall, reduced from the 25mm of the prototype, the issues raised included an increased corrosion risk, and the need to avoid circumferential welds to keep fatigue stresses within DNV limits. In general, corrosion and fatigue are the drivers for this design, for which high quality surface coating (epoxy paint) is essential. This is not the case with GRP and concrete, and the additional cost is a disadvantage for steel. The assumed manufacture cost of the 20mm wall segment was estimated to be £34.3k in high volume manufacturing without surface coating, and £48k with epoxy paint protection. A semi quantitative table of results is presented below in Table 2.

Given the work carried out, a 20% to 50% cost reduction by comparison to the prototype was possible using these three materials instead. A further consideration to ancillary issues such as rigidity, weight and ballasting, corrosion, damage tolerance, reparability, environmental cost of production, and disposability led to the conclusion that steel reinforced concrete was superior to other materials, with the greatest number of advantages but with a caveat that further testing is required, particularly fatigue testing.

SUMMARY TABLE. Qualitative ranking of the three preferred design options.

CRITERION	Thin-walled steel tube (20mm)		GRP sandwich construction		Post-tensioned concrete tube	
Segment cost in volume manufacture	£34.3k	1	£32.5k	2	£30k	3
Surface coating cost	£13.7k	1	Included	2	Included	2
Fatigue capability	Worst	1	Best	3	Middle	2
End-cap design	Constrained	2	Uncertain	1	Best	3
Antifouling protection	No	1	No	1	No	1
Bending rigidity	Excellent	2	Good	1	Excellent	2
Immersion buckling rigidity	Poor	1	Poor	1	Excellent	3
Ballast requirement as ratio of dry weight	1.8 – 3.0	2	11 – 16	1	0.2 – 0.7	3
Handling eg. by road	Difficult	2	Easy	3	v. Difficult	1
Damage resistance	Good	2	Poor	1	Good	2
Reparability	Fair	1	Good	2	Fair	1
Energy & CO_2 content	Worst	1	Best	3	Middle	2
Recycling capability	Good	3	Limited	1	Fair	2
Disposal at sea	Good	2	Fair	1	Good	2
Choice of manufacturing location (existing)	Many	2	Limited	1	Many	2
TOTAL		**24**		**24**		**31**

Table 2 – Pelamis materials selection study results summary [80]

5.2. WES Materials Landscaping study [81]

Wave Energy Scotland commissioned a study to critically evaluate materials (metals, composites, rubbers, plastics, liquid gels, and flexible membranes), coatings (resins, composites, metallic plating, and paints) and production techniques (component manufacture, fabrication and construction, assembly, coating applications techniques) available to the full range of WECs. The transfer of expertise between industry sectors with the critical objectives of cost reduction and reliability improvement for solutions that are not already commercially available were considered.

Most WECs are painted steel structures or reinforced concrete with some sub-structures in polymer composites. Materials and processes not previously used on WECs were targeted in this study to highlight potential innovative solutions. The WEC's main body, its structural integration and connections were considered. The team consisted of experts in materials, coatings, design and fabrication of offshore structures and the study was completed in 2016, with materials and manufacturing design requirement inputs from ten WEC developers from a technology and economic perspective.

The critical challenges faced in the WEC sector were investigated and the study boundaries defined - including the setting of typical WEC environmental exposure operation ranges, and typical indicative structural exposure loadings. A set of material prioritised statements were then defined and grouped into four main topic areas:

- **Construction Costs**
  - *Steel structures* – WEC developers did not believe a commercial LCOE could be reached using traditional materials and fabrication methods. Alternatives include concrete to reduce material costs, composites to reduce transportation and corrosion costs or better cheap steel fabrication methods.
  - *Composite structures* –GRP is believed to be too expensive for the primary structure but could offer savings at the multi-unit production stage given their lightweights, corrosion resistance and complex shape cutting.
  - *Transportation/Logistics costs* – A focus on modular construction or lighter weight materials could reduce costs.
  - *Fatigue* – Considering fatigue and strength, the first dominates design over strength. A better understanding of fatigue properties of candidate materials is required (polymers, polymer composites and adhesive joint performance) when immersed.
  - *Submersible buoyancy* – Buoyancy elements are expensive and unreinforced polymers lack sufficient mechanical qualities to resist connection/mooring loads.
- **Articulation Systems (between structural components)**
  - *Knowledge of wear characteristics* – A better understanding of plain bearing materials wear in marine environment is required.
  - *Cost of counter-face materials* – A better understanding of alternative material surfaces and their compatibility with corrosion resistant alloys used in oil and gas industry is required. Could coatings be used instead?
- **Environment**
  - *Limitations on corrosion protection systems* – Given a low priority for steel structures since paint coatings, cathodic protection and corrosion allowance can be effective but with some additional CAPEX, OPEX and performance costs.
  - *Effects of bio-fouling on performance* – A medium priority since some WECs are prone to hydrodynamic drag on surfaces. Maintenance free anti-biofouling methods would be advantageous.
  - *Effects of bio-fouling on loads* – Some WECs are prone to increase in weight on retrieval, thus important to consider the impact of bio-fouling on performance and survivability.
  - *Effects of bio-fouling on reliability/maintainability* – Marine growth may affect reliability (bearings) and maintainability (disconnection systems). Materials or coatings could perhaps be beneficial.
  - *UV degradation* – Polymers exposed to UV light are prone to degradation and require protective coatings.
- **Performance**
  - *Device mass* – For devices requiring inertia performance, lower weight materials have advantages for low inertia devices.

  - *Complex shapes* – Since shape impacts performance, with potentially more complex shape aiding performance but at extra manufacturing expense then a Polymer/composite moulding processes would be more suitable than steel.

These identified challenges formed the basis for solutions identified through teamwork with an emphasis on existing technical methods in other sectors. Through a screening process, 40 of the 61 technologies were chosen (Figure 18) for further evaluation using weight scoring (material costs, manufacturing costs, maintenance, durability, logistics etc.). The merits of material solutions were highly dependent upon the specific design. An 'impact vs. risk' technique was less qualitative and displayed in Figure 19 with the circle diameter reflecting the score - lower left quadrant solutions were considered industry best practice already and filtered out of the further investigation.

With respect to ACS for environmental protection, this study placed biocidal/anti-fouling release coatings and composite erosion protection coatings in the industry best practice position, along with cathodic protection (CP). Emerging coatings did not make this study's shortlist because they were all already commercially available. However, it is worth noting the following points were highlighted and not taken forward within this WES study, to provide context for NeSSIE's objectives:

- Passive CP is widespread in OFW, and impressed current CP systems are growing in use in OFW and should be monitored.
- Coatings corrosion protection for OFW is also already widespread [86], and suitable value chains for OFW coatings are already in place.
- Corrosion protection design software (Beasy CM/Elsyca CM) could be beneficial to ACS WEC design and is commercially available.
- Emerging corrosion protection is an active research area with current material suppliers. Research includes improving fatigue resistance through fibres addition to base materials, two coat systems (silyl hybrid/polyaspartic) for cost reduction, and anti-corrosion additives (nanotubes/zinc activators) to improve survivability and self-healing polymers.
- Composite tidal turbine blade erosion is predicted to be an issue. Polymeric composites including super tough UHMWPE coatings are being looked at to avoid erosion. Further investigation is required in this area.
- Conventional biocide release anti-fouling coatings depend upon vessel movement to self-polish to release the anti-fouling additives, eventually becoming depleted and requiring renewal. Fixed devices like WECs may not be suitable for these coatings, which could create environmental damage with the need to remove the devices periodically. A more detailed study on WEC anti-fouling coatings is required.
- Foul release coatings, free from biocides depend upon their ultra-smooth surface and low adhesion preventing biofouling. This technology is unproven for WEC in the long term, particularly as water velocities may not be sufficient to dislodge any biofouling that does form. A more detailed study is required. Ecospeed is a one-time application, hull protective coating that could be investigated due to its non-toxic and environmentally benign properties.
- Ultra-sonic fouling deterrence is at an early development stage with an uncertain efficacy and its marine environment impact poorly understood.

- Mechanical in-sea cleaning devices have been designed for fouling removal, e.g. remotely operated underwater vehicles (ROVs). The capture of effluent is key in hull cleaning to store invasive species for vessels, this however would not apply to fixed devices. These technologies could be investigated further.
- UV degradation of coating systems employs marine coatings with three layers; substrate primer, thick epoxy layer for adhesion/water resistance and a polyurethane top coat for weathering resistance. These are widely available commercially.
- Elastomer and polymer marine degradation requires full validation given identified breakdown mechanism prior to use in WECs to guarantee lifetime performance [87].

Steel	**Concrete**	**Composites**
Automated Welding	Post-Tensioned Concrete	Pultrusion
Design for Fabrication	Concrete - Durable Connections	Filament winding
Adhesive Bonding	Reinforcement Materials	Thermoset Resin Infusion
Rivetting / Spot Welding	Low Cost Concrete	Adhesive Bonding
Ductile Iron	High Performance Concrete	Mechanical Joints
Steel Casting	Sustainable Concretes	Composite Repairs
High Strength Steel	Repairability of Concrete Devices	Thermoplastic Monomer Infusion
Low Spec. Steel	Novel Production Techniques	Polymer/Composite Hybrids
New Welding Methods		
Logistics costs	**Fatigue**	**Submersible Buoyancy**
Modular Building	Improved SN Curves for steel	Cargo-Net Loading
	Optimised welding techniques (incl. prep)	Rotational moulding of plastics plus reinforcements
	Composites	Foam sandwich construction
	Polymers and Elastomers	
	Composite Adhesive Joints	
Load Shedding	**Articulation Systems**	**Corrosion Protection**
Elastomers	Improved Verified Wear Data	Cathodic protection / IC Systems
Shape Memory Alloys	Counterface Materials	Coatings
	Composite Hinge Shafts	CP Design Tools
	Laminated Elastomers (LECs)	Emerging Corrosion Protection Techniques
	Composite Springs	Erosion Protection Coatings for Composites
	Rolling Element Bearings	
Biofouling	**UV degradation**	**Device Mass**
Biocidic Release Coatings	Polyurethane Top Coats	Concretes
Foul Release Coatings	Elastomer & Polymer Formulations	Pumped Ballast
Ecospeed		Composite Materials
Ultrasonic Cleaning (UT)		
Mechanical Cleaning		
Complex shapes	**Novel concepts**	
Concrete Domes	Dielectric Elastomers	
Inflatable Bags		
Composite Materials		

Figure 18 – Innovative table of solutions shortlisting for novel materials study [81]

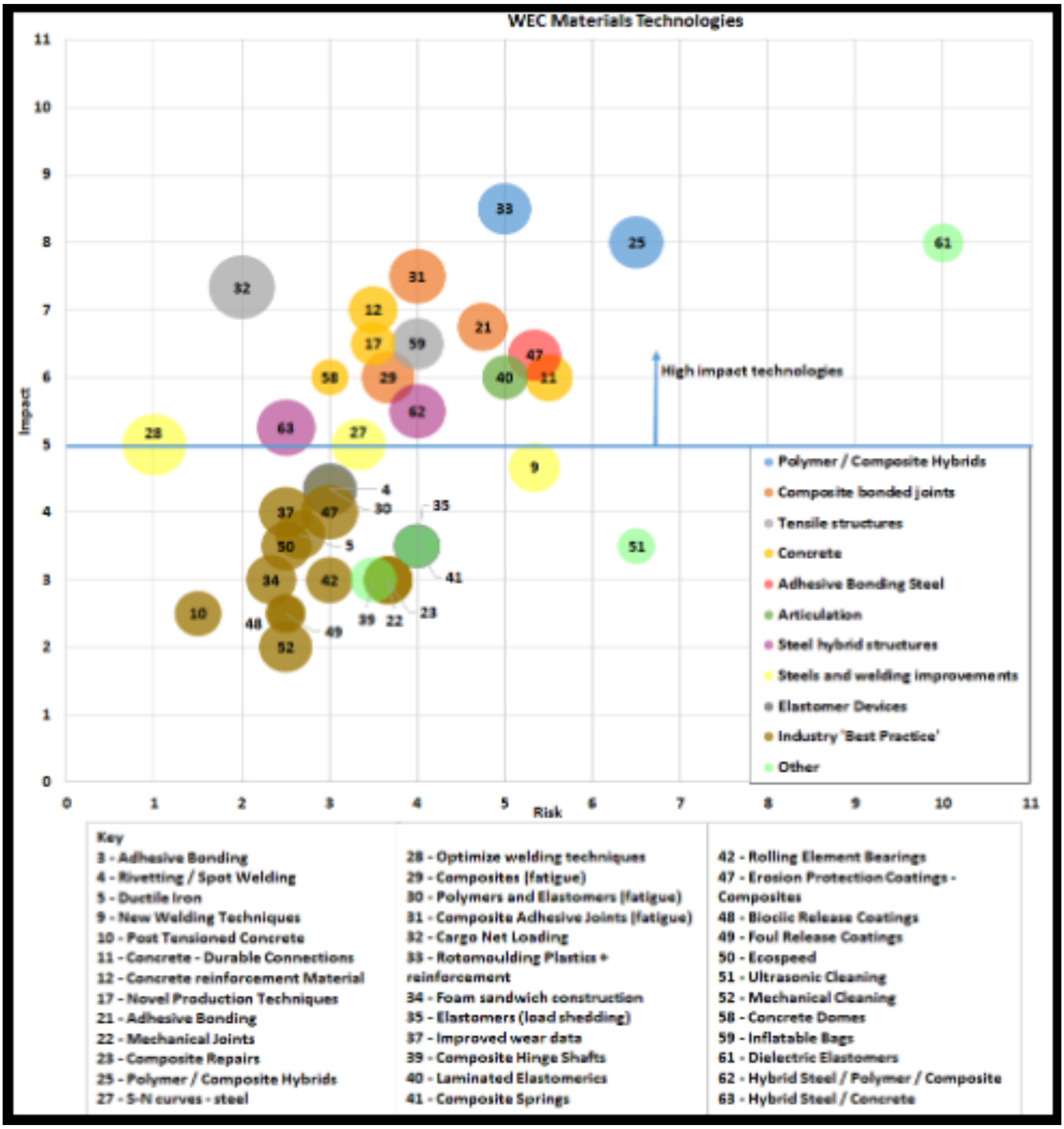


Figure 19 – Potential solutions on an impact versus risk chart [81]

The landscaping study decided to focus more attention on innovative materials. The following material technology solutions were selected as the least risky, highest reward candidates for WEC cost reduction and performance improvement from this study. Only the relevant research technologies to NeSSIE have been described:

- **Polymer/Composite hybrids using rotational moulding** - Large hollow polymer structures such as floats, buoys and tanks using polyethylene/polypropylene are inexpensive, able to be rotomoulded but lack mechanical properties to resist large loads in marine environment (Table 16, Annex I). Hybrid polymer/composite reinforcement around loading points using cost effective rotomoulding would be advantageous. Rotomoulded polyethylene hybrids are already widely used in marine and aquaculture industries for lightly loaded components, but for heavy loading no examples exist except a Total oil and gas hybrid example [87]. If proven however, they could provide a 60% saving in CAPEX spend.

- **Adhesive bonding of composites** - Composites are used for OFW turbines and widely in oil and gas, and maritime industries, but limited in WEC devices. Advantages of strength, stiffness, weight and corrosion resistance are well recognised. For WEC's modular components, this will mean composite joining to other materials and different exposure zones per component. Studies determined a high degree of reservation utilising composite joints for load bearing structures within submerged environments. The use of adhesive bonding is a common use in OFW (with no direct water contact) and TECs (direct water contact) with DNV-GL bonding guidelines in place. There exist few fatigue studies with adhesive bonding in WECs which experience a different loading/fatigue profile to tidal or OFW. The Warwick University 'DURACOMP' program aims to address concerns on durability of composites in the long term and is underway.
- **Concrete structures** - Reinforced concrete provides a building material with compressive and tensile load carrying properties. Durability of reinforced concrete structures depends upon protecting the reinforced steel from corrosion, i.e. the thickness of concrete cover and its permeability. Advances in concrete design include high performance/strength versions, pre-stressed concretes and various types of concrete reinforcements, such as non-corrosive FRP rods and fibres. Well established concrete technologies could be applied to WEC massive static structures directly, however for buoyant dynamic structures the various WEC load exposures require further investigation. The previously mentioned Pelamis device study indicated a possible 20% reduction in material cost using concrete [80], with greater savings for smaller modular units potentially.
- **Adhesive bonding of steel** - Steel marine structures are predominantly welded together, but there is a growing interest in other industries' using adhesives to give more design freedom, eliminate crevice corrosion, reduce fabrication costs and improve fatigue resistance. Certification authorities are taking a cautious approach to adhesive bonding in shipping and there is no evidence of adhesive bondings in direct contact to seawater, the existing adhesive bonding research for dry use is mainly on aluminium and composites. Using this type of bonding on the dry side of WEC devices is less problematic.
- **Polymers/Composites and steel hybrids** - Principal advantages of reduced weight, improved corrosion resistance and reduced installation costs mean developers predict WECs would ultimately be a mixture of steel and polymer/composites. The main improvement areas considered are joining technologies, composite connections, load bearing of polymers/composites and composites to increase steel load bearing capacity. Research requirements exist to better understand material design limits as well as marine environment exposure to steel backbone-polymer/composite structures for WEC devices using high production rate joining techniques via a design and optimisation strategy.
- **Elastomers** – Composite blended natural rubbers to enhance UV resistance and poor fatigue properties are required in the marine environment. Elastomers are polymers with a low modulus and high elastic strain range (rubbers/thermoset elastomers). Rubbers are widely used in the automotive and marine sectors already. The AWS-III point absorber WEC utilises rubber diaphragms covering air-filled cells as the primary wave absorber mover, with the laboratory scaled test devices having encountered fatigue problems during testing.

Several materials research projects were then taken forward by Wave Energy Scotland. The former WEC competitive procurement programme, with the following structural materials and manufacturing processes have been undertaken by consortia with a range of research institutes and private companies, and are ongoing since January 2017 [51]:

- Advanced concrete engineering;
- Advanced rotational moulding for ocean renewables (ARMOR);
- Advanced rotational moulding for wave energy technology (ARMWET);
- Netbuoy (buoyant modules made from impermeable fabrics and fibre ropes);
- Concrete as a technology enabler (CREATE);
- ELASTO (fabric/elastomer structures for WECs);
- Hydrocomp (hybrid fibre reinforced polymers applied to a WEC prime mover);
- Polyshell (high performance polymers/thermoplastic elastomers replacing steel WEC structures);
- RePOWER (reinforced polymers as a prime mover in wave power);
- RotoHybrid (use of rotational moulded polymers in hybrid structures).

5.3. Aquamarine Oyster testing materials and corrosion lessons learned [82] [83] [84]

A few knowledge-sharing reports completed by Aquamarine for the wave energy industry, with the aim of realising cost and time efficiencies across the sector, have been made available by Wave Energy Scotland. Aquamarine has accumulated knowledge through its design, fabrication, installation and operation of its Oyster 1/Oyster 800 WEC prototype devices. Corrosion and protection in the disturbed water environment was one of these reports, which utilised standard off the shelf components and materials. A summary of this report's lessons include:

- A combination of passive sacrificial CP, surface coatings and corrosion allowance can provide cost effective means of protecting steel alloy marine energy devices.
- High strength steel components require electrical isolation which can be difficult to achieve offshore.
- Designing of dissimilar materials in close proximity can be prone to galvanic corrosion. Select materials with low electrical differences if unavoidable.
- Smaller local components can utilise corrosion resistant alloys where CP is not reliable, i.e. the splash zone where higher levels of corrosion may exist. Stainless steel 316 was observed to have a better performance in the splash zone, potentially avoiding the need for expensive corrosion resistant alloys.
- Do not rely on CP to protect seals. Locally protect these with corrosion resistant alloys. Carbon steel pipes coated with three layers of polypropylene, with a HDPE liner to protect against high salinity levels and corrosion resistant alloy end fittings for long pipe protection along with CP protection were considered cost effective over 20 years. The high-pressure return line to shore which is a critical component and a permanent installation is an example.
- The wide variety of pipeline flange and gasket seal combinations requires different material combinations to ensure leak resistant. Dissimilar flange metals can localise corrosion. Stainless steel 316 is susceptible to crevice corrosion. Metallic flanges (carbon/duplex steel) and non-metallic (HDPE/GRE) are used, CP failed to protect the spiral wound metal gasket between

non-metallic flanges.

- Anodes should be placed on discrete parts, and not rely on electrically continual components and assemblies. Individual components on the main structure were found to be corroded due to inadvertent isolation from the CP system.
- A bathycorrometer can be used to reliably survey CP systems.

Aquamarine, like OFW developers referred to earlier in this report, segmented the water column into five main areas, simplifying the standard DNV-OS-C101; e.g. submerged, atmospheric, splash, dry internal and wet internal zones. The company utilised standard DNV-RP-B401 for CP design requirements in the submerged zone. Coating systems supplemented CP and used standards DNV-OS-C101, DNV-OS-C401 and Norsok M-501 – taking from the latter various recommended coating systems for different zones. Where CP was deemed unreliable, a corrosion allowance was designed for structural zonation.

Aquamarine also learned a number of valuable lessons from its interaction with marine supply chains:

- The supply of materials labelled 'subsea rated' should not be taken at face value with regards to corrosion. Recommended Norsok-M501 best practices on all supplied components needs to be verified.
- Metal shelled connectors have proven themselves to be reliable subsea connectors for the nearshore environment. Almost half of reported instrumentation failures were due to the sealing failure of rubber moulded wet mate connectors – marketed as subsea components.
- Standardisation of communications protocols across the system provides the best option for improved reliability and scalability of control and instrumentation.
- Stainless steel 316 is not suitable as a reliable corrosion resistant alloy in seawater without CP.
- WEC subsea cable design and manufacture required suitable design consultations with manufacturers, and the definition of a number of relevant criteria. Different environments require different subsea cables, hence standard subsea cables were not available 'off the shelf'.
- A general awareness of hydrogen induced stress corrosion is required between company and suppliers, with a high and low tolerance specified for material grades.
- Appropriate selection of a valve supplier with nearshore experience and a thorough factory acceptance test (FAT) procedure is required.

5.4. ReDAPT DEEP-Gen IV tidal turbine anti-fouling study lessons learnt [43]

The ETI's ReDAPT (reliable data acquisition platform for tidal) project saw the DEEP-Gen IV Alstom tidal turbine (Figure 20) undergo full-scale testing at EMEC for two years, starting January 2013, to demonstrate performance within an operational environment.

One aspect of this study was looking at anti-biofouling management systems. This involved defining an anti-fouling protocol for marine devices through anti-biofouling in-sea testing and a result analysis using the following steps:

- Experimental design (safety, statistical representation, etc.);
- Fouling potential characterisation on site;
- Lead coating products identification and performance assessment (earlier Figure 13), applicable to different components, materials and budgets;
- Deployed test panels for 2-year study (on separate seabed pods and the turbine itself);
- Post testing optimal protocol development and coating selection.

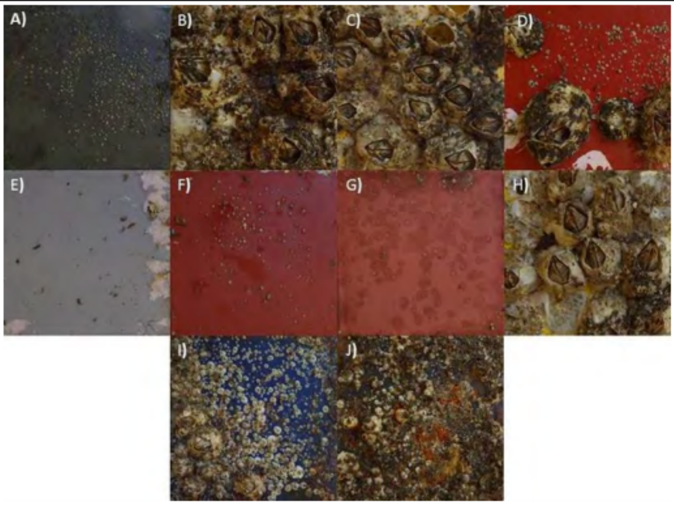
The submerged test results showed significant roughness caused by biofouling potential with a severe hydrodynamic drag penalty likely on the turbine blades. Untreated marine grade stainless steel (316) was found to have corrosion pitting and holes through it, approximating a 3-5mm loss per year. Niche areas essential for monitoring and recovery became biofouled after only a few months.

The painted test pod panels and various turbine recoveries showed varying degrees of anti-fouling (Figure 21):

- Fouling Release Coatings (FRCs) performed well until mechanical damage occurred, hence could be good for niche area protection;
- Hard epoxy coatings fouled readily, but can be cleaned and resist corrosion damage to the substrate;
- Hard biocidal self-polishing copolymers (SPCs) performed best overall but longevity could not be confirmed. These coatings are designed for five-year maritime vessel inspection life cycles, and not the seven years design recovery for tidal devices;
- There was no single coating that would protect all materials/components, thus requiring a designed coating application guide for the device;
- Higher fouling concentrations were found in sheltered/intricate areas;
- Biofouling removal on device recovery should occur <4 days after recovery to ease jet cleaning prior to biofouling drying out and hardening.

The report drew the overarching conclusion that biofouling damage needs consideration at project design stage in order to de-risk equipment maintenance planning, with a coating selection protocol and attention paid to key niche monitoring and installation/recovery areas. Coating testing periods require synchronisation with the turbines testing intervals. An additional area of future study could be combined active (Ultrasonic, UV, Electro-chlorination) and passive coating.

Figure 20 – ALSTOM tidal turbine DEEP-Gen IV EMEC testing programme for ReDAPT [43]



Representative image of the extent of biofouling due to panel coating type. Panel material: A) Coppercoat, B) Ecospeed, C) GRP, D) Hempel Red, E) International Grey, F) International Red, G) Jotun Red, H) Jotun Yellow, I) Pastimo AF and J) Primacon.

Figure 21 – 2 years coating panel recovery results (Primacon control coating) [43]

5.5. Ocean energy development in Japan, Tidal Project in Nagasaki [85]

This study was important in understanding the speed of biofouling buildup and inference of performance effects on a tidal power turbine. A number of different offshore technologies are actively being researched around Japan's Kyushu Island by Kyushu University and a number of private industrial companies. The Naru Sound Straits have been identified as an area of high potential resource for tidal energy stream devices. Biofouling effects were investigated as part of the research by immersing a steel test rig, with and without rotation components, using an identified maritime protection paint. Figure 22 shows the biofouling build-up over an eight-month period. With no protective paint, the biofouling accumulation hinders the test rig's performance markedly, and even with protective paint the device's performance over a short space of its operational lifetime will be compromised, given these test results.

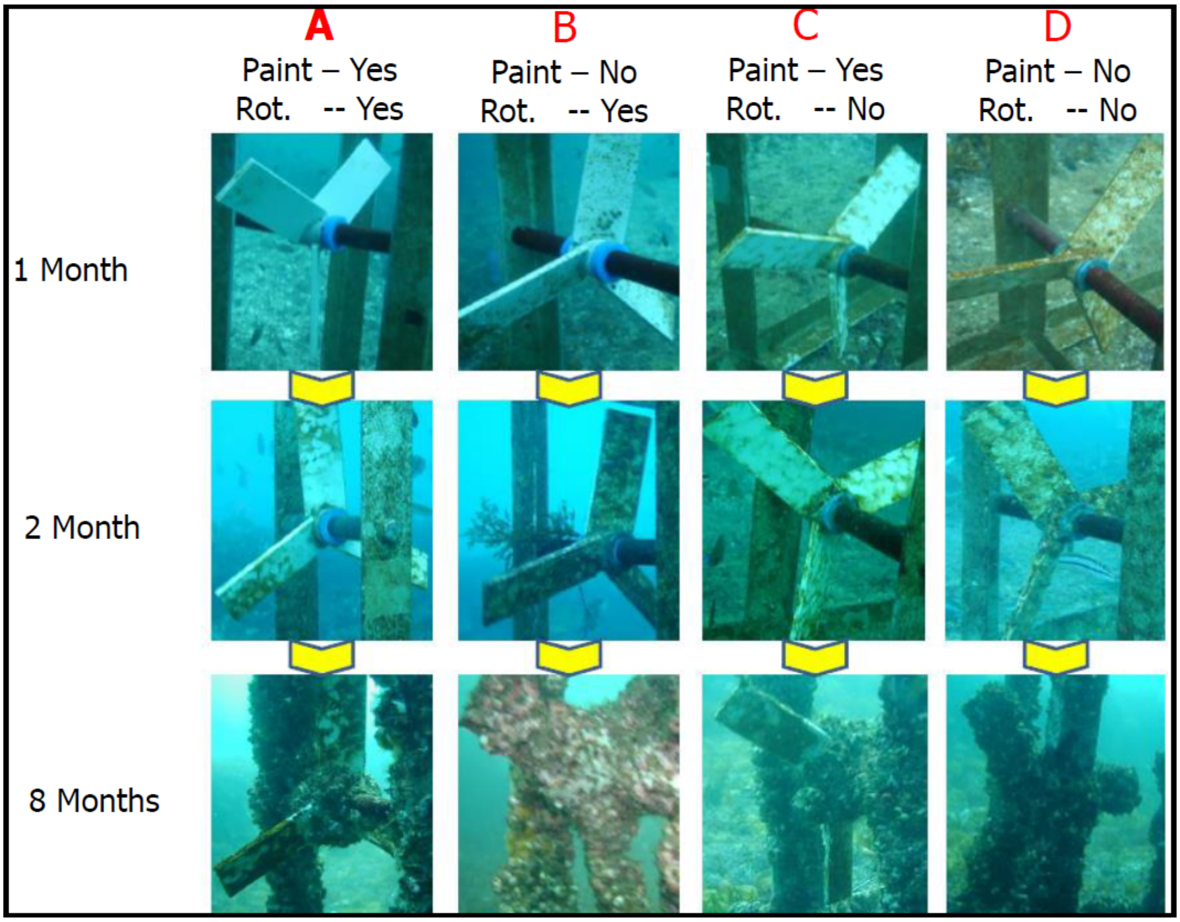


Figure 22 – Bio-fouling build up on a Japanese test rig in the Naru Sound Straits [85]

6. NSB economic potential of anti-corrosion solutions

Key messages

This study provides a wide range of developer savings and vendor prize values with the introduction of anti-corrosion solutions compared to the BAU case. This is based on the assumptions of cost reductions and additional cost with the solutions implementation and on projected installed capacity from literature research.

			WAVE		TIDAL		TOTAL MARINE			FIXED WIND		FLOATING WIND		TOTAL WIND		
			Developer Saving	Vendor Value	Developer Saving	Vendor Value	Capacity	Developer Saving	Vendor Value	Developer Saving	Vendor Value	Developer Saving	Vendor Value	Capacity	Developer Saving	Vendor Value
			NPV10 £M	NPV10 £M	NPV10 £M	NPV10 £M	MW	NPV10 £M	NPV10 £M	NPV10 £M	NPV10 £M	NPV10 £M	NPV10 £M	MW	NPV10 £M	NPV10 £M
Scenario 1	UK	2020	96	196	112	86	350	208	283	2,483	2,987	24	55	8,060	2,507	3,043
		2030	723	1,381	815	603	6,000	1,538	1,984	7,321	8,631	382	550	19,477	7,703	9,181
		2050	1,217	2,157	1,028	750	15,000	2,345	2,907	9,141	10,420	1,345	1,039	45,000	10,486	11,459
	EU	2020	116	237	90	70	350	206	307	10,244	13,071	32	75	23,493	10,276	13,146
		2030	4,961	9,572	988	739	25,282	5,949	10,311	23,780	29,135	3,051	4,083	66,488	26,831	33,218
		2050	12,332	21,014	1,887	1,389	188,000	14,219	22,403	38,720	46,670	21,633	14,221	460,000	60,353	50,891
Scenario 2	UK	2020	3	86	3	32	350	6	118	264	1,130	2	24	8,060	266	1,154
		2030	64	604	50	225	6,000	114	829	864	3,266	49	240	19,477	913	3,506
		2050	288	944	75	280	15,000	364	1,224	1,251	3,943	242	454	45,000	1,493	4,397
	EU	2020	3	104	2	26	350	5	130	728	4,946	2	33	23,493	730	4,979
		2030	395	4,188	50	275	25,282	445	4,463	2,273	11,024	297	1,786	66,488	2,570	12,810
		2050	2,308	9,194	123	518	188,000	2,431	9,712	4,073	17,659	2,223	6,222	460,000	6,296	23,881
Scenario 3	UK	2020	-17	115	-8	47	350	-21	162	-19	1,534	-3	32	8,060	-22	1,566
		2030	-76	806	-27	325	6,000	-87	1,131	90	4,432	-23	321	19,477	67	4,753
		2050	70	1,258	-20	404	15,000	43	1,662	411	5,351	33	606	45,000	444	5,957
	EU	2020	-21	138	-7	37	350	-23	175.5	-707	6,712	-5	44	23,493	-712	6,756
		2030	-574	5,583	-43	398	25,282	-502	5,981	-631	14,961	-337	2,382	66,488	-968	17,343
		2050	182	12,258	-53	748	188,000	157	13,006	-382	23,966	-2,196	8,295	460,000	-2,578	32,261

Previous report sections have highlighted the issue of offshore corrosion as regards a variety of infrastructure materials submerged in seawater, as well as solutions currently employed and undergoing research to combat corrosion. A range of organisational corrosion solution stakeholders in the NSB region were categorised according to their position within defined anti-corrosion supply value chains. In addition, potential NeSSIE demonstration partners were identified, including developers and their projects, as well as corrosion solution private vendors, research projects and test facilitators. Now the issue of corrosion and key stakeholders in the NSB offshore sector today is better understood, an estimation of the economic saving and prize available in employing anti-corrosion solutions to NSB based offshore marine renewable sectors can be estimated.

Literature searches on the actual cost of corrosion to existing offshore industries reveal very little publicly-available hard data upon which to base estimates. In 2002 a federally-initiated study in the USA attempted to estimate cross-sector corrosion related costs [88]. Direct corrosion related costs (ignoring reliability/labour losses) estimated that anti-corrosion methods and services (resistant alloys, cathodic protection etc.) were worth \$121 billion annually to the economy, and when analysing 26 industry sectors the direct costs were estimated at $138 billion annually. The oil and gas sector (which included onshore costs) and 'ships/maritime' sector, the closest analogies to offshore marine renewables, incurred an estimated $2.7 billion and $1.4 billion respectively annually because of direct corrosion controls. The NACE in 2016 conducted a study called IMPACT to assess the cost-of-corrosion globally - whilst noting a lack of consistent calculation methods, they estimated that by using available corrosion control practices savings of between 15-35% could be realised [89], or $375-$875 billion globally on an annual basis. Through near misses, forced shutdowns, accidents, etc., industries have realised that a lack of corrosion management can be very costly. What is apparent is that the savings to offshore renewables developers and the opportunity for vendors of applying corrosion control are also important. An estimation of this value is attempted and explained in the following sections.

6.1. Anti-corrosion solutions' key offshore technology impacts

Direct corrosion solutions (DCSs) and new materials (NMs) logically will have varying cost impacts on a project's CAPEX, OPEX, and performance for different offshore technologies. It was necessary to simplify the calculations into three scenarios; Scenario 1 (New materials including fabrication, manufacturing and assembly), Scenario 2 (Direct corrosion solutions without in- or decrease of CAPEX of BAU), and Scenario 3 (Direct corrosion solutions with 10% increase in CAPEX) – Figure 23. It was assumed illogical for an offshore project to apply NMs and DCSs at once, hence they have not been combined and form separate estimations.

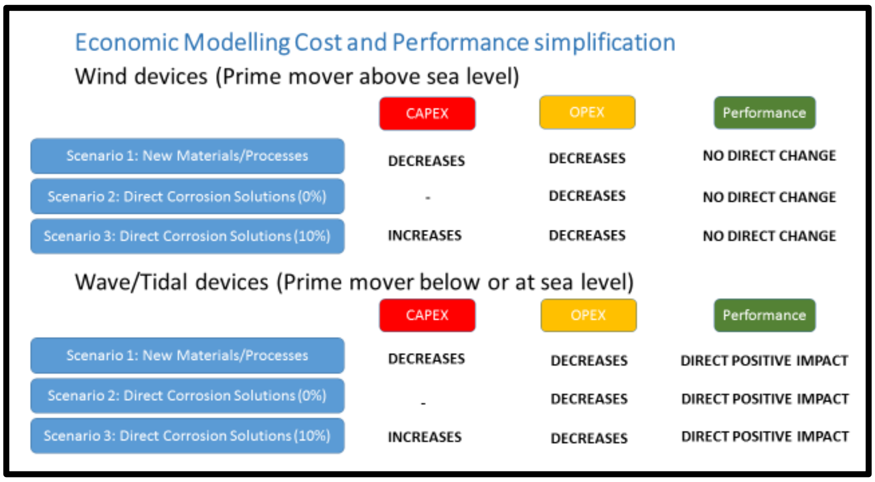


Figure 23 – Corrosion solution scenario economic model simplification

DCSs assume an adaptive technology or service is added to the existing primary device material, to decrease initial CAPEX expenditures with the hope of reducing future OPEX spend. In contrast, employing a NM replaces the primary device material to improve anti-corrosion resistance, whilst also offering a decrease in device CAPEX and with the anticipation of reducing future OPEX expenditures – 100% displacement of the original device's material, fabrication, manufacturing and assembly has been assumed. Both modifications will have direct device performance improvements for wave and tidal devices, whose prime movers are located at, or below sea level corrosion zones. Wind device turbines assumed no performance improvement, since turbines are above typical corrosion zones.

Maintaining or even improving a device's assumed design performance is important to the technology calculated LCOE, as well as delivering on promised project electricity generation targets. Quantified impacts of applying corrosion solutions on offshore marine devices' availability and reliability are not publicly available. There does, however, exist research on the impacts of marine fouling and corrosion effects on maritime vessel shaft powers and speeds through frictional surface changes. In this study, velocity dependent, fouling impacts reduced shaft powers by 4%-59%, and vessel speeds by 0.9%-10.7% for a range of biofouling intensities [90]. This same study was cited in a modelling paper attempting to calculate the decrease in a typical tidal turbine's efficiency caused by the build-up of surface biofouling, with an average 4.5% drop in efficiency annually due to 'thick slime' (coating 2) simulated (Figure 24) [8]. Vessel speed and hence drag are loosely analogous to immersed water motion operated tidal turbines or WEC device power generation – hence it's simply assumed in this study that applying an anti-corrosion solution to the devices will fully mitigate biofouling or corrosion-related drag increases over their lifetime. For wind devices not immersed in seawater, no direct performance advantage is assumed to be gained from employing corrosion solutions, only reduced CAPEX and OPEX expenditures.

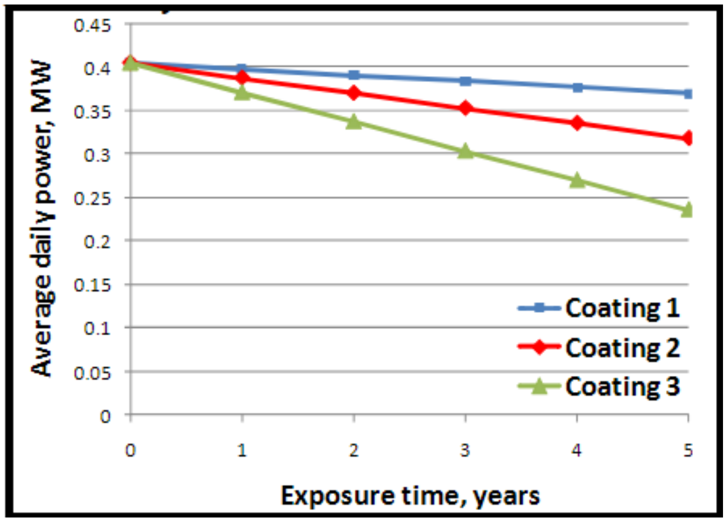


Figure 24 – Simulated power loss over 5 years due to progressive fouling [8]

6.2. *Key economic modelling assumptions*

Estimate boundary conditions for the economic modelling were based on logical and simplifying assumptions, which are transparently described here for third party repeatability and displayed in Table 3.By referring to this report's references, it should be remembered that the publicly available data on CAPEX and OPEX from reports, which this report utilises, was in itself often based on sets of unique, and sometimes complex assumptions. In order to refrain from an over-reliance upon the results of a single report, a process of validation through cross-referencing across different sources has been employed for all numbers calculated where possible, and high and low values for costings used to create a range of uncertainty.

Key Assumptions	Description
General	
	The status quo position for all offshore renewables technologies is that they do not currently employ at large scale direct corrosion or novel materials solutions
	Direct corrosion protection encompasses inspection, monitoring, corrosion solution application and the repair of marine devices.
	Novel materials solutions assumed to apply to the range of new materials (currently not used in offshore renewables), fabrication, manufacturing and assembly processes
	Novel materials/process solutions assumed relevant to offshore devices main structural components-SPM, turbine, PTO and foundation/mooring systems, not to installation, connection or O&M costs.
	All devices are assumed to be generically similar and able to adapt to direct corrosion solutions or new materials application.
	Corrosion solutions remain in place for the projects lifetime
	No equipment product or services supply constraints or market failures were assumed to influence the estimation
	No public funding input is included in any of the costings
	Given the similar offshore construction and limited data on floating wind - the technology has assumed to be analogous to wave devices in this study of corrosion impacts
	Ranges for all costs metrics have been included to attempt to account for variations in sectors technologies, site specific costs, supply chain variations, exchange rates etc......
	Tidal energy refers to tidal stream only - not Tidal Range
	Ocean OTEC and Salinity gradient technologies have not been assessed
	Technology costs based on UK sources are assumed to be universal across the EU
CAPEX impacts	
	The device technology lifetime %LCOE breakdown from various references for each technology were used as a proxy for different technologies, generic internal cost distribution
	CAPEX breakdowns have taken account of the technical and non technical portions by accounting for 'pre-development' and electrical infrastructure components.
	Technology cost internal breakdowns assumed to remain unchanged through time
	CAPEX ranges for all technologies were inflation corrected to 2017 UK pound values using UK inflation history
OPEX impacts	
	The O&M portion of the technology lifetime %LCOE breakdown was used as a proxy for different technology, generic OPEX percentages.
	OPEX breakdowns have focused only on O&M technical cost portions, and accounted for other OPEX costings such as Crown Rents, TNuOS and insurance costs
	Technology cost internal breakdowns assumed to remain unchanged through time
	OPEX ranges for all technologies were inflation corrected to 2017 UK pound values using UK inflation history
Performance	
	Both novel materials and direct corrosion solutions are assumed to enable maintenance of baseline design performance - not increase it.
	An annual degradation % term was added to the LCOE calculation to account for biofouling/corrosion performance impacts - using maritime sector studies as a reference.
	Availability and load factor reliability % terms were referenced to current conditions, and assumed constant throughout project life.
LCOE	
	Discount factors for LCOE/NPV calculations were tied to technology development status, i.e. 10% for pre commercial/development wave, tidal and floating wind, 6% for commercial fixed offshore wind
	As with CAPEX & OPEX cost ranges - LCOE's study values were cross referenced for validation using up to date data
Projections	
	All publicly utilised projections are inherently dependent on specific sets of chosen variables and assumptions, some more scientific than others.
	UK ESME model projections were used as the BUA case because they best integrate technology costings, infrastructure and competing demand modelling.
	EU target capacity projections were more aspirational and based on NREAP's given the increased complexity of modelling an EU, not just UK simulation of offshore renewables capacities.
	No financial incentives were assumed for any of the technologies
	100% materials displacement effects were assumed for novel materials introductions
	Were capacity projections were shared between technologies, i.e. wave/tidal, and fixed/floating wind - an estimation of relative technology proportions were modelled.
	CAPEX and OPEX savings employed an annual reduction factor to mimic future price drops in anti corrosion savings arising from improved competition, economies of supply scale etc.....
Limitations	
	Where made available, Developers cost estimations from reports as a source for this study are themselves inherently uncertain, subjective and generic.
	Large uncertainties arise from commodities price, exchange rates and trading conditions (Brexit) projections amongst others. The NPV value calculated is a one point in time value
	Logical and simplifying assumptions based on key research reports were employed to counter the lack of empirical research and publicly available hard data that exists in this studies specific area.
	Given the long list of assumptions incorporated, final NPV estimates for Developer savings and Vendor sales opportunities are for guidance only, not literal use.

Table 3 – Listing of key study assumptions used for the economic estimation calculations

6.3. Economic estimation methodology

The cross-industrial integration of existing NM and DCS value chains into the offshore renewable energy generation sector will have a wide range of financial, as well as socio-economic benefits to a wide range of stakeholders. This economic estimate focuses only on the direct financial benefit to developers and private vendors in employing these solutions to reduce the CAPEX and OPEX costs, and maintaining operational device performance levels of offshore renewable devices as the optimal way to measure their economic impact. The LCOE impact is calculated for each technology, allowing developers to observe corrosion solutions' potential project performance impacts. There is minimal quantified data available from either existing or immature offshore industries with which to compare estimated results.

The calculation method follows the flow diagram illustrated in Figure 25. At the most simplistic level - a benchmark business as usual (BAU) case has been researched (left side of diagram), and then compared to calculated scenarios 1, 2 and 3, which employ NM and DCS (0% CAPEX increase) and DCS (10% CAPEX increase) respectively (right side of diagram). BAU data was exclusively obtained using UK-based reports, simply because they represented the most extensive publicly available hard data sets available – it is assumed these same costs per technology are echoed elsewhere in the EU. The result of the comparison is a technology specific 'delta' value difference between the BAU status quo technology CAPEX per MW, OPEX per annum MW (termed

Original CAPEX/OPEX) and LCOE £/MWh metrics, and the post new corrosion solutions scenarios. This 'delta' value is then projected into the future using resource specific capacity offshore renewable projections, with values then discounted to Net Present Values (NPV) in Billions of nominal British pounds tied to 2017 for each scenario at different points in time (2020/2030/2050). High and low ranges for benchmark metrics allowed the incorporation of a range of uncertainty on the most likely 'mid' case results. The 'delta' differences were calculated from a developer CAPEX and OPEX saving perspective, and vendor CAPEX prize perspective to appeal project NeSSIE demonstrations to both parties.

All utilised capacity projection data assumed a medium available technical resource for wave, tidal and wind energies - this is a key factor in positioning the economic evaluation within a realistic technical and spatially representative frame in the UK and wider EU. It should be noted however that less-reported data and reasoning existed for cumulative projected European wide targets.

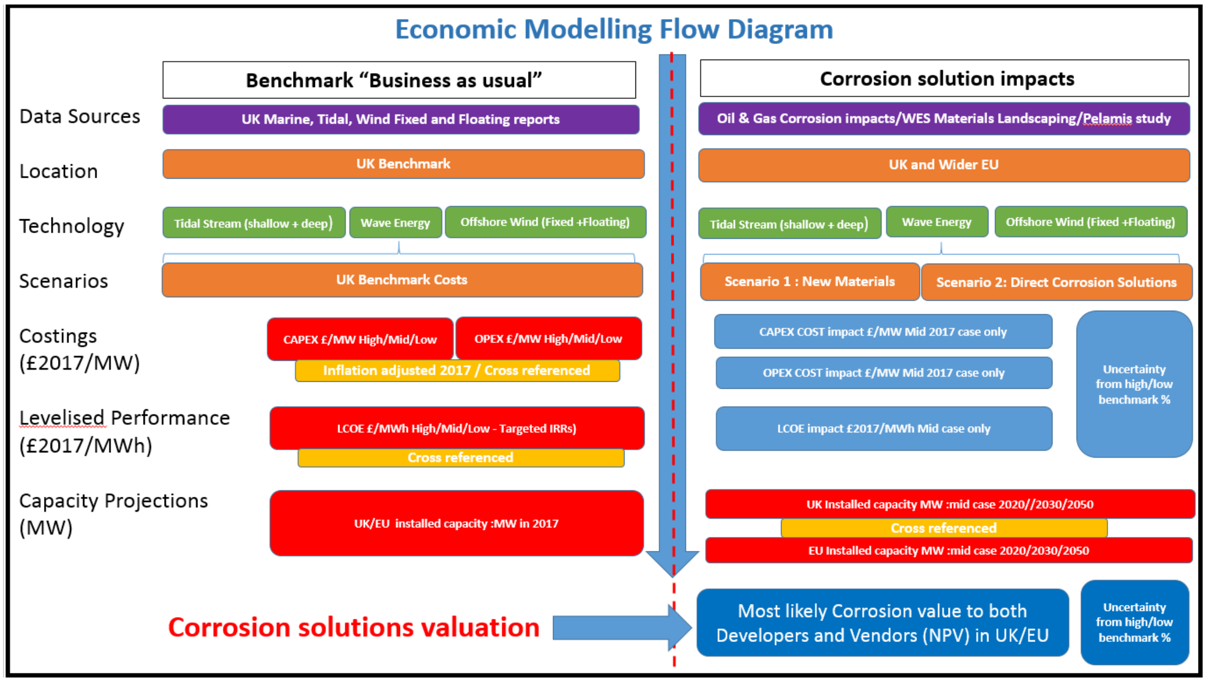


Figure 25 – NeSSIE corrosion and novel materials economic modelling workflow

6.4. *Key impacts of ACS on different offshore energy devices*

The calculation of CAPEX and OPEX savings, and possible performance level sustainability by employing anti-corrosion solutions focused on several key statements unearthed from across industry literature reviews (as noted earlier there is very limited hard data applicable and available):

- Oil and gas industry: "Preventative Capital expenditure because of corrosion in North Sea projects undertaken by BP in 1980's averaged **8%** of total project CAPEX" [91].
- Oil and gas industry: "In 1988, 25-33% planned/unplanned maintenance costs of BPs UK continental shelf oilfields were corrosion related". In addition, "54% of corrosion related failures in the Petroleum industry are caused by non-CO2 and H2S related issues" (Table 4) [91]. By removing the toxic substance related corrosion failures, **18%** of all annual

maintenance costs can be attributed to corrosion.

- Offshore renewables industry: A Wave Energy Scotland materials landscaping study [81] estimated that if various novel materials were to replace conventional steels in WEC devices, an approximate CAPEX saving between 15% to 50%, with an average of **30%** could be made (Table 5). Considering the different materials' applications for wave, tidal and wind, the average estimated CAPEX savings are **33%**, **30%** and **26%** respectively.
- Offshore renewables industry: A main body structural design and materials selection study conducted by Pelamis for their WEC in 2003 identified 'thinner coated steel', 'post tensioned concrete' and 'glass reinforced plastics' as an alternative main structure and prime mover (SPM) material saving between **20% to 50%** on the original material costs. The thinner steel material with an epoxy coating solution highlighted that **28.5%** of the total cost of this solution was from the coating alone [80].
- Maritime industry: "Vessel performance reduction because of bio-fouling was estimated as a percentage of original vessel speed for different levels of biofouling by Schultz [90] (Table 6). Although vessel speed dependent, it was found that the highest level of bio-fouling could reduce speed by up to 11%. Yebra et al. in 2010 made use of this study to determine average coating tidal turbine efficiency drops (earlier Figure 23) over five-year turbine cleaning time periods – an annual average **4.5%** performance reduction was estimated [8]".

-ANALYSIS OF SELECTED NUMBER OF FAILURES IN PETROLEUM RELATED INDUSTRIES

Type of failure	Frequency (%)
Corrosion (all types)	33
Fatigue	18
Mechanical damage/overload	14
Brittle fracture	9
Fabrication defects (excluding welding defects)	9
Welding Defects	7
Others	10

–CAUSE OF CORROSION-RELATED FAILURE IN PETROLEUM-RELATED INDUSTRIES

Type of failure	Total failure (%)
CO_2 related	28
H_2S related	18
Preferential weld	18
Pitting	12
Erosion corrosion	9
Galvanic	6
Crevice	3
Impingement	3
Stress corrosion	3

Table 4 – Causes of offshore Petroleum related industry failures [91]

WES WEC materials landscaping study (2014)					
Materials description	Suggested savings CAPEX	OPEX	Cost saving tech category Main	Secondary	Main Application
Roto Moulded Polymer & Composite Hybrids	50%	Yes (NQ)	SPM		WEC/TEC
Adhesive bonding of composites	15%	Yes (NQ)	SPM	Turbines	TEC/WIND
Concrete Structures/Novel	20%	No	SPM	Foundations	WEC/TEC/WIND
Adhesive bonding of steel	50%	Yes (NQ)	SPM		WEC/TEC/WIND
Polymer & Composite steel hybrids	15%	Yes (NQ)	SPM	PTO	WEC/TEC/WIND
Steels & Welding improvements	30%	No	SPM	PTO/Foundations	WEC/TEC/WIND
Elastomers	Not defined	Not defined	SPM		WEC/TEC
		NQ (not quantified)			
		SPM (Structure and Prime Mover)	PTO (power take off)		
Employed Novel Materials study factors					
	CAPEX	OPEX	Cost saving categroies		
Novel materials solution estimation (average)	30%	Yes (NQ)	SPM/Foundations/Moorings/Turbines		

Table 5 – WES new materials landscaping study for WEC overall average anticipated cost reduction of 30% of total original CAPEX, applicable to wave an average of 33%, to tidal 30% and to offshore wind 26% [81]

Predictions of the change in required shaft power (ΔSP) for an *Oliver Hazard Perry class* frigate (*FFG-7*) with a range of representative coating and fouling conditions at a speed of 15.4 m s^{-1} (30 knots). Also presented is the percentage decrease in speed for a fixed shaft power.

Description of condition	ΔSP @ $U_s = 15.4$ m s^{-1} (kW)	% ΔSP @ $U_s = 15.4$ m s^{-1}	% reduction in speed for fixed $SP = 2.7 \times 10^4$ kW
Hydraulically smooth surface	–	–	–
Typical as applied AF coating	1004	4%	0.9%
Deteriorated coating or light slime	2618	10%	2.7%
Heavy slime	4311	16%	4.0%
Small calcareous fouling or weed	6934	26%	5.8%
Medium calcareous fouling	10,329	38%	7.5%
Heavy calcareous fouling	16,043	59%	10.7%

Table 6 – Vessel performance impact caused by hull bio-fouling [90]

From these statements, key quantifiable deterministic anti-corrosion solution cost impact percentages were used to calculate scenario 1, 2 and 3 deltas. In reality there is likely to be a range of percentage impacts, for example the BP statement above is representative of the early life in North Sea platform corrosion mitigation in the 1980s – the likely corrosion expenditures today given the ageing of offshore structures is likely to be far higher. This uncertainty is assumed to be accounted for by using OPEX/CAPEX ranges – it is however recognised as a key limitation.

It was first necessary to determine proportional impacts of the major statements on researched original CAPEX and OPEX £/MW costs. For the three scenarios, the reduced, equal or increased CAPEX costs are based on the total original CAPEX of the BAU case. This percentage of the original CAPEX forms an additional cost or cost savings for the developer. However, as the CAPEX difference data was original, per-technology total CAPEX that included non-technical costs (management fees), the value to the vendors – assuming a 100% displacement – is calculated by eliminating the non-technical aspects of the CAPEX. In addition, NM and DCS would only directly impact 'material' parts of the devices, i.e., the structure and prime Mover (SPM)/the turbine, foundation and mooring systems (F&M) and the power take off (PTO) – hence original CAPEX data had to include other costs for installation, operation and maintenance (O&M), whereas connection costs had to also be factored in. The newly obtained CAPEX, consisting of the technical elements and the directly impacted components, is referred to as the modified CAPEX. Similarly, for OPEX, not all OPEX is technical: some relates to rents, transmission charges and insurance – these also required elimination, referred to as technical OPEX. The apportioning of technical percentages comes from established Carbon Trust TINA reports [92] [64], as shown in Figures 26, 27 and 28. These percentage costs were cross-referenced with other reports for validity. Figures 29 (CAPEX) and 30 (OPEX) illustrate how the ACSs for the scenarios, and for each technology were applied to the technical CAPEX and OPEX portions of the data, based upon the previously quoted statements:

- Scenario 1 – NM:
    - **33%**, **30%** and **26%** of total original CAPEX saving for Developer wave, tidal and offshore wind respectively;
    - **18%** technical OPEX saving for Developer;
    - **33%**, **30%** and **26%** of modified CAPEX for Vendor NM supply for wave, tidal and offshore wind respectively (100% displacement).
- Scenario 2 – DCS (0%):
    - **0%** of total original CAPEX difference for Developers (thus equal to the BAU CAPEX);
    - **18%** technical OPEX saving for Developer;
    - **28.5%** of modified CAPEX for Vendor DCS supply.
- Scenario 3 – DCS (10%):
    - **10%** of modified CAPEX additional cost for Developer;
    - **18%** technical OPEX saving for Developer;
    - **38.5%** of modified CAPEX for Vendor DCS supply.
- For all scenarios:
    - In the case of wave and tidal, a 4.5% annual performance reduction factor is used prior to ACS (thus for the BAU case).

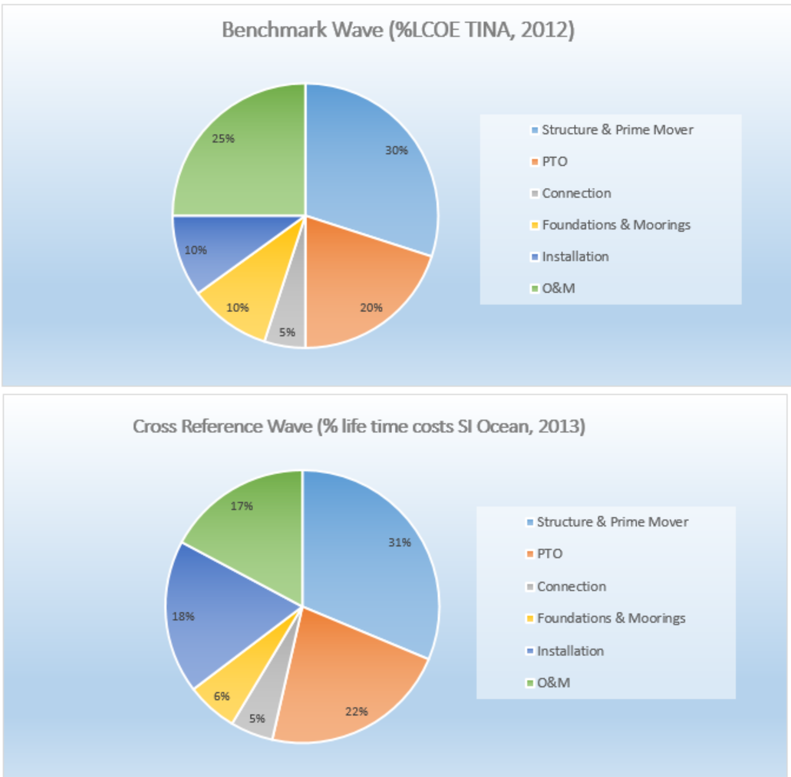


Figure 26 – Wave % lifetime costs split: technical portions impacted by ACS [92]/ [93]

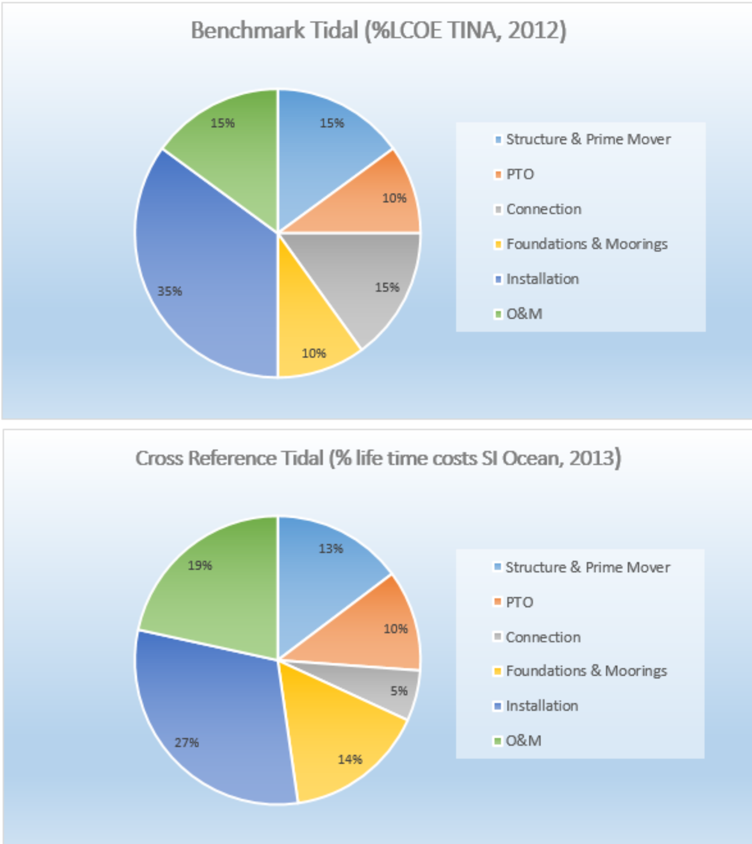


Figure 27 - Tidal % lifetime costs split: technical portions impacted by ACS [92]/ [93]

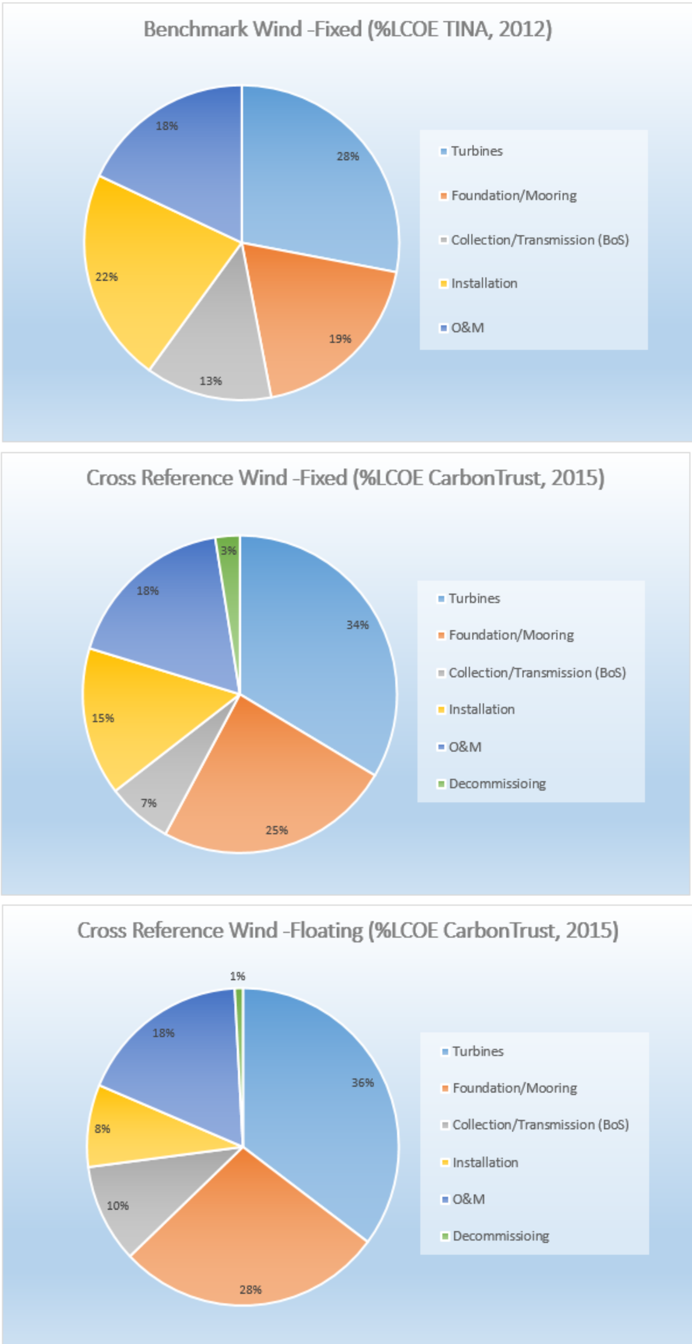


Figure 28 – Fixed/Floating % lifetime cost split: technical portions impacted by ACS [92]/ [94]

Figure 29 – Scenario 1&2&3 modification of original CAPEX to account for ACS solution

Essentially for both CAPEX and OPEX ACS impact percentages, eliminate the actual effects on the technical portion of each cost for each technology acts to reduce the overall percentage impact in real terms (as shown to the far right of each bar graph in Figures 29 & 30).

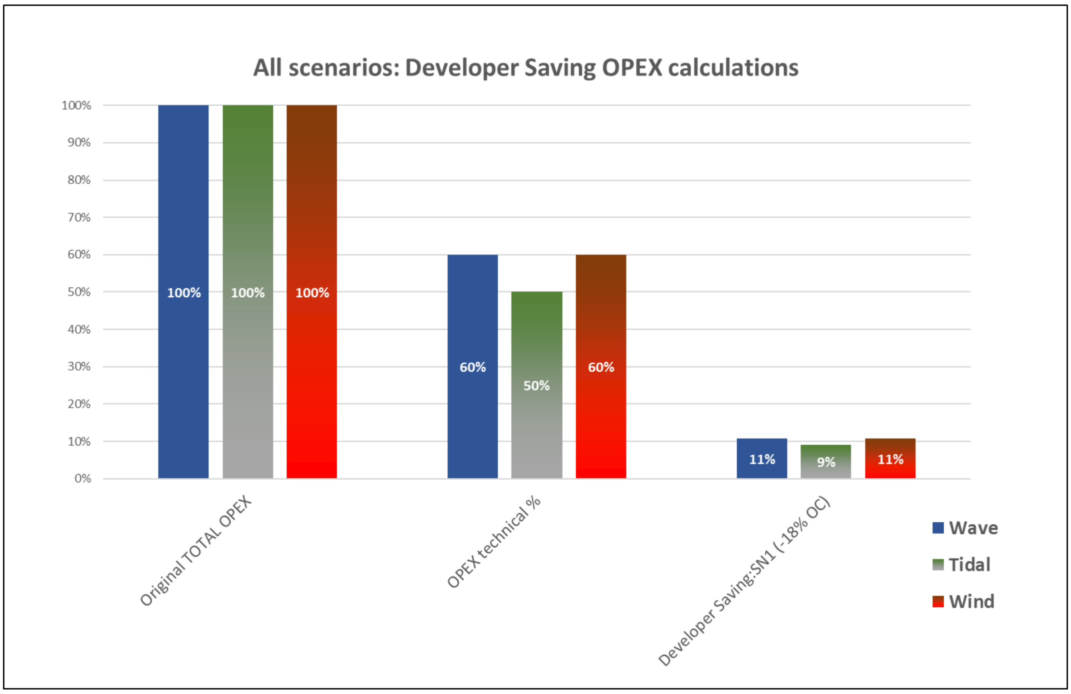


Figure 30 - Scenario 1, 2 & 3 modification of original OPEX to account for ACS solution

The original CAPEX and OPEX percentage impacts were then used to determine the ACS impact 'delta' in £/MW in order to calculate a scenario for developer savings and vendor prizes into the future by applying them to a projected technology capacity increase over time in the UK and wider EU. The same 'delta' ACS impacts were applied to base literature LCOE values for each technology, along with the performance impact of bio-fouling and corrosion factor.

6.5. CAPEX and OPEX ACS delta impacts per technology

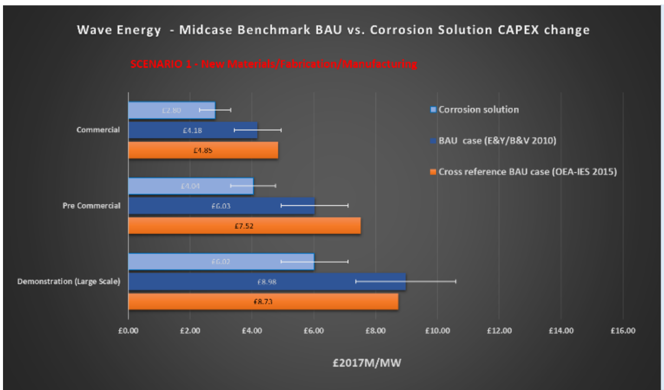
For each scenario, using the described methodology the following Figures 31 and 32 display the 'delta' CAPEX and OPEX impact of employing new ACS technologies for each resource (wave, tidal stream - shallow and deep, fixed wind and floating wind). Resource definitions were taken from the BAU benchmark reports and defined as:

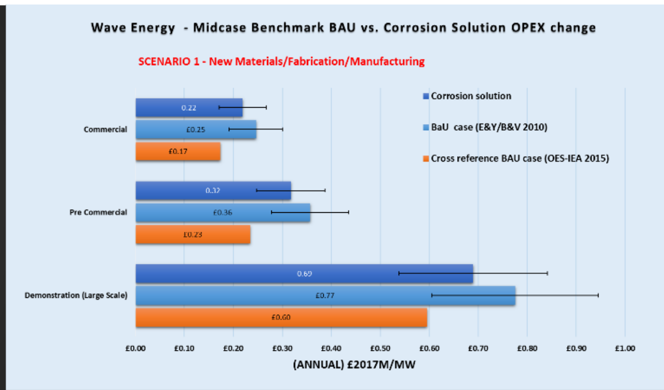
- Wave:
    - >30m depth/20 years life/3-7km offshore/33% LF/80% Availability
    - Status - Pre-commercial
- Tidal Stream Shallow:
    - <20m depth/20 years lf/MSP>2.5ms/4km offshore/37% LF/90% Availability
    - Status - Commercial
- Tidal Stream Deep:
    - >20m depth/20 years life/MSP>2.5ms/7km offshore/37% LF/90% Availability
    - Status – Pre-commercial

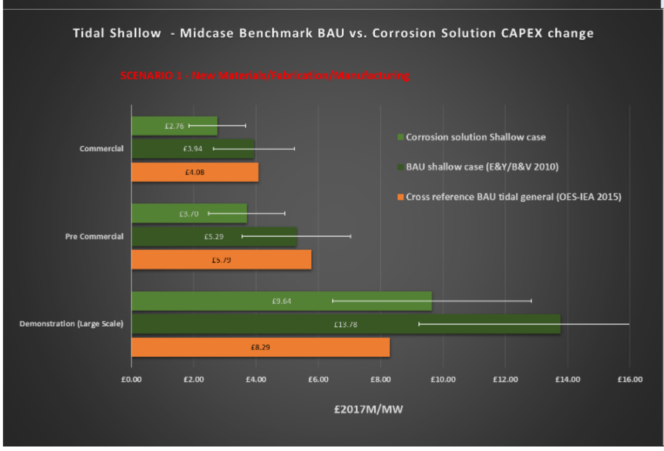
- Fixed Wind:
    - <50m depth/20 years life/45% LF/95% Availability
    - Status - Commercial
- Floating Wind:
    - >50m depth/20 years life/50% LF/90% Availability
    - Status - Pre-commercial

The important general distinction between fixed and floating wind is that as water depths deepen beyond 50m, floating wind begins to become cost competitive with fixed wind. The possibility to disconnect and tow floating wind for repair offers a 35%-50% OPEX cost saving over fixed wind [94], as well as accessing stronger winds to improve load factor harnessing, e.g. Statoil's Hywind project. As previously mentioned, no performance degradation factor has been applied to wind devices, only wave and tidal equal to 4.5% annually.

In the following Figures, BAU refers to the benchmark cost data taken from reports [94]/ [95]/ [96], which were collected either directly from developer surveys or as part of the detailed market research process. In each case, a cross-referenced report has been incorporated to validate base data used [97]/ [98]/ [99]. All cost data was corrected to 2017 terms using historical UK inflation. Uncertainty bars were placed on the values to represent high and low ranges detailed in base data reports.







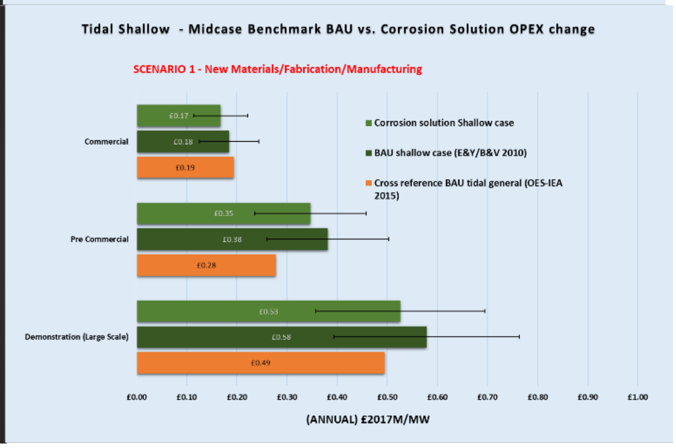
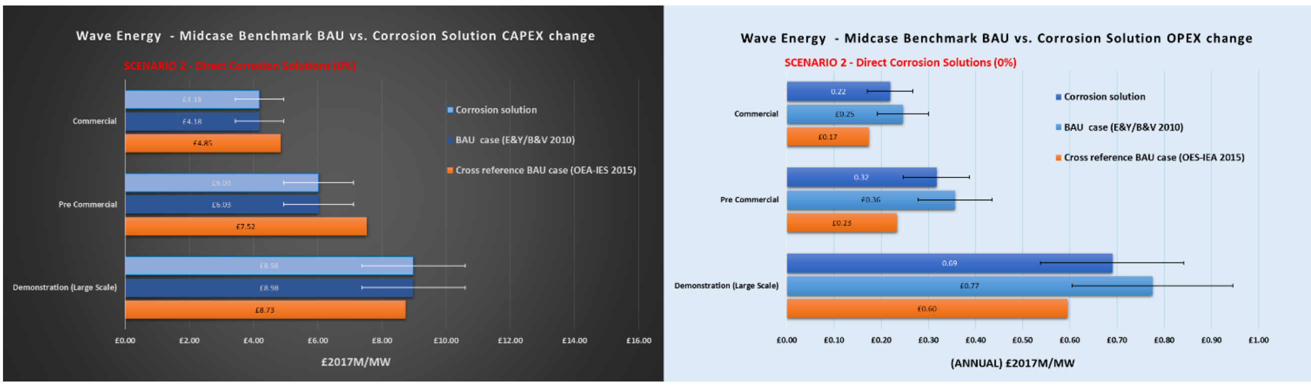


Figure 31 – Scenario 1 CAPEX/OPEX ACS affects all resource types



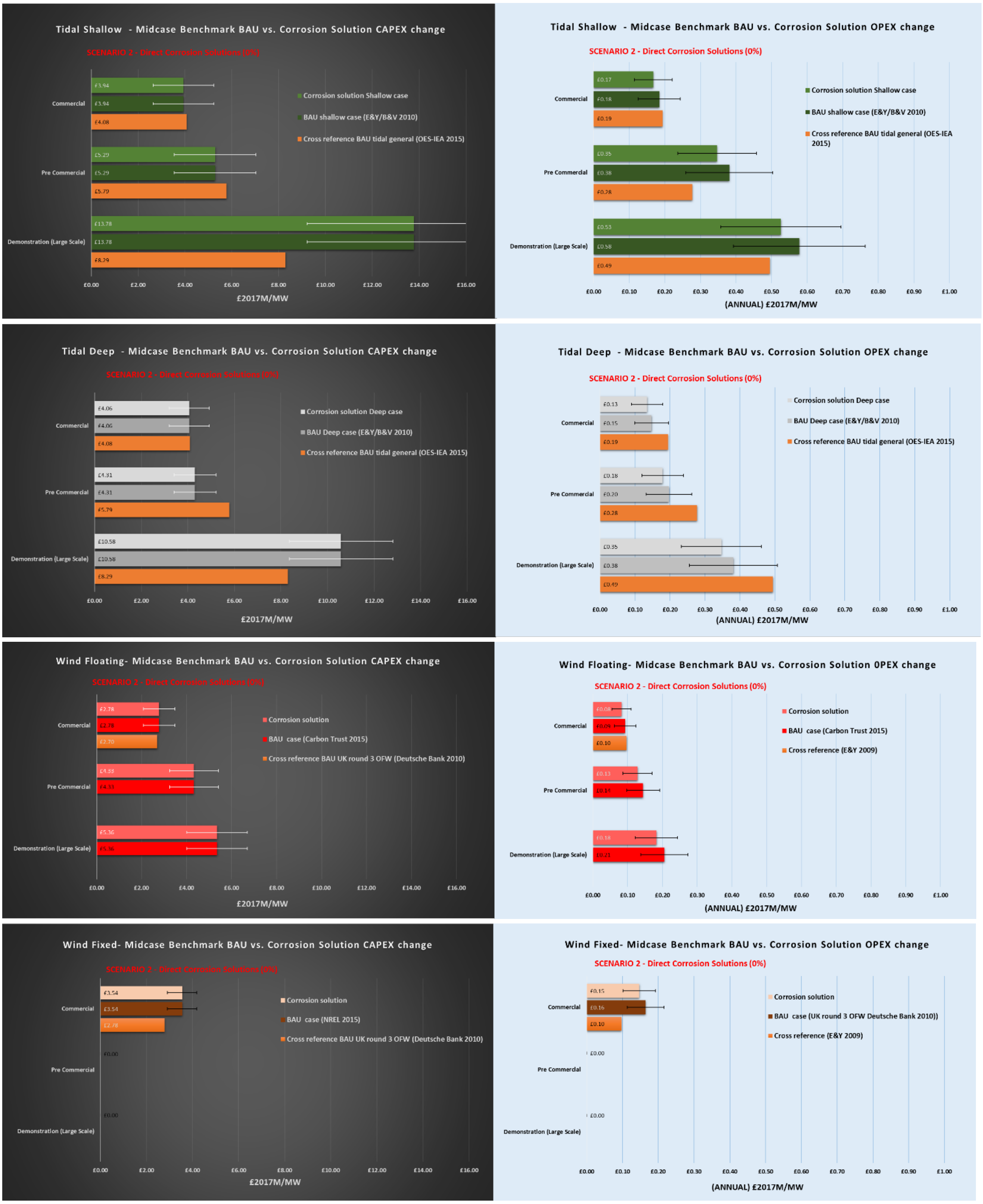
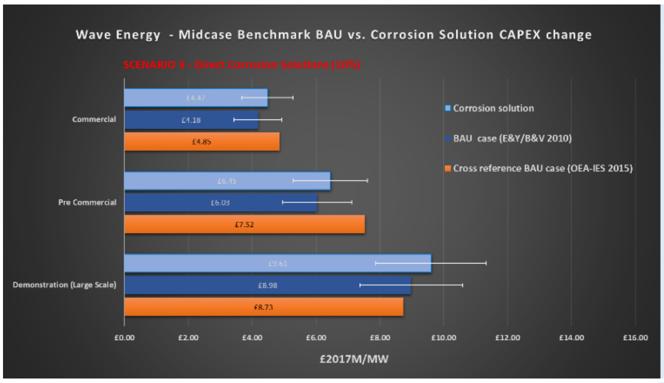
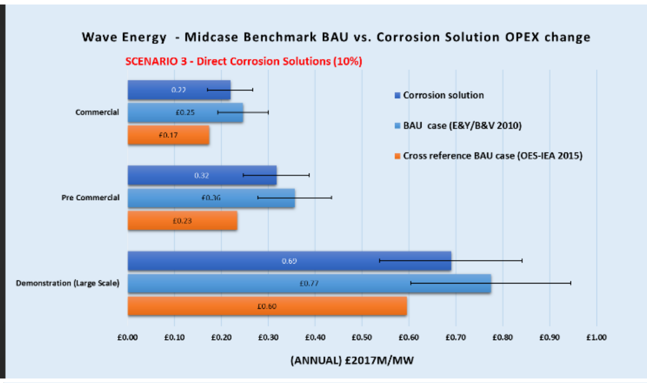
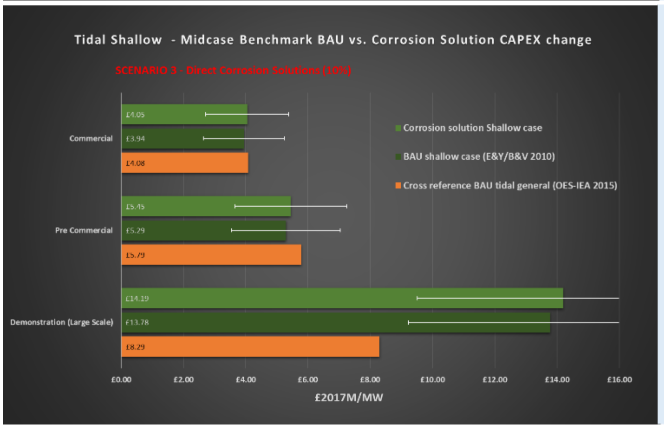
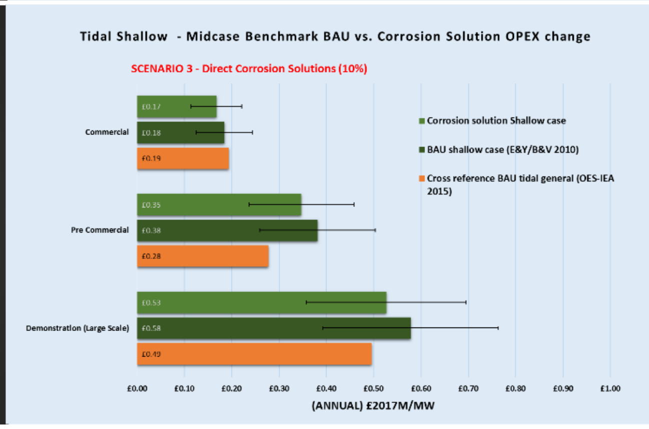


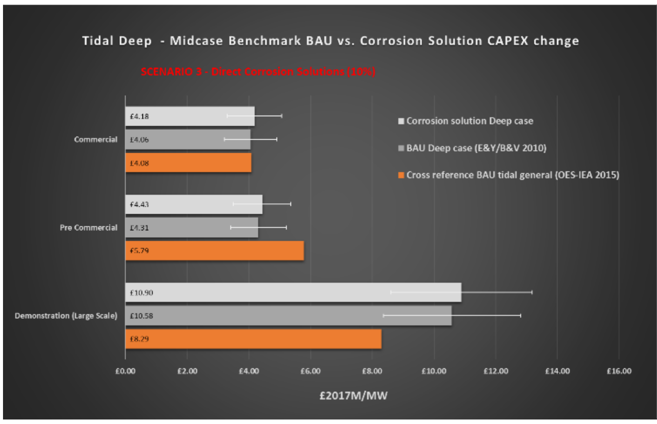
Figure 32 - Scenario 2 CAPEX and OPEX ACS affects all resource types

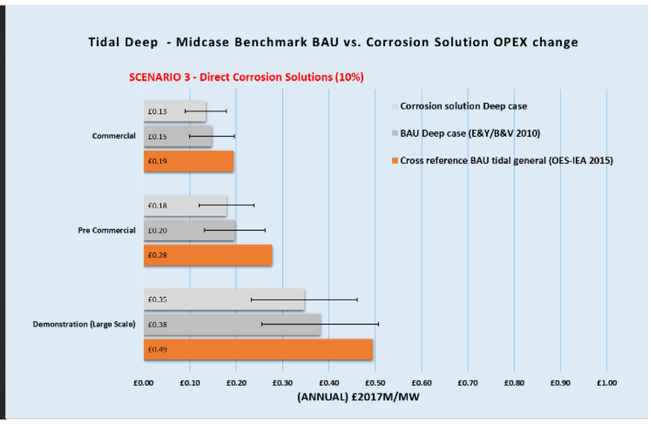

Wave Energy - Midcase Benchmark BAU vs. Corrosion Solution CAPEX change
SCENARIO 3 - Direct Corrosion Solutions (10%)
Commercial
Pre Commercial
Demonstration (Large Scale)
£4.18
£4.85
£6.03
£7.52
£8.98
£8.73
Corrosion solution
BAU case (E&Y/B&V 2010)
Cross reference BAU case (OEA-IES 2015)
£0.00 £2.00 £4.00 £6.00 £8.00 £10.00 £12.00 £14.00 £16.00
£2017M/MW

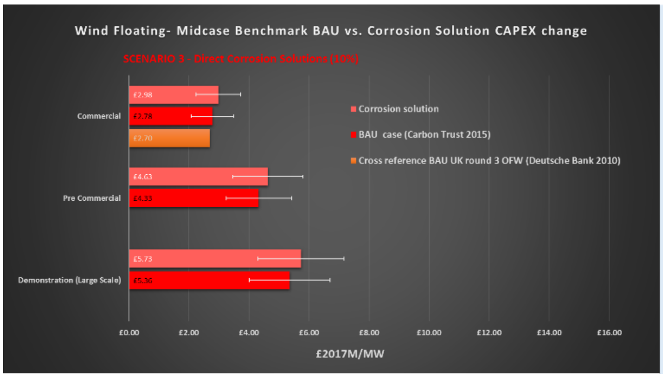

Wave Energy - Midcase Benchmark BAU vs. Corrosion Solution OPEX change
SCENARIO 3 - Direct Corrosion Solutions (10%)
Commercial
Pre Commercial
Demonstration (Large Scale)
0.22
£0.25
£0.17
0.32
£0.36
£0.23
0.69
£0.77
£0.60
Corrosion solution
BAU case (E&Y/B&V 2010)
Cross reference BAU case (OES-IEA 2015)
£0.00 £0.10 £0.20 £0.30 £0.40 £0.50 £0.60 £0.70 £0.80 £0.90 £1.00
(ANNUAL) £2017M/MW

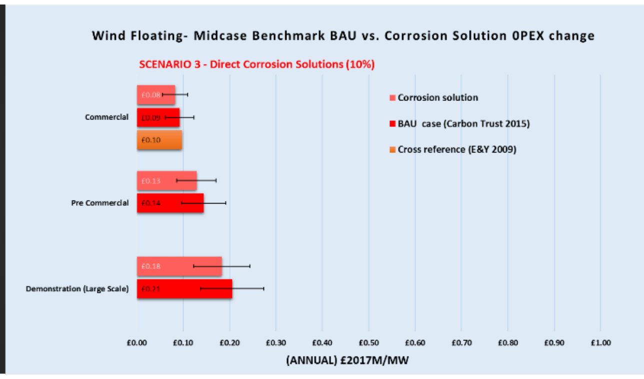

Tidal Shallow - Midcase Benchmark BAU vs. Corrosion Solution CAPEX change
SCENARIO 3 - Direct Corrosion Solutions (10%)
Commercial
Pre Commercial
Demonstration (Large Scale)
£4.05
£3.94
£4.08
£5.45
£5.29
£5.79
£14.19
£13.78
£8.29
Corrosion solution Shallow case
BAU shallow case (E&Y/B&V 2010)
Cross reference BAU tidal general (OES-IEA 2015)
£0.00 £2.00 £4.00 £6.00 £8.00 £10.00 £12.00 £14.00 £16.00
£2017M/MW


Tidal Shallow - Midcase Benchmark BAU vs. Corrosion Solution OPEX change
SCENARIO 3 - Direct Corrosion Solutions (10%)
Commercial
Pre Commercial
Demonstration (Large Scale)
£0.17
£0.18
£0.19
£0.35
£0.38
£0.28
£0.53
£0.58
£0.49
Corrosion solution Shallow case
BAU shallow case (E&Y/B&V 2010)
Cross reference BAU tidal general (OES-IEA 2015)
£0.00 £0.10 £0.20 £0.30 £0.40 £0.50 £0.60 £0.70 £0.80 £0.90 £1.00
(ANNUAL) £2017M/MW


Tidal Deep - Midcase Benchmark BAU vs. Corrosion Solution CAPEX change
SCENARIO 3 - Direct Corrosion Solutions (10%)
Commercial
Pre Commercial
Demonstration (Large Scale)
£4.18
£4.06
£4.08
£4.43
£4.31
£5.79
£10.90
£10.58
£8.29
Corrosion solution Deep case
BAU Deep case (E&Y/B&V 2010)
Cross reference BAU tidal general (OES-IEA 2015)
£0.00 £2.00 £4.00 £6.00 £8.00 £10.00 £12.00 £14.00 £16.00
£2017M/MW


Tidal Deep - Midcase Benchmark BAU vs. Corrosion Solution OPEX change
SCENARIO 3 - Direct Corrosion Solutions (10%)
Commercial
Pre Commercial
Demonstration (Large Scale)
£0.13
£0.15
£0.19
£0.18
£0.20
£0.28
£0.35
£0.38
£0.49
Corrosion solution Deep case
BAU Deep case (E&Y/B&V 2010)
Cross reference BAU tidal general (OES-IEA 2015)
£0.00 £0.10 £0.20 £0.30 £0.40 £0.50 £0.60 £0.70 £0.80 £0.90 £1.00
(ANNUAL) £2017M/MW


Wind Floating- Midcase Benchmark BAU vs. Corrosion Solution CAPEX change
SCENARIO 3 - Direct Corrosion Solutions (10%)
Commercial
Pre Commercial
Demonstration (Large Scale)
£2.98
£4.63
£5.73
Corrosion solution
BAU case (Carbon Trust 2015)
Cross reference BAU UK round 3 OFW (Deutsche Bank 2010)
£0.00 £2.00 £4.00 £6.00 £8.00 £10.00 £12.00 £14.00 £16.00
£2017M/MW


Wind Floating- Midcase Benchmark BAU vs. Corrosion Solution OPEX change
SCENARIO 3 - Direct Corrosion Solutions (10%)
Commercial
Pre Commercial
Demonstration (Large Scale)
£0.10
Corrosion solution
BAU case (Carbon Trust 2015)
Cross reference (E&Y 2009)
£0.00 £0.10 £0.20 £0.30 £0.40 £0.50 £0.60 £0.70 £0.80 £0.90 £1.00
(ANNUAL) £2017M/MW

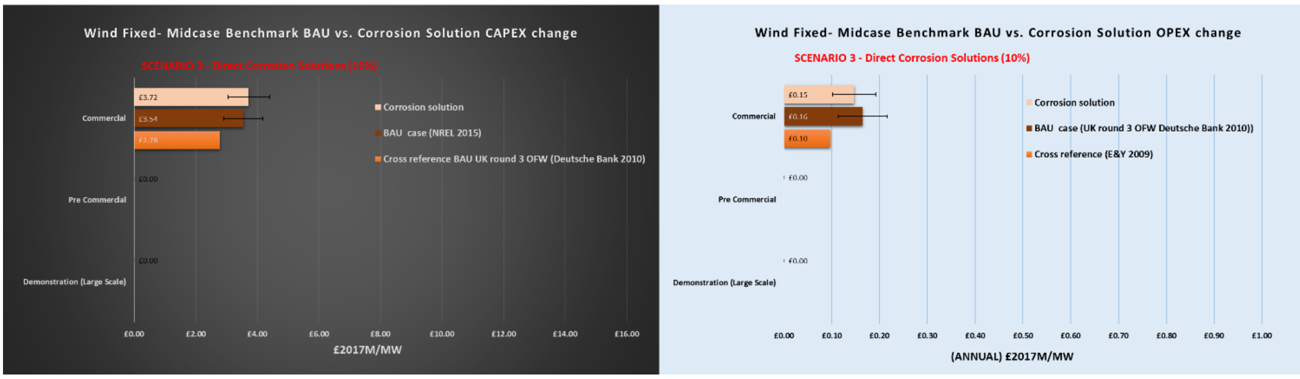


Figure 33 - Scenario 3 CAPEX and OPEX ACS affects all resource types

Before final validation of these estimates, it is wise to check the calculated and reported cost impact data at this stage:

- Absolute wave costs quoted by Developers are consistently more optimistic than tidal stream costs. The report used [95] stated recurring survey feedback that wave costs were more uncertain given its more immature state of development compared to tidal.
- In all cases, BAU data inclusive of error bars falls within cross-referenced values taken from different reports. This provides a positive 'sense check', in that the data used shows a degree of overlap between different vintage reports. It is unlikely however that the cost values used in this report are accurate beyond 2015, especially for faster developing commercial costs like fixed wind.
- As indicated, for all scenarios the OPEX decreases with the introduction of ACSs. Considering the £/MW CAPEX, with Scenario 1 the introduced ACS reduces CAPEX in all cases. With Scenario 2, the £/MW CAPEX of the solution is equal to the BAU case. Lastly, in Scenario 3, the £/MW CAPEX increases compared to the BAU case.
- As expected, scenario 1 NM ACS introduces a larger developer saving than scenario 2 DCS.

6.6. LCOE ACS delta impacts per technology

In a similar way to £/MW CAPEX and OPEX BAU and ACS costings, current technology levelised cost of electricity (LCOE) metrics were researched (same references as CAPEX/OPEX), and the impact of ACSs for the first and second scenarios estimated. This metric also allows for the integration of corrosion device/array performance impacts, which will be of use to developers assessing the importance of ACSs in reducing their project costs.

The method referenced the most up-to-date and relevant mid-case BAU benchmark LCOEs for each resource type, along with a high and low range to define uncertainty. A simple LCOE calculation based upon the assumptions in Table 7 was then used to mimic the referenced LCOEs; one calculation with, and one without, the 4.5% performance degradation factor for wave and tidal devices (Table 8). A well-modelled approximation of BAU LCOEs within defined uncertainties was first achieved, then a degradation factor LCOE included. Introducing a new ACS technology was then assumed to be able to reduce this degradation factor to 0% over five-year 'maintenance' intervals, sustaining baseline electrical generation, availabilities and reliabilities. Ultimately, an LCOE ACS impact delta was calculated for each resource technology in each scenario.

Mid resource case LCOE Assumptions all technologies (£2017/MWh)					
Basecase	**Wave**	**Tidal (shallow)**	**Tidal (deep)**	**Fixed Wind (UK R3)**	**Floating Wind**
Project life (years)	20	20	20	20	20
Availability %	80%	90%	90%	95%	90%
Average load factor %	33%	37%	37%	45%	50%
Discount rate %	10%	10%	10%	6%	10%
Annual Performance degredation % (fouling only)	4.5%	4.5%	4.5%	0% (Dynamic generation above main corrosion zonations)	
Resource assumed	Medium	Medium	Medium	Medium	Medium
Project array size (MW)	5	10	10	100	5
CAPEX (£/MW) - mid case 2017 value	6.03	3.94	4.31	3.54	4.33
Annual OPEX (£/MW) - mid case 2017 value	0.36	0.18	0.20	0.16	0.14
Decomissioning (% CAPEX)	0	0	0	0	0
Construction time (years)	1	1	1	1	1
Start date	2017	2017	2017	2017	2017
End date	2037	2037	2037	2037	2037
Technology Status	Pre Commercial	Commercial	Pre Commercial	Commercial	Pre commercial

Corrosion solution changes (delta)	**Wave**	**Tidal (shallow)**	**Tidal (deep)**	**Fixed Wind**	**Floating Wind**
CAPEX change (%)	-33%	-30%	-30%	-26%	-26%
CAPEX (£/MW) reduction	2.96	1.59	3.17	0.92	1.12
OPEX (%) reduction	-11%	-9%	-9%	-11%	-11%
Annual OPEX (£/MW) - commercial mid case 2017 value	0.09	0.034	0.018	0.02	0.02
New Annual Performance degredation % (fouling)	0%	0%	0%	0%	0%

Corrosion solution changes (delta) Scenario 2	**Wave**	**Tidal (shallow)**	**Tidal (deep)**	**Fixed Wind**	**Floating Wind**
CAPEX change (%)	0%	0%	0%	0%	0%
CAPEX (£/MW) reduction	0.00	0.00	0.00	0.00	0.00
OPEX (%) reduction	-11%	-9%	-9%	-11%	-11%
Annual OPEX (£/MW) - commercial mid case 2017 value	0.09	0.034	0.018	0.02	0.02
New Annual Performance degredation % (fouling)	0%	0%	0%	0%	0%

Corrosion solution changes (delta) Scenario 2	**Wave**	**Tidal (shallow)**	**Tidal (deep)**	**Fixed Wind**	**Floating Wind**
CAPEX change (%)	7%	3%	3%	5%	7%
CAPEX (£/MW) reduction	-0.63	-0.16	-0.32	-0.18	-0.30
OPEX (%) reduction	-11%	-9%	-9%	-11%	-11%
Annual OPEX (£/MW) - commercial mid case 2017 value	0.09	0.034	0.018	0.02	0.02
New Annual Performance degredation % (fouling)	0%	0%	0%	0%	0%

Table 7 – Assumptions used for BAU LCOE calculation

	BUA Reference	+/- MAX (All maturities)	Calculated BUA + degregation	Calculated BUA only
Wave	496	18%	609	472
Tidal Shallow	213	22%	294	228
Tidal Deep	250	23%	319	247
Wind Fixed	121	29%	131	131
Wind Floating	150	8%	170	170

Table 8 – BAU reference and calculated LCOEs with degradation and ACS impact

Scenarios 1, 2 and 3 with the ACS calculations produced the ‘delta’ results seen in Figures 34, 35 and 36. All resource technologies observed a reduction in a developers’ LCOE when introducing new ACS technologies through a combination of performance improvements and cost reductions.

Figure 34 – Scenario 1 LCOE impacts on introducing new ACS technologies

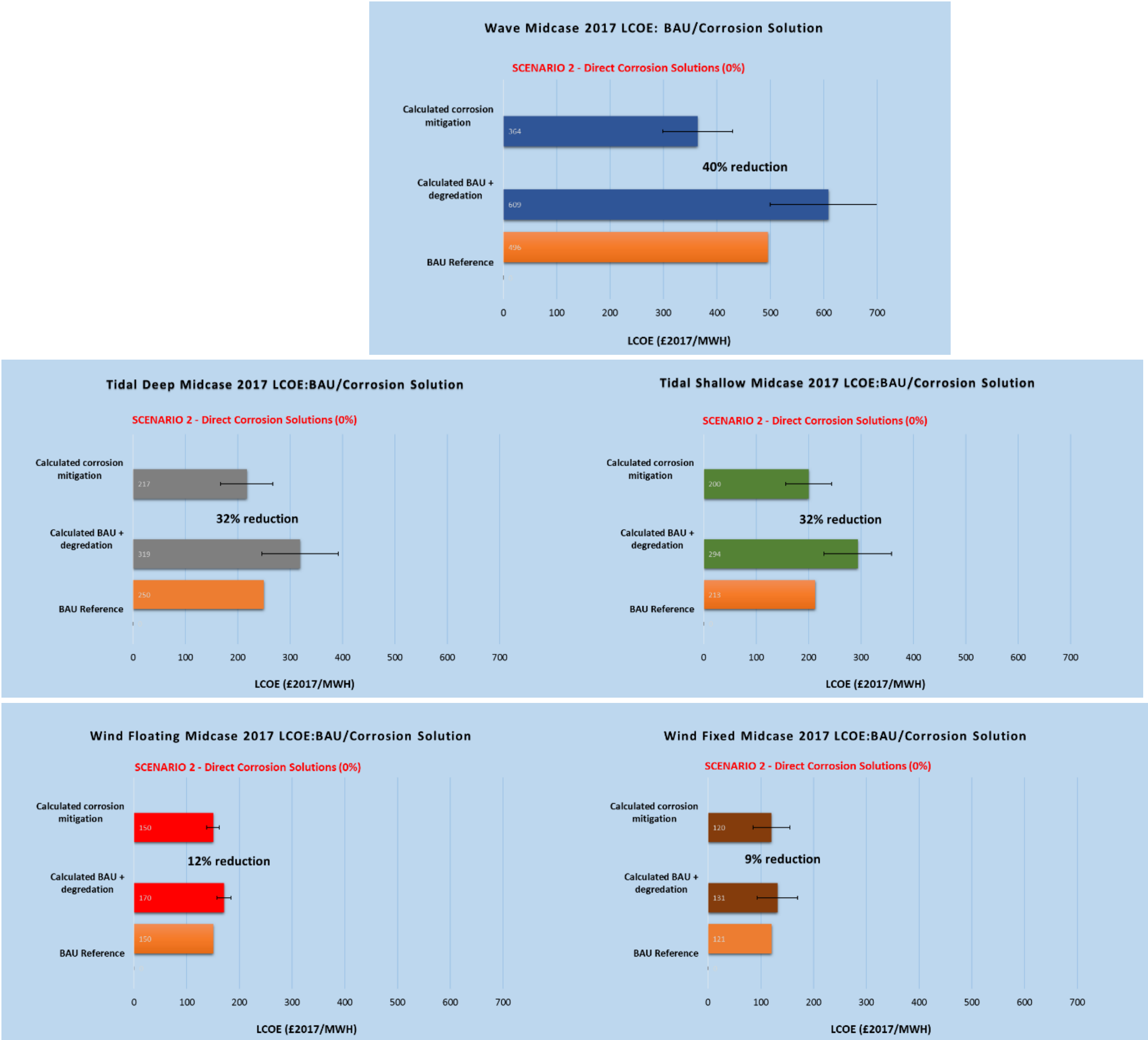


Figure 35 – Scenario 2 LCOE impacts on introducing new ACS technologies

Figure 36 – Scenario 3 LCOE impacts on introducing new ACS technologies

LCOE improvements in wave and tidal were greater than for wind, given the positive impact new ACS technologies have on negating device/array performance degradation which will occur once immersed in seawater. LCOE reductions for fixed wind technologies reflect its advanced state of commercialisation compared to the other technologies, whilst wave, at the other end of the commercialisation spectrum, displays the largest ACS impact.

6.7. Projected ACS estimation results

New ACS technology Scenarios 1 and 2 were calculated for each resource to include 'delta' difference impacts as shown in Tables 9, 10 and 11– the upper table shows developer 'delta' savings or additional cost in CAPEX and OPEX £2017/MW terms – depending on the scenario. The same Table (lower section) displays the starting £2017/MW original CAPEX values, with associated vendor prize percentages used to calculate a value to the vendor in delivering ACS technologies to developers. No OPEX prize was assumed for vendor delivery of corrosion monitoring services, as well as repair and assessment services because of the lack of publicly available hard data for Scenario 2. For Scenario 1, including an OPEX Vendor price was illogical.

SCENARIO 1

New ACS technology cost 'deltas' - Developer calculation £2017/MW

Corrosion solution savings/cost	Wave	Tidal (shallow)	Tidal (deep)	Fixed Wind	Floating Wind
CAPEX per MW (%)	-33%	-30%	-30%	-26%	-26%
OPEX Per MW (%)	-11%	-9%	-9%	-11%	-11%
Low case savings					
CAPEX (£2017/MW)	1.137	0.996	1.033	0.838	0.696
Annual OPEX (£2017/MW)	0.023	0.013	0.010	0.012	0.008
Mid case savings					
CAPEX (£2017/MW)	1.380	1.181	1.218	0.921	0.723
Annual OPEX (£2017/MW)	0.027	0.017	0.013	0.018	0.010
High case savings					
CAPEX (£2017/MW)	1.583	1.439	1.476	1.087	0.750
Annual OPEX (£2017/MW)	0.033	0.021	0.018	0.024	0.014

Original 2017 CAPEX £/MW used for Vendor value calculations

Corrosion solution value	Wave	Tidal (shallow)	Tidal (deep)	Fixed Wind	Floating Wind
CAPEX per MW (%)	48%	23%	23%	37%	48%
Low case					
CAPEX (£2017/MW)	5.04	3.32	3.44	3.22	4.12
Mid case					
CAPEX (£2017/MW)	6.03	3.94	4.31	3.54	4.33
High case					
CAPEX (£2017/MW)	7.01	4.80	4.92	4.18	4.53

Table 9 – Scenario 1 Developer ‘delta’ savings and vendor value starting values

SCENARIO 2

New ACS technology cost 'deltas' - Developer calculation £2017/MW

Corrosion solution savings/cost	Wave	Tidal (shallow)	Tidal (deep)	Fixed Wind	Floating Wind
CAPEX per MW (%)	0%	0%	0%	0%	0%
OPEX Per MW (%)	-11%	-9%	-9%	-11%	-11%
Low case savings					
CAPEX (£2017/MW)	0.000	0.000	0.000	0.000	0.000
Annual OPEX (£2017/MW)	0.023	0.013	0.010	0.012	0.008
Mid case savings					
CAPEX (£2017/MW)	0.000	0.000	0.000	0.000	0.000
Annual OPEX (£2017/MW)	0.027	0.017	0.013	0.018	0.010
High case savings					
CAPEX (£2017/MW)	0.000	0.000	0.000	0.000	0.000
Annual OPEX (£2017/MW)	0.033	0.021	0.018	0.024	0.014

Original 2017 CAPEX £/MW used for Vendor value calculations

Corrosion solution value	Wave	Tidal (shallow)	Tidal (deep)	Fixed Wind	Floating Wind
CAPEX per MW (%)	21%	9%	9%	14%	21%
Low case					
CAPEX (£2017/MW)	5.04	3.32	3.44	3.22	4.12
Mid case					
CAPEX (£2017/MW)	6.03	3.94	4.31	3.54	4.33
High case					
CAPEX (£2017/MW)	7.01	4.80	4.92	4.18	4.53

Table 10 - Scenario 2 Developer ‘delta’ savings and vendor value starting values

SCENARIO 3

New ACS technology cost 'deltas' - Developer calculation £2017/MW

Corrosion solution savings/cost	Wave	Tidal (shallow)	Tidal (deep)	Fixed Wind	Floating Wind
CAPEX per MW (%)	7%	3%	3%	5%	7%
OPEX Per MW (%)	-11%	-9%	-9%	-11%	-11%
Low case savings					
CAPEX (£2017/MW)	-0.241	-0.100	-0.103	-0.161	-0.187
Annual OPEX (£2017/MW)	0.023	0.013	0.010	0.012	0.008
Mid case savings					
CAPEX (£2017/MW)	-0.293	-0.118	-0.122	-0.177	-0.195
Annual OPEX (£2017/MW)	0.027	0.017	0.013	0.018	0.010
High case savings					
CAPEX (£2017/MW)	-0.336	-0.144	-0.148	-0.209	-0.202
Annual OPEX (£2017/MW)	0.033	0.021	0.018	0.024	0.014

Original 2017 CAPEX £/MW used for Vendor value calculations

Corrosion solution value	Wave	Tidal (shallow)	Tidal (deep)	Fixed Wind	Floating Wind
CAPEX per MW (%)	28%	13%	13%	19%	28%
Low case					
CAPEX (£2017/MW)	5.04	3.32	3.44	3.22	4.12
Mid case					
CAPEX (£2017/MW)	6.03	3.94	4.31	3.54	4.33
High case					
CAPEX (£2017/MW)	7.01	4.80	4.92	4.18	4.53

Table 11 - Scenario 3 Developer ‘delta’ savings and vendor value starting values

To convert 'delta' developer savings and vendor prize value into a 2017 nominal Net Present Value (NPV) - technology installed capacity at the UK-level, and then scaled projections for the wider EU-level, were required. A simplified, conservative 10% discount value was universally selected for the discount rate to reflect the breakthrough status of coupling established corrosion technologies with emerging offshore renewable technologies – in reality, a lower fixed wind discount rate, and higher discount rate for wave reflecting their relative maturities could be applied. All scenario calculations were subject to the same projection multiplication.

Installed capacity projections for the UK and wider EU were obtained from a range of publicly available literature sources, with cross-referenced and actual 2017 installed capacities incorporated. The following capacity projections were used:

- UK Wave/Tidal capacity to 2050: ETI Energy System Modelling Environment (ESME) UK market allocation projection [100], Figure 37. The projection made use of UK fourth carbon budget targets, DECC 2050 low carbon generation predictions and customised parameters that included practical resource limits, transmission grid limits, decreasing CAPEX and OPEX profiles and limits on capacity build outs. This was the most complete and realistic projection available for wave and tidal, suggesting a combined 15 GW installed by 2050, with cross-referenced studies [95] being overly optimistic without these imposed limits. Because the projection was for combined wave and tidal, build out proportion cost allocation per technology were determined using proportions modelled in the BAU-benchmark Ernst & Young/Black & Veatch costs study for wave and tidal as a proxy [95].

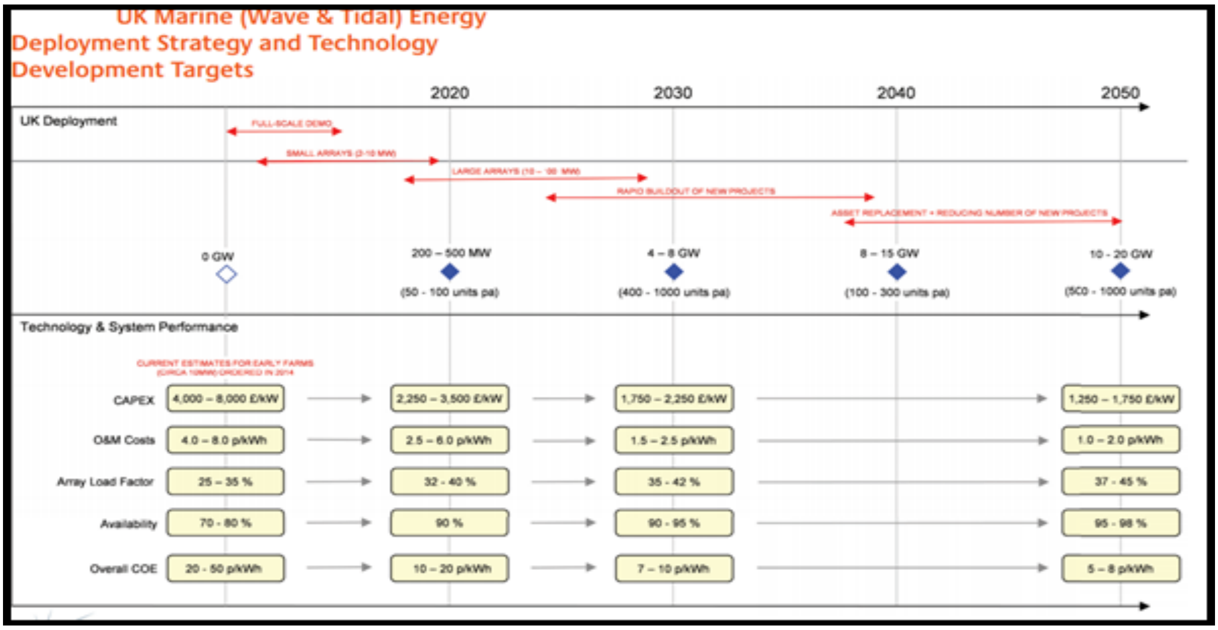


Figure 37 – ETI ESME MARKALL wave and tidal capacity projections for UK [100]

- UK Wind capacity to 2050 (both technologies): Carbon Trust TINA offshore wind summary report also used the ETI ESME UK market allocation model under a similar set of assumptions to the later wave and tidal study [94]. The medium case model forecast was used which predicts 45 GW of offshore UK wind power by 2050. This forecast was cross-checked against a European Wind Energy Association (EWEA) reference [101] and found to be a representative mid case profile. CAPEX and OPEX cost reductions employed a 3% per annum linear reduction, in line with the ORE Catapult's Cost Reduction Monitoring Framework [102], which used data between 2010 and 2014. Beyond 20 GW installed capacity in the UK, it is predicted the need to increasingly move further offshore will favour floating wind technologies, with the ETI expecting that if deployment exceeds 40 GW, than a mid-case 12GW in Scottish waters could be generated from floating wind [94]. Since no publicly available data exists on floating wind projection for the UK alone, the ETI criteria were used to apportion costs between fixed and floating wind in time.

- EU Wave/Tidal to 2050: Very little hard data existed at the EU level for capacity projections. The European Ocean Energy Association (ORECCA report) predicted 188 GW of combined wave and tidal energy capacity by 2050 in place in the EU [103]. It is noted here that this is an aspirational target with a best-fit profile as per Figure 38. Similar UK CAPEX and OPEX annual cost reductions, and technology apportioning were used.

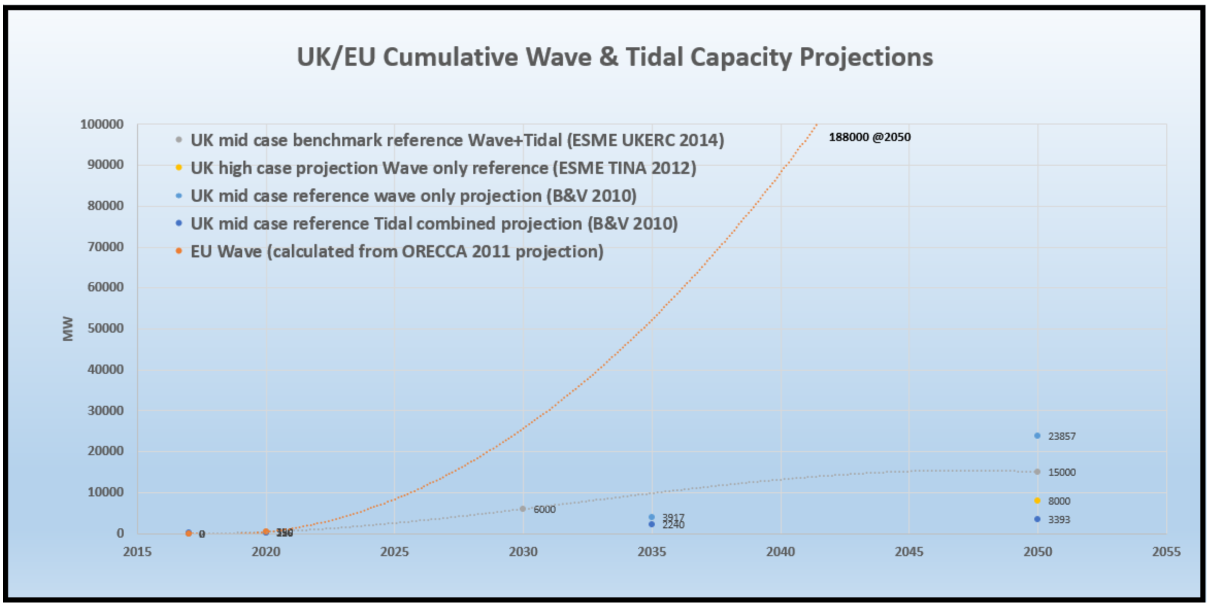


Figure 38 – UK and EU Wave/Tidal Stream projections [100] [104]

- EU Wind to 2050: For wind at the EU level, more data capacity projection data existed. A EWEA study projected 66 GW of offshore wind generation up to 2030 [101]. Between 2030 to 2050 a different EWEA deep water study determined an aspirational target of 460 GW [105] (Figure 39). Similar UK CAPEX and OPEX annual cost reductions, and technology apportioning were used.

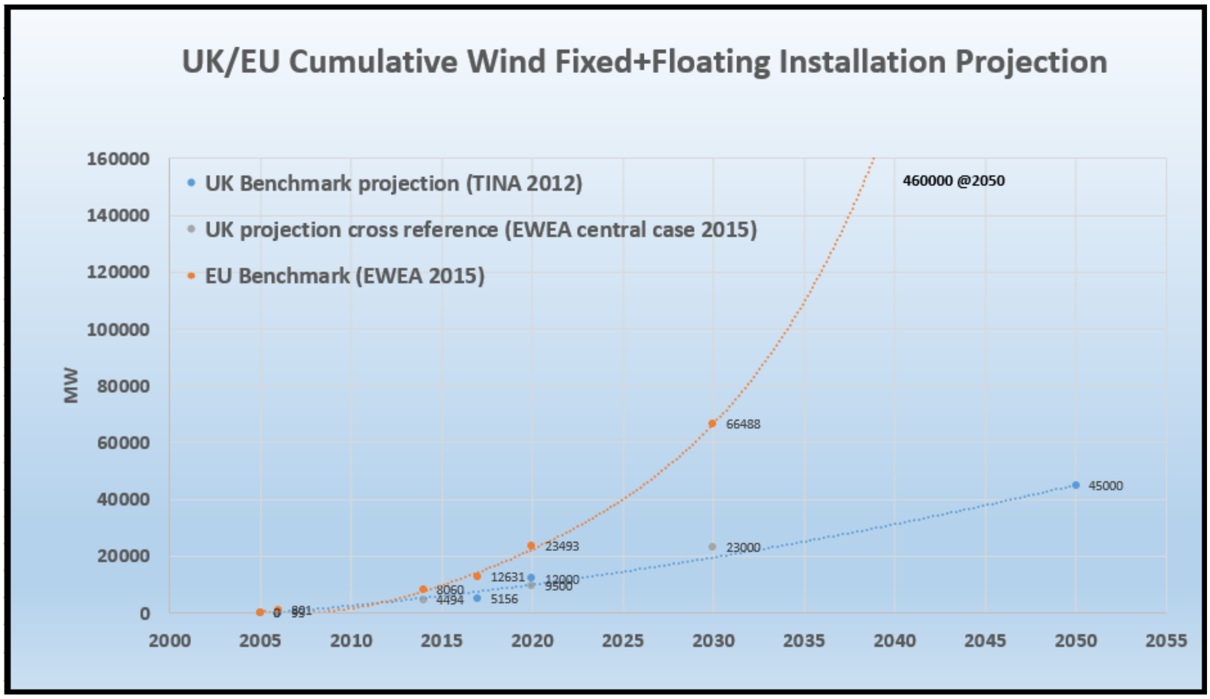


Figure 39 – UK and EU Wind projections [104]

The final step was to couple all UK and EU technology ACS calculations to the capacity projections, to determine total 2017 billion nominal Net Present Value (£) with 10% discount rate (NPV10) estimates for different points in the future –both developer savings (upper table) and vendor prize (lower table). Tables 12, 13 and 14 illustrate the report's Scenario 1, 2 and 3 mid-case results, each of which has a high and low uncertainty range attached.

	SCENARIO 1 - New materials and processes Developers savings		
Wave+Tidal+Fixed Wind+Floating Wind	Projected Installed Capacity		Corrosion solution Developer SAVINGS (NPV10) - £BILLION (NOMINAL)
UK only	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	avg. 30% CAPEX saving per MW by using anti-corrosion materials 18% technical OPEX per MW per year saving from corrosion mitigations performance/availability/reliability maintained - corrosion solutions
Mid case values (2017)			
2020	350	8060	£2.7
2030	6000	19477	£9.2
2050	15000	45000	£12.8
Low/High case Uncertainty % (+/-)			(-17%/+15%)
Wider EU	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	avg. 30% technical CAPEX saving per MW by using anti-corrosion materials 18% technical OPEX per MW per year saving from corrosion mitigations performance/availability/reliability maintained - corrosion solutions
Mid case values (2017)			
2020	350	23493	£10.5
2030	25282	66488	£32.8
2050	188000 (EU-OEA 2010)	460000 (EWEA 2013)	£74.6
Low/High case Uncertainty % (+/-)			(-17%/+15%)

	SCENARIO 1 - New materials and processes Vendor Prize		
Wave+Tidal+Fixed Wind+Floating Wind	Projected Installed Capacity		Corrosion Vendor Potential Value (NPV10) - £BILLION (NOMINAL)
UK only	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	For Wave/Floating Wind, 48% of original technical CAPEX For Tidal, 23% of original technical CAPEX For Fixed Wind, 37% of original technical CAPEX
Mid case values (2017)			
2020	350	8060	£3.3
2030	6000	19477	£11.2
2050	15000	45000	£14.4
Low/High case Uncertainty % (+/-)			(-17%/+17%)
			(Assumes 100% material displacement)
Wider EU	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	For Wave/Floating Wind, 45% of original technical CAPEX For Tidal, 20% of original technical CAPEX For Fixed Wind, 31% of original technical CAPEX
Mid case values (2017)			
2020	350	23493	£13.5
2030	25282	66488	£43.5
2050	188000 (EU-OEA 2010)	460000 (EWEA 2013)	£83.3
Low/High case Uncertainty % (+/-)			(-17%/+16%)

		SCENARIO 1 - Corrosion solution Developer SAVINGS and Vendor POTENTIAL VALUE (NPV10) - £MILLION (NOMINAL) and Projected Installed CAPACITY											
		Wave			Tidal			Fixed wind			Floating wind		
Mid case values (2017)		Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW
UK	2020	96.4	196.4	143	112.4	86.4	207	2,483.3	2,987.0	7,951	24.4	54.5	109
	2030	722.8	1,381.3	3,110	815.2	602.9	2,890	7,321.2	8,630.6	17,469	382.0	549.5	2,008
	2050	1,317.1	2,157.3	13,132	1,027.6	750.1	1,868	9,141.4	10,419.7	35,537	1,344.7	1,038.5	9,463
EU	2020	116.2	236.7	213	90.2	69.5	137	10,244.0	13,070.5	23,378	32.4	75.4	115
	2030	4,960.7	9,571.5	21,332	987.8	738.8	3,950	23,779.5	29,134.5	51,166	3,051.1	4,083.3	15,322
	2050	12,332.4	21,013.8	161,225	1,886.7	1,389.2	26,775	38,720.3	46,670.4	346,920	21,632.7	14,220.8	113,080

Table 12 – Scenario 1 Developer's savings/cost and Vendor prize using new ACS technology, shown as all markets combined (upper tables) and the separate markets (lower tables)

Wave+Tidal+Fixed Wind+Floating Wind	SCENARIO 2 - Direct Corrosion Solutions Developers savings		
	Projected Installed Capacity		Corrosion solution Developer SAVINGS (NPV10) - £BILLION (NOMINAL)
UK only	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	0% increase of total CAPEX spent per MW by using new anti-corrosion solutions 18% technical OPEX per MW per year saving from corrosion mitigations performance/availability/reliability maintained - corrosion solutions
Mid case values (2017)			
2020	350	8060	£0.4
2030	6000	19477	£1.4
2050	15000	45000	£2.5
Low/High case Uncertainty % (+/-)			(-31%/+24%)
Wider EU	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	0% increase of total CAPEX spent per MW by using new anti-corrosion solutions 18% technical OPEX per MW per year saving from corrosion mitigations performance/availability/reliability maintained - corrosion solutions
Mid case values (2017)			
2020	350	23493	£1.1
2030	25282	66488	£4.1
2050	188000	460000	£11.2
Low/High case Uncertainty % (+/-)			(-31%/+24%)

Wave+Tidal+Fixed Wind+Floating Wind	SCENARIO 2 - Direct Corrosion Solutions Vendor prize		
	Projected Installed Capacity		Corrosion Vendor Potential Value (NPV10) - £BILLION (NOMINAL)
UK only	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	For Wave/Floating Wind, 21% of original technical CAPEX For Tidal, 9% of original technical CAPEX For Fixed Wind, 14% of original technical CAPEX
Mid case values (2017)			
2020	350	8060	£1.3
2030	6000	19477	£4.3
2050	15000	45000	£5.6
Low/High case Uncertainty % (+/-)			(-16%/+15%)
Wider EU	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	For Wave/Floating Wind, 21% of original technical CAPEX For Tidal, 9% of original technical CAPEX For Fixed Wind, 14% of original technical CAPEX
Mid case values (2017)			
2020	350	23493	£5.1
2030	25282	66488	£17.3
2050	188000 (EU-OEA 2010)	460000 (EWEA 2013)	£33.6
Low/High case Uncertainty % (+/-)			(-16%/+15%)

	SCENARIO 2 - Corrosion solution Developer SAVINGS and Vendor POTENTIAL VALUE (NPV10) - £MILLION (NOMINAL) and Projected Installed CAPACITY												
		Wave			Tidal			Fixed Wind			Floating Wind		
Mid case values (2017)		Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW
UK	2020	2.7	85.9	143	2.9	32.2	207	264.2	1,130.2	7,951	2.0	23.8	109
	2030	63.9	604.3	3,110	49.7	224.7	2,890	863.8	3,265.6	17,469	48.9	240.4	2,008
	2050	288.0	943.8	13,132	74.6	279.5	1,868	1,250.9	3,942.6	35,537	242.2	454.4	9,463
EU	2020	3.3	103.6	213	2.1	25.9	137	728.3	4,945.6	23,378	2.0	33.0	115
	2030	394.7	4,187.6	21,332	50.3	275.3	3,950	2,273.3	11,023.9	51,166	296.6	1,786.4	15,322
	2050	2,307.9	9,193.6	161,225	122.5	517.7	26,775	4,073.3	17,659.1	346,920	2,223.3	6,221.6	113,080

Table 13 – Scenario 2 Developer’s savings/costs and Vendor prize using new ACS technology, shown as all markets combined (upper tables) and the separate markets (lower tables)

	SCENARIO 3 - Direct Corrosion Solutions Developers savings		
Wave+Tidal+Fixed Wind+Floating Wind	Projected Installed Capacity		Corrosion solution Developer SAVINGS (NPV10) - £BILLION (NOMINAL)
UK only	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	10% increase of total CAPEX spent per MW by using new anti-corrosion solutions 18% technical OPEX per MW per year saving from corrosion mitigations performance/availability/reliability maintained - corrosion solutions
Mid case values (2017)			
2020	350	8060	-£0.05
2030	6000	19477	-£0.04
2050	15000	45000	£0.5
Low/High case Uncertainty % (+/-)			(-445%/+299%)
Wider EU	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	0% increase of total CAPEX spent per MW by using new anti-corrosion solutions 18% technical OPEX per MW per year saving from corrosion mitigations performance/availability/reliability maintained - corrosion solutions
Mid case values (2017)			
2020	350	23493	-£0.7
2030	25282	66488	-£1.6
2050	188000	460000	-£2.5
Low/High case Uncertainty % (+/-)			(-76%/+142%)

	SCENARIO 3 - Direct Corrosion Solutions Vendor prize		
Wave+Tidal+Fixed Wind+Floating Wind	Projected Installed Capacity		Corrosion Vendor Potential Value (NPV10) - £BILLION (NOMINAL)
UK only	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	For Wave/Floating Wind, 28% of original technical CAPEX For Tidal, 13% of original technical CAPEX For Fixed Wind, 19% of original technical CAPEX
Mid case values (2017)			
2020	350	8060	£1.7
2030	6000	19477	£5.9
2050	15000	45000	£7.6
Low/High case Uncertainty % (+/-)			(-16%/+15%)
Wider EU	Wave & Tidal (Shallow+Deep) MW	Wind (Fixed + Floating) MW	For Wave/Floating Wind, 28% of original technical CAPEX For Tidal, 13% of original technical CAPEX For Fixed Wind, 19% of original technical CAPEX
Mid case values (2017)			
2020	350	23493	£6.9
2030	25282	66488	£23.3
2050	188000 (EU-OEA 2010)	460000 (EWEA 2013)	£45.3
Low/High case Uncertainty % (+/-)			(-16%/+15%)

		SCENARIO 3 - Corrosion solution Developer SAVINGS and Vendor POTENTIAL VALUE (NPV10) - £MILLION (NOMINAL) and Projected Installed CAPACITY											
		Wave			Tidal			Fixed wind			Floating wind		
Mid case values (2017)		Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW	Developer saving NPV10 - £M	Vendor value NPV10 - £M	Capacity MW
UK	2020	-17.2	114.6	143	-8.0	46.5	207	-19.4	1,533.9	7,951	-3.4	31.8	109
	2030	-75.9	805.8	3,110	-26.6	324.5	2,890	90.1	4,431.9	17,469	-23.0	320.5	2,008
	2050	69.7	1,258.4	13,132	-20.3	403.8	1,868	411.4	5,350.7	35,537	33.2	605.8	9,463
EU	2020	-20.7	138.1	213	-6.7	37.4	137	-707.0	6,711.9	23,378	-5.5	44.0	115
	2030	-573.9	5,583.4	21,332	-43.2	397.7	3,950	-630.5	14,961.0	51,166	-337.4	2,381.9	15,322
	2050	181.5	12,258.1	161,225	-53.3	747.8	26,775	-382.0	23,965.9	346,920	-2,196.1	8,295.5	113,080

Table 14 – Scenario 3 Developer's savings/costs and Vendor prize using new ACS technology, shown as all markets combined (upper tables) and the separate markets (lower tables).

The developer saving and vendor prize for employing new materials and processes in their offshore renewable energy devices/arrays is larger than simply adding direct corrosion solutions to existing marine steel structural materials. As expected, both Scenario 1 and 2 of new ACSs show considerable worth on a UK and EU forward basis to developers and supply chain vendors – as CAPEX is either reduced or equal to the BAU scenario and OPEX is reduced. Fixed wind energy provides by far the largest savings to developers, and potential value to the vendors, followed by wave energy.

However, in Scenario 3, where the implementation of the new ACS comes with an additional 10% of modified CAPEX cost to the developer, a negative saving is encountered – meaning a cost to the developer. In the cases of wave and floating wind in the UK, and wave and fixed wind in the wider EU, a tipping point is reached after 2030. After this point, the cost reduction of OPEX outweighs the cost of the new installed capacity. This even leads to a developer saving by 2050. For tidal energy in the UK and the wider EU, the additional cost to the CAPEX does not outweigh the benefits of the reduced OPEX, which is relatively low for tidal energy – there is no tipping point within the investigated timeframe. For this scenario, the corrosion solution does not lead to a developer saving in the wider EU, which can be attributed to the lack of corrosion impact on the performance in the BAU case. The large uncertainty of the high and low case for this third scenario can be attributed to the difference in the tipping point location for these cases.

The overall combined market numbers in 2017 NPV10 terms applicable to offshore renewable technology developer savings and vendor supply chain prizes are as follows (based on an installed ocean and wind capacity of 26 GW in the UK and 92 GW in the wider EU by 2030 and 60 GW and 650 GW by 2050 in the UK and wider EU respectively):

- Scenario 1: New Materials and processes with both CAPEX and OPEX reduced relative to BAU
  - By 2030, Developer's savings with a NPV10 of £9.2bn and £32.8bn will be possible in the UK and wider EU, respectively.
  - By 2050, Developer's savings with a NPV10 of £12.8bn and £74.6bn will be possible in the UK and wider EU, respectively.
  - By 2030, Vendor supply chain values with a NPV10 of £11.2bn and £33.6bn will be available in the UK and wider EU, respectively.
  - By 2050, Vendor supply chain values with a NPV10 of £14.4bn and £83.3bn will be available in the UK and wider EU, respectively.

- Scenario 2: Direct Corrosion Solutions with the BAU CAPEX and reduced OPEX relative to BAU
  - By 2030, a Developer's savings with a NPV10 of £1.4bn and £4.1bn will be possible in the UK and wider EU, respectively.
  - By 2050, a Developer's savings with a NPV10 of £2.5bn and £11.2bn will be possible in the UK and wider EU, respectively.
  - By 2030, a Vendor supply chain value with a NPV10 of £4.3bn and £17.3bn will be available in the UK and wider EU, respectively.
  - By 2050, a Vendor supply chain value with a NPV10 of £5.6bn and £33.6bn will be available in the UK and wider EU, respectively

- Scenario 3: Direct Corrosion Solutions with CAPEX increased and OPEX reduced relative to BAU
  - By 2030, the Developer will have an additional cost with a NPV10 of £0.04bn and £1.6bn in the UK and wider EU, respectively.
  - By 2050, the Developer will have an additional cost with a NPV10 of £2.5bn in the wider EU. Whereas in the UK, due to surpassing the balance point between the cost of CAPEX and OPEX, there will be a Developer's savings with a NPV10 of £0.5bn.
  - By 2030, Vendor supply chain values with a NPV10 of £5.9bn and £23.3bn will be available in the UK and wider EU, respectively.
  - By 2050, Vendor supply chain values with a NPV10 of £7.6bn and £45.3bn will be available in the UK and wider EU, respectively.

Validating these headline figures is challenging given the lack of direct comparisons. Some limited data however do exist. The calculations in this report are 2017 nominal term NPV10 numbers; yet it is worth comparing them to available market data to ensure they represent realistic outputs for real world offshore sector vendor markets.

Direct corrosion solutions include coating, paints and inhibitors – a market research report estimated these solutions in 2015 were worth to the global oil and gas industry a market value of USD $8Bn, with an expected CAGR of 4.3% and future market size in 2025 of USD $12.2Bn [106] (or $15Bn in 2030 using the same CAGR). If we compare the Scenario 1 estimate on an EU-wide basis for these direct corrosion solutions, in 2030 the model estimated an NPV10 of £17Bn vendor market value to the offshore renewables industry.

Obtaining a relevant new materials market valuation is even harder because of the range of materials and processes under consideration for 100% displacement in NeSSIE. However, a comparison of marine component markets can be made in order to understand their magnitude. For example, marine propellers made from aluminium, bronze and stainless steel for all vessels had an estimated global market value of USD$3.7Bn in 2015, and projected 2020 value of USD$6Bn [107]. At the other end of the maritime market scale, Figure 46 in Annex III displays a breakdown of EU-wide products and services on an average basis between 2006 and 2010 in the marine supplies industry [108]. The marine supplies industry participates in a widely diversified market, including shipbuilding, offshore oil and gas, offshore wind, subsea infrastructure, etc., in public and private domains and in organisations of various sizes. EU28 suppliers on average annually served €52.5Bn of global demand, with NSB region countries making up 75% of the production volumes (UK, Germany, Italy, Netherlands and France). Figure 46 further splits its estimates, paints/coatings make up €1.3Bn and aggregated materials (steel, other), steel products and mechanical engineering make up €23.9Bn. Across the EU (as well as Norway and Turkey), the marine supplies industry employed 451,000 people across 30,000 companies. It is envisioned that the new materials/processes and direct corrosion solutions industry sector in the future will be of a comparable size, with EU projections stating wind power alone could provide 50% of the entire EU's electricity supply by 2050 [109].

This report's vendor revenue estimates could be considered optimistic compared to the market research. Without knowing the full calculation assumptions which went into the other market research estimations, this comparison is however problematic. Additionally, offshore renewables device corrosion is a far more important factor given submersed dynamic movement is paramount for efficient generation compared to static structures in oil and gas production. What can be concluded is that this report's calculated market value estimates are of the same order of magnitude as the limited wider EU market data described above, allowing a certain confidence in the valuations.

6.8. Limitations to economic estimates

Although an uncertainty range has been included in the estimates, a range of literature sources researched, and a 2017 offshore renewable cost sense check undertaken, there are limits to the estimate - as with any forecast. A concise list of the main estimate uncertainty components includes:

- Capacity projections: ESME market allocations modelling data was used which incorporates a wide range of technical and financial parameters in the UK to improve the forecast. However, future government policy, public opinion towards electrical generation/demand and technology development, to name but a few factors, will all heavily influence capacity build out rates. At EU-level, the forecast is even more uncertain given the lack of detail in the renewables target.

- Cost changes: The CAPEX and OPEX used in this report were of various vintages, with commercial wind expenditures rapidly changing on an annual basis. Figure 40 illustrates the difficulty in using a simple technology cost decline function over time – historically offshore wind CAPEX has followed the easiest location, nearshore cheaper shallow sites firstly, before location limitations and better resource harnessing dictate a move to deeper waters and higher expenditures [96]. Future cost prediction is therefore inherently uncertain.
- All WEC, TEC and Wind turbine device were assumed to be generic and fall within the researched OPEX and CAPEX ranges. In reality, only offshore fixed wind turbines have achieved full design convergence, and hence there is also a regional semblance of competitive market technology cost convergence.

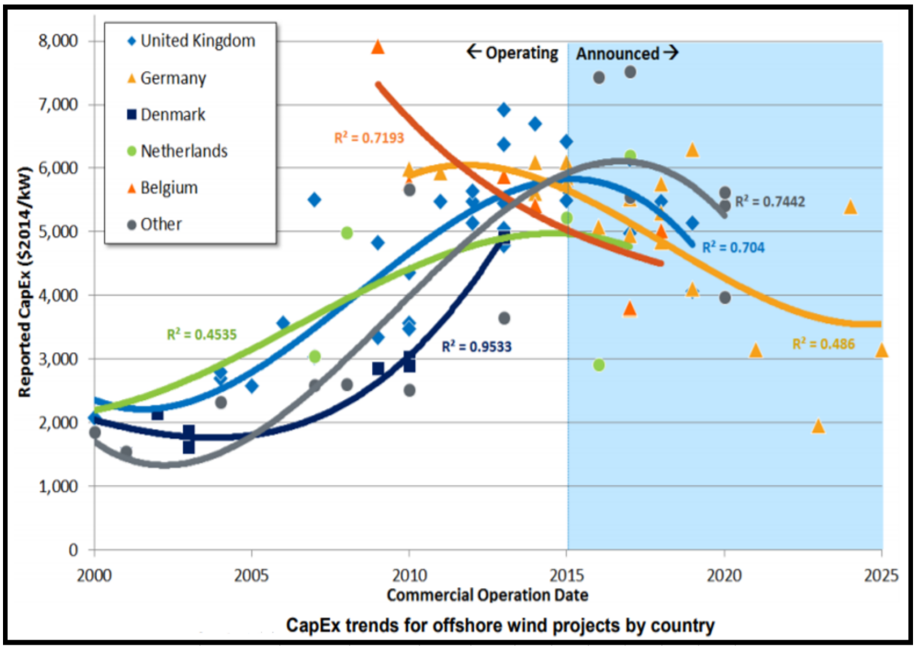


Figure 40 – Historical versus future offshore wind CAPEX variations [96]

The absolute forecasted estimates determined in this report should not be used literally, but instead be used as an indicator that a positive and potentially lucrative market for new materials/processes and direct corrosion solutions coupling to offshore renewable energy devices does indeed exist. Developers can act to reduce costs and increase competitiveness, whilst cross-industry sector vendors can recognise that a market does exist outside of their normal operating markets.

7. UK/EU wide offshore renewable energy status and outlook

> Key messages
>
> NeSSIE can play a significant role in the goal of moving marine renewables towards commercialisation; exerting a potentially significant influence on and taking advantage of the key technology action areas as identified by Ocean Energy Forum (development of phase gate validation, innovative financing and insurance solutions, de-risking of environmental consenting).

To conclude this report, a brief review of the key points surrounding the current and future development status of offshore wave, tidal and wind deployment in the UK and wider EU will be included. The intention is to enlighten people working outside of the renewables sector of the key development challenges, which are largely similar on a regional basis. Additionally, research carried out to date on cross industry supply chain diversification in the offshore renewables sector will also be summarised to better inform both developers and vendors as to how cross-industry skills transfer is being actively managed and encouraged. The identified development challenges can also be used to frame DCS and NM NeSSIE solutions through demonstration projects that lie at the heart of current developer challenges with a view to encouraging project collaboration.

7.1. Existing research into UK/EU offshore renewables deployment – NeSSIE integration

The most relevant document to summarise and inform the current outlook on the future of ocean energy, and how NeSSIE can be integrated into it, is the recently published Ocean Energy Forum's 'Ocean Energy Strategic Roadmap' [110]. Leading from an EU perspective – which is currently shared by the UK -it suggests ocean energy is set to play an important role in the Union's transition away from fossil fuel electricity generation, to help meet greenhouse gas emissions reductions of 80-95% below 1990 levels by 2050. The EU is a world leader in ocean energy and the market opportunity to supply global supply chains exists to significantly benefit the EU economy. According to the 2016 JRC Ocean Energy Status report [109], Europe hosts 52% of tidal stream, and 60% of wave developers globally, but installations are occurring at a slow pace - with only 14MW of ocean energy capacity by the end of 2016 installed from a National Renewable Energy Action plan sum of 641 MW. There is no lack of projects in the pipeline (planned tidal stream and wave projects in Europe by 2020 amount to 600 MW and 65 MW respectively), and if funding approval is taken into account the planned installation amounts to 71 MW and 37 MW by 2020 respectively [109]. There is no doubt however that there is a strong commitment from the EU to develop ocean energy, as described in the OEF Roadmap.

Ocean energy technologies (wave, tidal stream, tidal range, OTEC, salinity gradient) are at varying stages of development across Europe, and far more juvenile than offshore wind, and hence would require a different approach to integration within NeSSIE. If ocean technologies are to develop through the various R&D, prototyping, demonstration, pre-commercial phases to commercialisation, they all face similar technological, financial and regulatory challenges. Through the ETIP ocean knowledge-sharing platform, industry experts have identified several priority areas to develop technologies along the strategic roadmap:

- Testing sub-system components/devices in real sea conditions.
- Increasing reliability and performance of ocean energy devices.
- Stimulating a dedicated installation and operation and maintenance value chain.
- Delivering power to the grid via hubs.
- Devising standards and certification, to facilitate access to commercial financing.
- Reducing costs and increasing performance through innovation and testing.

Both DCS and NM corrosion solutions will directly affect reliability and performance, supply chain development, standards development and cost reductions through performance enhancements. NeSSIE is well placed to answer the technical priority needs of ocean energy developers.

The OEF Roadmap puts forward four key action plans to smoothen transition between the development phases and into full industrial commercialisation –NeSSIE can position itself to take advantage of these ocean energy actions:

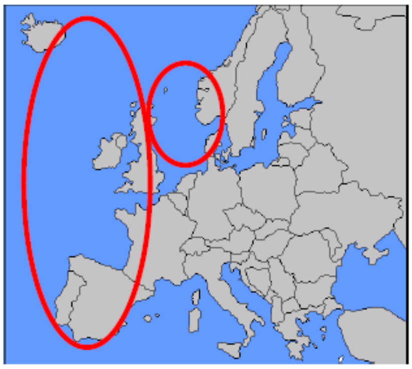
- (1) Industry and EU member States are to establish a recognised and agreed-upon phase gate development scheme to validate subsystems and early prototypes to enhance public funding accessibility through trusted standards applications:
    - Existing offshore cross sector standards and certifications processes for materials selection, fabrication, and manufacturing and corrosion management could be adapted and transferred into the marine renewables realm.

- (2&3) Innovative financing and insurance solutions should bridge the gap between demonstration and pre-commercial phases. Uncertainties in performance levels and maintenance requirements at the larger scale deter potential investors once single device testing is completed. Perceived risks prevent access to commercial bank loans and private equity investments. The OEF roadmap therefore suggests two innovative funding instruments; an Insurance and Guarantee Fund, and an Investment Support Fund.
    - NeSSIE's technology corrosion solutions are principally aimed at ensuring continued device/array performance levels are maintained, and hence directly acting to reduce perceived production risks, and therefore improve funding attractiveness. Cross-sector corrosion management monitoring, assessment and repair systems could be directly translated to marine devices as a performance drop mitigation tool. Equally, corrosion resistant new materials integrated into early device design phase stages, if demonstrated at sea to be effective for a single device will again directly appeal to funding support through reliability and risk mitigation.

- (4) De-risking of environmental consenting by an integrated programme of measures to develop guidance on planning, consenting, research, socio-economic and demonstrations to share best practice and streamline processes.
    - Future ocean energy deployment must be environmentally benign and local supply

chains included in smoothening the technologies' pathway to growth. NeSSIE has regionally focused consortia of local industries and a remit to diversify existing in-place knowledge and expertise over to ocean renewables to sustain their communities' long-term growth prospects. The selected demonstration projects will aim to practically define the optimum method of adhering to EU and national development licensing and environmental standards, and identify gaps that need to be addressed and the most efficient decision making process.

The ORECCA European offshore renewable energy roadmap [111] states that across Europe approximately 80% of the combined wave and wind resource is in water depths greater than 60m, with 50% greater than 100km offshore. Deeper water and further afield offshore wave and floating wind developments will be necessary to access these to achieve Europe's low carbon generation targets, particularly in sea basins outside of the NSB region (Figure 41). Growth outlooks for offshore renewables to achieve earlier target projections is technically feasible and local supply chains will need enabling to support these developments.



The roadmap identified two principal 'hotspots' where a large amount of high intensity combined resource (across offshore wind, wave and tidal energy) exists in Europe:

- The Western facing Atlantic coastline, off the coasts of Scotland, the UK, Ireland, Spain and Portugal.
- The Northern North Sea, off the coasts of Norway and the UK.

Figure 41 – ORECCA combined ocean and wind resource map potential across Europe [111]

The status of offshore wind energy, along with NeSSIE's aims, align differently with ocean energy systems. The most up-to-date outlooks relating directly to offshore wind in Europe were taken from Wind Europe's 'Unleashing Europe's offshore wind potential' [112] baseline scenario (Figure 42) - which limits the 2030 target to 64 GW based upon technical resource potentials and LCOE cost reductions, or 7-11% of the EU's electricity demand. Floating wind by 2030 makes up 14% of the economically attractive resource potential, but in the upside scenario 70% compared to fixed foundation types. Offshore wind in the UK alone is predicted to meet 35% of the UK's electricity demand by 2030 [113].

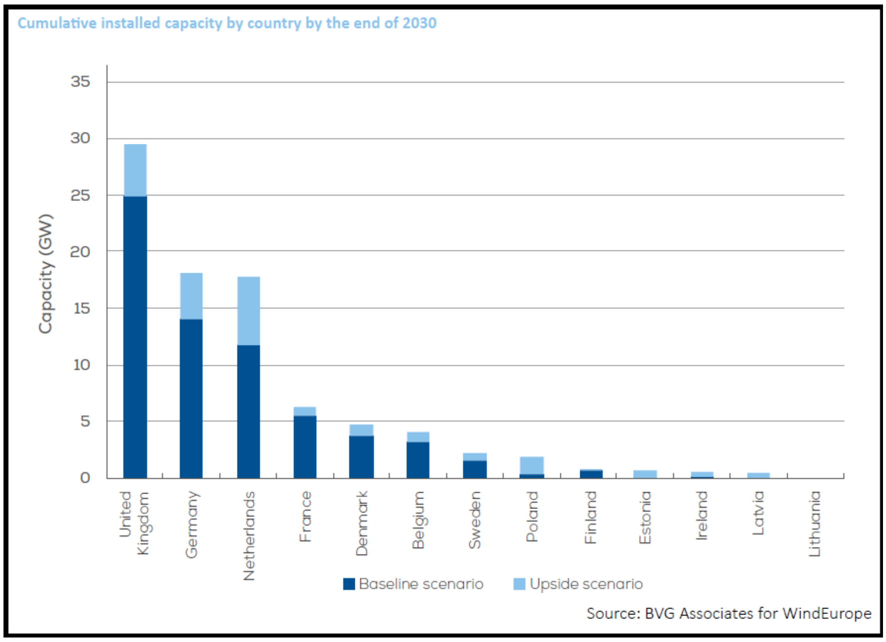


Figure 42 – Cumulative installed capacity by country up to 2030 [113]

Concerning the barriers and challenges to offshore wind energy (OWE) development, the NSB region can be considered a typical location example of relevance to the wider EU area. It currently has the world's highest currently installed wind capacity. Amongst the many offshore wind roadmaps produced, the WINDSPEED project 2011 roadmap [114] provided a good technical summary of the key challenges and the actions to overcome them using a range of competing marine spatial planning issue deployment scenarios in the NSB region to assess potential (Figure 43).

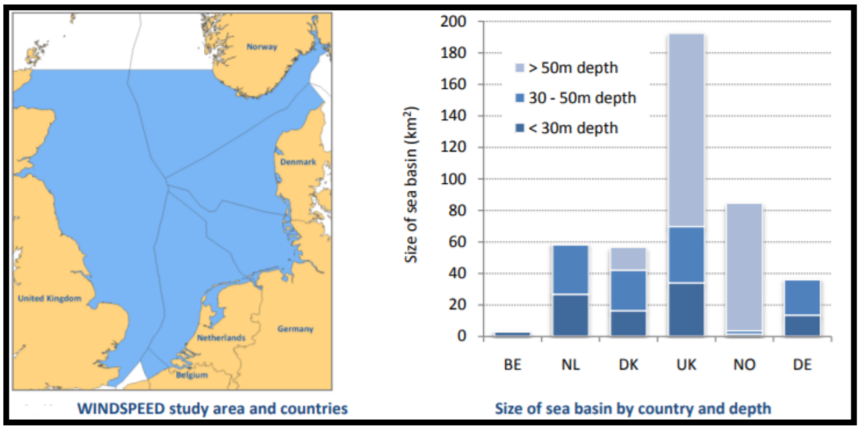


Figure 43 – WINDSPEED project NSB study region and sea basin sizes [117]

WINDSPEED looked at two main aspects of OWE deployment: competing sea space and technology development. Taking a competing sea space perspective for the NSB region differs from other roadmaps and offers an interesting overlapping view of how OWE and ocean energy share commonalities with other cross-sector industries and their supply chains. Spatially, governments deploying renewable energy technologies will need to balance low cost generation versus non-generation sea usages such as shipping, fisheries, military areas, cabling, pipelines, oil and gas extraction, sand extraction and the natural environment – all having a different, and annually varying situational presence. NeSSIE offers the opportunity to identify established NSB regional supply chains and any integrated planning synergies with competing sea users facing similar cost reduction pressures, corrosion offshore and environmental planning issues and leverage against ambitious OWE and ocean renewables deployment targets.

Although fixed OWE can be considered a fully commercial technology, there are many technical aspects ranging from component design, installation techniques and O&M methods that are continually evolving and which reflect the changing market in terms of water depths, distance offshore, array scale and electricity delivery costings. The main technical challenges compared to onshore wind identified are; fixed foundation depth constraints, corrosion, O&M cost penalties relating to reliability, safe weather working windows and accessibility, large distances to grid connection points and limited environmental impact knowledge. As identified previously in Figure 38, unexpectedly the cost decline associated with up-scaled economies of OWE scale over the past decade has failed to materialise, and the situation has arisen because of rising global material and labour costs, exchange rate movements, turbine price increases, supply chain constraints and planning/consenting delays (Greenacre et al. 2010). As developers are pushed into deeper waters further from shore, it also has repercussions for energy costs. NeSSIE is uniquely placed to directly impact OWE build-out in key financial areas: LCOE, CAPEX and OPEX reductions through novel materials and corrosion solutions improving performance maintenance and reducing O&M time. In addition, the diversification of existing supply chains across offshore renewables will act to ease supply chain constraints and dampen price fluctuations, with developers having a more competitive selection of vendors to approach for corrosion solutions.

7.2. UK supply chain diversification into renewables case study

Through diversification, established offshore materials/processes and corrosion solution suppliers can build new revenue streams, capabilities and respond more efficiently to changing market demands and costs. Scottish Enterprises 'Oil and Gas diversification opportunities' [115] report is a good example of how established supply chains are being encouraged to diversify into the growing offshore renewables markets, and one that could be applied to regional consortia elsewhere across the wider EU. The guide is split into three sections:

1) An oil and gas industry shared similarities industry sector analysis (Figure 44), offering relative market size diversification opportunities. Broad oil and gas supply chain capabilities could potentially be applied to other sector development challenges, based upon degrees of technical crossover, defined market new entrant accessibility, growth rates and sizes.
    - The largest oil and gas diversification opportunities based on this study were in the areas of decommissioning and offshore wind, with commercialisation of wave and tidal energy noted as an important opportunity.
2) The industry cross-sector analysis results were then cross-referenced with intra upstream oil and gas industry segment skills – intra expertise segments included reservoir, wells, facilities, subsea and support skills.
    - Below water supply chain activities like subsea engineering and controls systems were highlighted as a key strength area, as well as above water topsides design, installation,

and support logistics. All have transferrable capabilities to other offshore areas like wind, wave and tidal.

3) Long-term corporate strategy diversification models were designed, and were shown in Figure 45, these include:
    - **Direct sales** of product and services in short term (although deemed exceptional).
    - **Product/Service** department develops a targeted product/service after a specific opportunity is identified.
    - **Targeted Recruitment/Acquisition** of individuals or businesses to better understand new sector enabling synergy development.
    - **Alliance/Partnerships** are identified with mutual benefits through collaboration that would not have been possible on their own.
    - **Establish subsidiary** if confident or affluent enough to enable targeted and focused product and service development without the diversion of normal oil and gas activities.
    - **Partner/Subcontract** by identifying another oil as gas supply chain company active in new sector with whom synergies exist to pull through new products.
    - **Collaborative group creation** with other SME's to create compelling new sector offers.
    - **Mutual support exchange** if a new sector business is willing to provide mutual exchange support to an oil and gas company wanting into the new sector also.

Using this introductory analysis, Scottish Enterprise then goes on to offer further service support to encourage business to seek out diversification opportunities. This model provides a good template for diversification that could be applied to other established offshore industries in any other European sea basin.

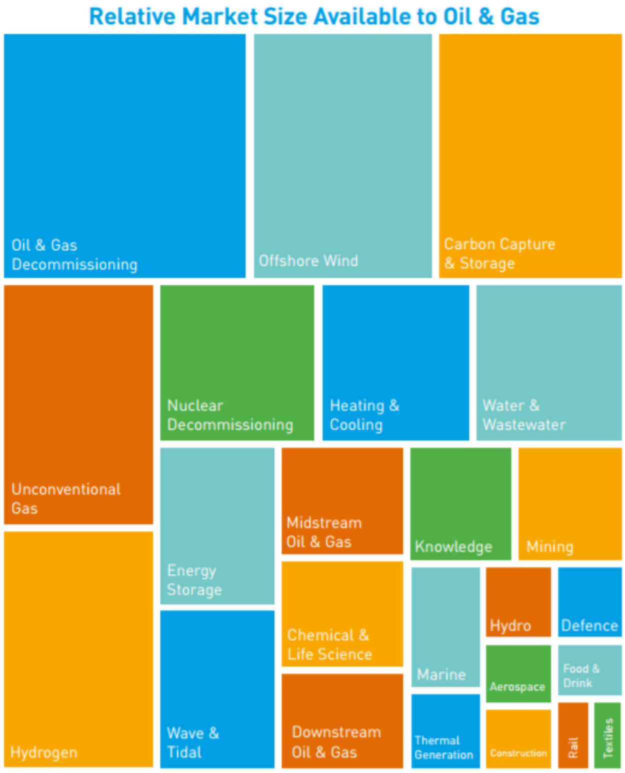
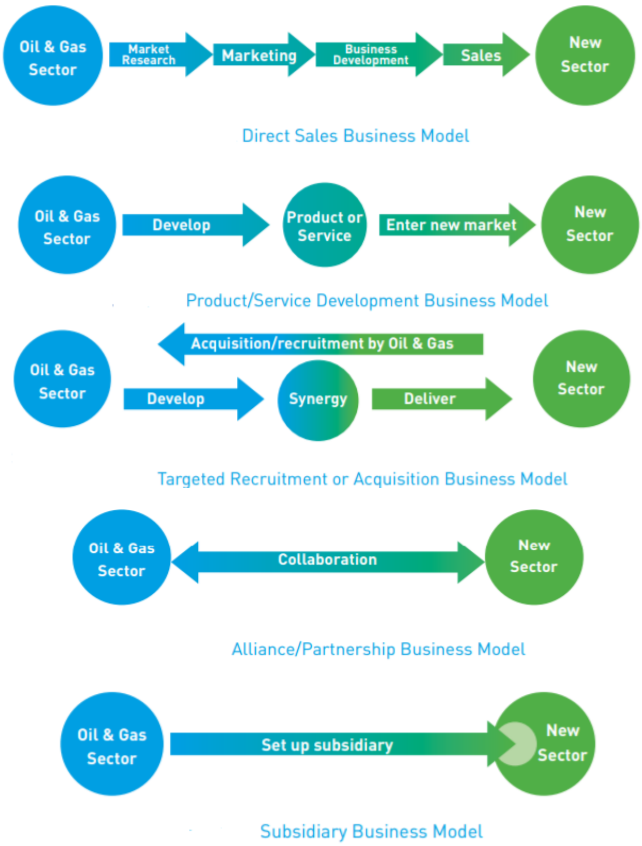


Figure 44 – Relative market size sectors available for oil and gas diversification



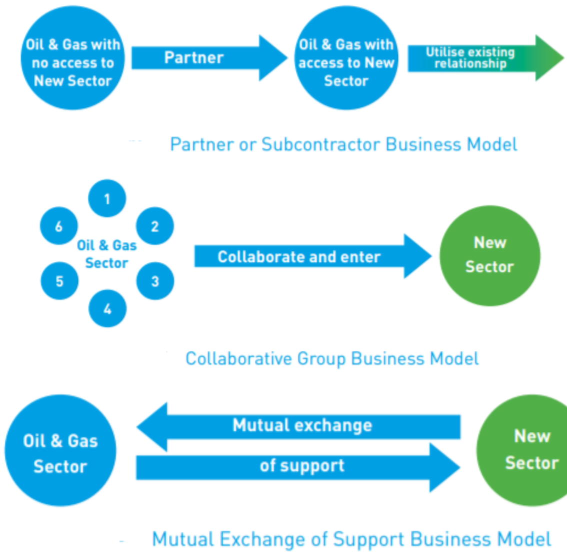


Figure 45 – Scottish Enterprise Oil and Gas diversification models [115]

8. Concluding remarks

This report was designed as an introduction to the problems caused by corrosion in existing offshore industries, and the opportunity that existing expertise presents to emerging offshore renewable generation technologies on a qualitative and quantitative basis. Through an introduction of what corrosion actually is and how it is currently managed, the report progressed through examples of how corrosion has been researched within emerging wave, tidal and wind resource technologies from a novel material and direct corrosion solution perspective. It then moves on to identify relevant supply chains able to source new materials and direct corrosion solutions, along with NSB region based real world stakeholders. For developers, the primary new materials and corrosion management requirements are realising cost reductions and ensuring array performance levels. For vendor supply chains, they need to better understand corrosion solutions diversification opportunities. The potential value to each was quantified logically and referenced to real world market data comparisons. A brief snapshot of the importance that Europe places on wind, wave and tidal technologies was then explained, along with each technology's current development barriers and challenges. Finally, a small diversification case study highlighted how through NeSSIE, an established offshore industry could possibly diversify into emerging offshore renewable generation.

The report was intended as a synopsis only, not an in depth offshore corrosion and materials diversification study. Developers and vendors interested in collaborating with the demonstration projects will possess their own individual and specialist bespoke knowledge, in their particular market product or service and generation device areas. Later work packages will facilitate this external input to the project.

The mission goal of NeSSIE is to "tap into the existing knowledge of novel materials and direct corrosion solutions in established offshore supply chains to develop demonstration projects that will benefit the growing offshore renewables sector in the North Sea Basin region. The solutions, when demonstrated and commercialised, will provide global growth and job creation opportunities across the wider EU". What this report has researched and proven is that there is a quantifiable benefit to all parties, and capabilities on both sides of the corrosion solution equation, and the support mechanisms to facilitate materials and corrosion expertise transfer between sectors.

9. Annex I

Company category	Staff headcount	Turnover	or	Balance sheet total
Medium-sized	< 250	≤ € 50 m		≤ € 43 m
Small	< 50	≤ € 10 m		≤ € 10 m
Micro	< 10	≤ € 2 m		≤ € 2 m

Table 15 - EU SME definition 'recommendation 2003/361'

Metallic Materials

Generic type	UNS	Typical alloy composition			
		% Cr	% Ni	% Mo	others
Carbon and low alloy steels					
235[1]					
235LT					
360LT					
3.5% Ni			3.5		
Martensitic stainless steels					
13Cr		13			
13Cr 4Ni		13	4		
SM13Cr		12	6	2	C<0.015%
S13Cr		12	6	2	
17 - 4 PH	S17400	17	4		
Austenitic stainless steels					
310	S31000	25	20		
316	S31600	17	12	2.5	C<0.035
6Mo	S31254 N08925 N08926 N08367	20 20 20 21	18 25 25 24	6 6 6 6	N=0.2 Cu=1, N=0.2 N min. 0.15 N=0.2
904	N08904	21	25	4.5	Cu=1.5
Superaustenite	S34565	24	17	4-5	Mn=6 N=0.40-0.60
Duplex stainless steels					
22Cr	S32205 S31803	22	5.5	3	N
25Cr	S32550 S32750 S32760	25 25 25	5.5 7 7	3.5 3.5 3.5	N N N
Nickel base alloys					
Alloy C22	N26022	21	rem.	14	W=3
Alloy C-276	N10276	16	rem.	16	W=4
Alloy 625	N06625	22	rem.	9	Nb=4
Alloy 718	N07718	19	53	3	Nb=5
Alloy 800H/Alloy 800HT	N08810 / N08811	21	33	-	Al + Ti
Alloy 825	N08825	21	42	3	Ti
Co-base alloys					
Elgiloy	R30003	20	16	7	Co=40
MP-35-N	R30035	20	35	10	Ti, Co rem.
Copper base alloys					
Cu-Ni 90-10	C70600	-	10	-	Fe, Cu rem.
Cu-Ni 70-30	C71500	-	31	-	Fe, Cu rem.
NiAl bronze	C95800	-	4.5	-	9Al, Fe, Mn, Cu rem.
Gun metal	C90500	-	-	-	10Sn, Zn, Cu rem.
Titanium					
Ti grade 2	R50400	-	-	-	C max 0.10 Fe max 0.30 H max 0.015 N max 0.03 O max 0.25 Ti rem.

Table 16 - Main classification of metal alloys listing used offshore *[21]*

Material	Modulus	Strength
	(GPa)	(MPa)
Steel [9]	203.0	600-2000
Aluminium [9]	75.0	70.0-80.0
Low-Density PE [10]	0.2	10.0
High-Density PE [10]	1.2	32.0
PP [10]	1.5	33.0
PA-66 [10]	2.8	70.0
ABS [10]	2.2	38.0
PC [10]	2.8	65.0

Table 17 - Properties of rotational moulded polymers versus steel and aluminium *[46]*

Comparison of thermoset and thermoplastic resins

	Thermosets	Thermoplastics
Material costs	Lower than thermoplastics	Higher than thermosets
Shelf life – raw material	Limited to a few months whilst under refrigerated temperature	Near infinite
Processing	Chemical reaction to form cross links – curing	Melts when heated
Suitability for application	Careful selection from a limited range of chemistries	Careful selection from wide range of resins required to match material properties to the application
Processing costs	Higher manufacturing costs than thermoplastics	Lower manufacturing costs than thermosets
Mechanical properties	Good dimensional stability Good temperature resistance Relatively brittle	Good chemical resistance High toughness Good impact properties Can have good temperature resistance Can have poor water absorption compared to thermosets Improved flammability, smoke and toxicity performance over thermosets
Joining	Adhesively bonded or laminated with similar material	Can be 'welded', bonded or laminated with similar material
Recycling	Difficult	Easy through re-heating

Table 18 – Comparison of thermoset and thermoplastic composite resins *[11]*

Material capabilities

Material	Type	Capabilities	Limitations
PA11/PA12	Thermoplastic	Moderate thermal resistance Resistant to CO_2	Maximum temperature 80 °C Not resistant to hot water, acids, bases or aqueous H_2S above 65 °C
PE/HDPE/PEX	Thermoplastic	Good chemical resistance Resistant to CO_2 Resistant to H_2S	Maximum temperature 90 °C Not resistant to aromatics Not resistant to hydrocarbons above 65 °C
PVDF	Thermoplastic	Good chemical and thermal resistance Resistant to CO_2	Maximum temperature 130 °C Not resistant to bases (e.g. amines)
PEEK	Thermoplastic	Temperature resistant up to 330 °C. Good flame retardant properties and chemical resistance	Expensive, high viscosity
PP	Thermoplastic	Moderate cost Good processability Good chemical resistance	Maximum temperature 110 °C Not resistant to aromatics
POM	Thermoplastic	Good mechanical properties Excellent fatigue strength Short term temperature exposure up to 150 °C	Not flame retardant or UV resistant Not resistant to hydrocarbons above 80 °C
PPS	Thermoplastic	Short term temperature exposure up to 260 °C Very good chemical resistance Flame retardant	Difficult to extrude unless using special variants – limited to 180 °C
Epoxy	Thermoset	Good chemical resistance, moderate thermal resistance	Maximum temperature <100 °C
Phenolic	Thermoset	Good chemical resistance, moderate thermal resistance, naturally fire retardant	Maximum temperature <100 °C

Table 19 - Resin classification for thermoplastics/sets used in composite manufacturing *[11]*

10. Annex II

Wave energy development protocol **Task report 02-2.1**		**Tidal current development protocol** **Task report 02-2.2**	
Stage 1 TRL 1-3	Concept validation. Prove the basic concept from wave flume tests in small scale	Tidal-current energy conversion concept formulated (Scope of Protocol begins here)	Stage 1
Stage 2 TRL 4	Design validation. Subsystem testing at intermediate scale, Flume tests scale 1:10, Survivability; Computational Fluid Dynamics; Finite Element Analysis Dynamic Analysis; Engineering Design (Prototype); feasibility and costing	Intermediate scale subsystem testing, Computational Fluid Dynamics, Finite Element Analysis, Dynamic Analysis	Stage 2
Stage 3 TRL 5-6	Testing operational scaled models at sea + subsystem testing at large scale	Subsystem testing at large scale	Stage 3
Stage 4 TRL 7-8	Full-scale prototype tested at sea	Full-scale prototype tested at sea	Stage 4
Stage 5 TRL 9	Economic validation; several units of pre-commercial machines tested at sea for an extended period of time.	Commercial demonstrator tested at sea for an extended period.	Stage 5

Table 20 – EMEC technology TRL levels *[64]*

Company name	Main sectors	Country HQ	Value Chain	SME/Employees	ACS Marine Products/Services	Notes	Website link
CWIND	Maritime	UK/Germany	Services/CP	Yes / < 250	Multi-vessel owner for in-sea servicing	Mainly a corrosion servicer	http://cwind247.com/on-demand-services/corrosion-protection/
Jotun	Shipping/O&G	Norway	Coatings	No / >250	BaltoFlake	Steel/Concrete Anticorrosion	http://www.jotun.com/
					PenguardPro	Wide material range AC	
					Seaquantum	Anti fouling (AL/C-Steel)	
					Hull performance solutions		
Hempel	Shipping	Denmark	Coatings	No / >250	ANTIFOULING	AntiFouling paints	http://www.hempel.co.uk/
					HEMPASIL	Fouling release coatings	
AkzoNobel	Automotive/Marine	Netherlands	Coatings	No / >250	Intershield300	Epoxy coating	https://www.akzonobel.com
(International)					Interzone 101 (Underwater curing)	Epoxy coating	
					Intersleek	Foul release polymer	
Subsea Industries	Marine	Belgium	Coatings	Yes / < 250	EcoSpeed (Steel/Al/GRP)	Non toxic anti fouling	https://subind.net/
			Services	(Turnover n/a)	Ecolast	UV corrosion resistance OFW	
					Ecoshield/Ecofix	Cavitation protection/repair	
					Underwater cleaning systems		
Coppercoat	Shipping	UK	Coating	Yes / < 250	Coppercoat	Epoxy anti fouling	http://coppercoat.com/
				(Turnover n/a)			
Whitford	All sectors	UK	Coating	No / >250	Corrosion resistance specialist		http://www.whitfordww.com/
UltraSonic	Shipping	UK	Services	Yes / < 250	Ultrasonic wave treatments	Fouling deterrents	http://www.ultrasonic-antifouling.com/
Antifouling ltd				(Turnover n/a)	(to be used with paints)		
Surface Technology	O&G/Automotive	UK	Coating/Services	Yes / < 250	Thermal spray coatings	including Aluminium (TSA)	http://www.surfacetechnology.co.uk/
(Norma Hay grp)				(But NHG No)	Metal plating	including Nickel	
					Anti Corrosion paints		
GCG-Group	O&G	UK	Coating	Yes / < 250	Coating specialist		http://www.gcgshotblasting.co.uk/
RS Blastech	All offshore	UK	Coatings	Yes / < 250	Surface preparation specialist		http://www.rsblastech.com/
Winn & Coales Denso	All sectors	International	Coatings	Yes / < 250	SeaShield/Rigspray coatings	Corrosion prevention specialists	http://www.denso.net/
Chemco	All offshore	International	Coatings	No / >250	Coatings specialist		www.chemcoint.com
Teknos	All sectors	International	Coatings	No / >250	Epoxy powerd coatings/paints		http://www.teknos.com/
Hoganas	All sectors	Sweden	Coatings	Yes / < 250	Metal powder surface coatings	Metal powder surface coatings	https://www.hoganas.com/
CWIND	OFW sector	UK/Germany	Services	Yes / < 250	Corrosion services/advisors	Large fleet of OFW vessels	http://cwind247.com/on-demand-services/corrosion-protection/
HBM	Marine/O&G/OFW	Germany	Services	No / >250	SHM services	Structural Measurements	https://www.hbm.com/en/
					(OFW/Wave/Tidal)	(Seatricity WEC)	
Oxifree Global Ltd	All sectors	UK	Coatings	Yes / < 250	Polymelt		http://www.oxifree.com/
ABB	OFW	International	Services	No / >250	Electrical/systems/services	OFW sector	
					18% of OFW electrical cabling 2016		
4C engineering	All	UK	Services	Yes / < 250	Engineering design consultancy	Marine Energy sector	http://www.4cengineering.co.uk/
3X Engineering	O&G	Monaco	Services	Yes / < 250	Composite repair/leak sealing	Mainly O&G sector	http://www.3xeng.com/
Arc Energy Resources	All offshore	UK	Services	Yes / < 250	Corrosion resistant weld overlay cladding	Cladding & Fabrication	http://www.arcenergy.co.uk/
Belzone Polymerics	All offshore	UK	Coating/Services	Yes / < 250	Corrosion repair, materials, protection	Composites and all other materials	http://www.belzona.co.uk/en/index.aspx
Blastrac	All offshore	UK	Coating/Services	Yes / < 250	Surface preparation equipment specialist	Equipment manufacturers	https://www.blastrac.eu/
Cactus Industrial	All offshore	UK	Coating/Materials	Yes / < 250	Composites and Coating specialist		http://www.cactusindustrial.com/
MG Duff International	O&G/Maritime	UK	CP	No / >250	CP protection specialist	Worldwide distributors	http://mgduff.co.uk/
Presserv	O&G/Maritime	Norway	Coating/Services	No / >250	Coating /surface preparation/management	Asset integrity/Preservation	http://www.presserv.com/
BAC corrosion control	Marine/OFW	UK	CP	No / >250	Cathodic Protection specialist		http://www.bacgroup.com/
Corrosion	Marine/OFW	Netherlands	CP	Yes / < 250	ICCP solutions for offshore structures		https://www.corrosion.nl/
Cathelco	Shipping/O&G/OFW	UK	CP	No / >250	Active CP	ICCP systems	http://www.cathelco.com/
3C Corrosion Control	Maritime	Sweden	CP	Yes / < 250	Range of ICCP/CP and monitoring		http://www.3ccc.se/
Deepwater EU Ltd	O&G	International	CP/Services	No / >250	CP protection and Management	Range of inspection services	https://stoprust.com/
Immenco	All offshore	Norway	CP/services	Yes / < 250	CP equipment supply & design	Inspection services	http://imenco.no/
ITW Engineered Polymers	OFW	Denmark	Materials/Services	Yes / < 250	Ducorit (High performance concrete)	Offshore foundations/wind turbine bonding	http://itwengineeredpolymers.com/
					Plexus (Adhesive for composite blades)		
Krebs Korrosionsschutz GmbH	Maritime/O&G	Germany	Coating/Services	Yes / < 250	Coating specialists		http://www.krebsgruppe.de/
MME Group	Maritime/O&G	Netherlands	CP/Services	Yes / < 250	Impressed current anti fouling		http://www.mme-group.com/
					Impressed current cathodic protection		
AISUS	O&G	UK	Services	Yes / < 250	Ultrasonic in-sea inspection solutions		http://www.aisus-offshore.com/
Proserv	All offshore	UK	Services	Yes / < 250	Engineering consultancy	Design,manufacture,management	http://www.proserv.com/solutionsservices
SGS	All offshore	International	Services	No / >250	Corrosion monitoring services		http://www.sgs.co.uk/en-GB/Oil-Gas/Asset-Integrity-Management-Services/Corrosion-Monitoring.aspx
Arc Energy Resources	All offshore	UK	Coating/Services	Yes / < 250	Corrosion resistant weld overlay cladding		http://www.arcenergy.co.uk/
Cosasco	Offshore O&G	USA	Services	Yes / < 250	Corrosion monitoring services		https://www.cosasco.com/index.php
Clampon	O&G sector	Norway/USA	Services	No / >250	Ultrasonic corrosion detection monitoring		http://www.clampon.com/
Bohler	All offshore	Austria/UK	Materials	No / >250	Steel alloy suppliers/manufacturers		http://www.bohlersteels.co.uk/english/766.php
PEC composites	Maritime/OFW	UK	Materials	Yes / < 250	Composites/GRP manufacturing	Composites specialist	www.pecomposites.com
BMP	Offshore O&G	International	Materials	No / >250	Elastomer manufacturers	Supply O&G immersed accessories	http://www.bmpworldwide.com/markets/offshore-energy.cfm
Aviation Enterprises	Offshore renewables	UK	Materials	Yes / < 250	Composites/manufacturing	Composites tidal turbine blades	https://aviationenterprises.co.uk/
Floatex	Offshore systems	Italy	Materials	Yes / < 250	Rotomoulding elastomer specialist	Offshore buoys construction	http://www.floatex.com/offshore-products.html
Airborne	Offshore renewables	Spain/UK	Materials		High end composites manufacturing	Tidal turbine blade maker	http://www.airborne.com/maritime/
Rubber Company	All sectors	UK	Materials	No / >250	Rubber manufacturing for Offshore		http://therubbercompany.com/about-us/industries/offshore-oil-gas-chemical/
Sandvik	All sectors	Sweden	Materials	No / >250	Steel alloys manufacturer		http://smt.sandvik.com/en/about-us/
Windar Renovables	OFW	Spain	Materials	No / >250	OFW tower construction		http://www.windar-renovables.es/
ArcelorMittal	All sectors	International	Materials	No / >250	Steel manufacture and R&D		http://corporate.arcelormittal.com/
Bayards	All sectors	Netherlands	Materials	No / >250	Specialists in Aluminimum offshore		http://www.bayards.nl/en/
DJJ Precision Engineering	All sectors	UK	Materials	Yes / < 250	Materials fabrication	Wide range of materials fabrication	http://www.djjengineering.co.uk/materials.html
Scott Fyfe	All sectors	UK	Materials	No / >250	Polymer matrix composites specialist		http://www.scott-fyfe.com/products.aspx
A&P Marine	Shipping	UK	Materials	No / >250	Fabrication	Aluminium Fabricators	http://www.ap-group.co.uk/energy/
Ensinger Group	O&G	UK	Materials	Yes / < 250	High performance plastics		https://www.ensingerplastics.com/en-gb/oil-gas
Rochling	All sectors	International	Materials	No / >250	Theromplastics/composites manufacturers		http://www.roechling-plastics.co.uk/en/oil-gas.html
Prysmian	OFW	Italy	Materials	No / >250	53% of OFW electrical cabling 2016	OFW Sector supply	http://uk.prysmiangroup.com/en/business_markets/markets/ti/products/
Hutchinson Engineering	All offshore	UK	Materials	Yes / < 250	Steel fabrication for offshore industries		http://www.hutchinsonengineering.co.uk/

Table 21 – Private companies offering ACS solutions in NSB region

Project/Institute	Project focus	Country HQ	Value Chain	Projects	Notes	Website link
NSRI	National subsea research centre	UK	Research	Research arm of subsea UK - industry collaboration aim NSRI research matchmaker database: R&D to industry matching	Offshore wind active Wave/Tidal coming soon	http://www.nsri.co.uk/
ACORN	Long lasting solution to marine biofouling	UK/Europe	Research	Novel Thermal Sprayed Alloys application Cavitation/corrosion resistant coating tidal turbines	Ended 2015	http://www.acorn-project.eu/
WES (Edinburgh University) (University Bath) (EMEC) (Ove Arup) (Tension Tech Int) (CorPower Ocean) (Cruz Atcheson) (AWS Energy) (Checkmate) (4C Engineering) (Mocean) (Joules Energy) (Albatern)	WEC PTO/Novel designs/Materials	UK	Research	Advanced concrete engineering Advanced rotational moulding technologies for WECs Concrete technology enabler ELASTO - elastomer bodies research Hydrocomp - High FRP prime mover integration Polyshell - delivery of polymer load bearing properties RePOWER - reinforced polymers for prime mover WECs RotoHybrid - hybrid structures using rotomoulded plymes WaveSwing (AWS Ocean Energy) - WEC cost reductions Anaconda (Checkmate Seaenergy) - WEC feasibility studies SeaPower (4C engineering) - WEC feasibility testing Mocean (Mocean Energy) - WEC feasibility testing Wavetrain (Joules Energy) - WEC Testing and design optimisation WaveNET (Albatern) - WEC optimisation	Started 2017	http://www.waveenergyscotland.co.uk/programmes/
EMEC/Whitford	High performance coatings testing	UK	Research	Splash zone long term fluoropolymer coating panels project	Started 2016	http://www.theconstructionindex.co.uk/news/view/research-focuses-on-marine-corrosion
OCEANIC	AntiFouling surface production research	EU	Research	8 WP programme - Thermally Sprayed Aluminium/Antifouling composite WAVEROLLER WEC test site trials		http://oceanic-project.eu/
OWI-lab (Sirrus) (BERA/EERA/BruWIND)	Support innovation for offshore wind	Belgium	Research	VIS-Project OWOME project - offshore wind O&M reduction O&O Parkwind - monitoring offshore WT foundations	R&D innovation support	http://www.owi-lab.be/content/about-us
Carbon Trust	Offshore Wind Accelerator	UK	Research	Current phase involves 76% of europes installed offshore wind capacity Cost reduction technology targets through innovation Foundations working group most appliable to NeSSIE	R&D innovation support	https://www.carbontrust.com/offshore-wind/owa/ https://www.carbontrust.com/offshore-wind/owa/foundations/
MERIKA (University of Highlands Islands) (Env Research Institute)	Marine energy research and innovation	UK	Research	Knowledge accelertor via knowledge pooling and innovation research Growing inudstry linkages WaveRoller WEC biofouling tests (WAVEC/Peniche)	R&D innovation support Dissemination	https://www.uhi.ac.uk/en/merika/ http://aw-energy.com/wavec-offshore-renewables-conducted-biofouling-tests-at-aw-energys-site-in-peniche
MAST research (Plymouth University) (PRIMaRE partners)	Materials and Structures	UK	Research	Materials design	Composites	https://www.plymouth.ac.uk/research/materials-and-structures-research-group
ESB (MaREI) (University Cork)	Novel material integration	Ireland	Research	MARINCOMP - cost reduction for offshore marine devices Fatigue design/testing for MRE composites	ends 2018	http://www.marei.ie/
SINTEFT	O&G/Offshore research	Scandinavia	Research	Well resourced collection of Industry/R&D research		https://www.sintef.no/en/sintef-materials-and-chemistry/about-us/departments/corrosion-and-tribology/
Energy Technology Partnership	Access to mainly onshore smaller scale R&D prototype test facilities	UK	Research	Wide range of Wind, Wave, Tidal energy testing facilities		http://www.etp-scotland.ac.uk/Portals/57/SEL%20Directory/Scottish%20Energy%20Laboratory%20Test%20and%20Demonstration%20Facilities%20Directory%20(1).pdf
(Scottish Universities/Industry) (Doosan Babcock) (Energy Technology Centre)	Full scale R&D onshore structure performance testing Mechanical/Renewable onshore test facilities	International UK	Materials Testing Materials Testing	Univ Dundee - Concrete Foundation testing Onshore based facilities (part of ETP research) Onshore based facilities (part of ETP research)		http://www.doosanbabcock.com/en/service/componenttesting.do http://www.e-t-c.co.uk/test-facilities/
ITMA	R&D materials/Assay services	Spain	Research	Surface integrity and Corrosion materials R&D		http://www.itma.es/
ORJIP	Offshore renewables	UK	Research	Environmental risk Consenting research	Monitoring/R&D	http://www.orjip.org.uk/
ORE Catapult (Scottish Enterprise) (NCCUK)	Offshore renewables	UK	Research	Foundation designs, Corrosion, High Value materials (HVM) manufacturing The National Composites Centre is allied to the HVM ORE Catapult Biofouling Research Study (Catapult Funded)	Ongoing 2017 Ongoing 2017 Began 2016	https://ore.catapult.org.uk/our-knowledge-areas/foundations-substructures/ https://hvm.catapult.org.uk/hvm-centres/advanced-forming-research-centre-afrc/ http://www.srsl.com/ http://nccuk.com/
DuraComp/Limes Net (Warwick University) (Bath University) (Leeds University) (Newcastle) (Gurit) (Aquamarine)	R&D architectural materials	UK	Research	Advanced Composites R&D	Ended 2016	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/K026925/1 http://www2.warwick.ac.uk/fac/sci/eng/duracomp/
University of Manchester (Akzo-Nobel / BP)	Coatings R&D	UK/Netherlands	Research	SUSTICOAT Organic ANTI corrosion protection R&D Graphene-Oxide paint R&D	Started 2017	http://www.materials.manchester.ac.uk/our-research/research-groupings/corrosion-and-protection/major-projects/akzo-nobel/ http://cordis.europa.eu/project/rcn/205558_en.html
AEMRI	Advanced Materials Research	UK	Research	Tidal technology inspection methods R&D		http://www.aemri.co.uk/aemri-research/
DEMOWIND2	R&D Wind Energy in the EU	EU	Research	Innovative wind cost demonstration support fund		http://cordis.europa.eu/project/rcn/199382_en.html
Swerea	Materials/Corrosion R&D	Sweden	Research	Materials sciences and Manufacturing engineering	5 owned research institutes	https://www.swerea.se/en/about-swerea

Table 22 – Research organisations/collaborations listing applicable to Project NeSSIE

In Sea Testing Organisation	Main facilities/functionality	Country	Value Chain	Details	Website link
MaRINET/MARINET2	EC funded network of marine test centres	EU	Research	MaRINET finished in 2015 MaRINET2 01/07/2017 - 34 technology development teams Provided funded access to wide range of marine test sites	https://www.oceanenergy-europe.eu/en/communication/publications/marinet http://www.marinet2.eu/
FORESEA	EC funded network of marine test centres	EU	Research	Access to EMEC/SEMREV/SmartBay/TTC Netherlands sites 2016-2019 timeline	http://www.nweurope.eu/projects/project-search/funding-ocean-renewable-energy-through-strategic-european-action/
EMEC	Scaled/Full scaled wave/tidal tests sites (Grid Connected) Research Consultancy/service position	UK	Wave/Tidal testing Services Standards	Numerous Wave/Tidal Device testing since 2004 ReDAPT Project	http://www.emec.org.uk/
ECN-SEMREV	Open Sea wave & wind testing site offshore NW France (Grid Connected)	France	Wave/Wind testing	FLOATGEN (Floating Wind)	https://sem-rev.ec-nantes.fr/
Alkmaar TTC	Project/Processing Offshore tidal test sites x 2	Netherlands	Tidal Testing Standards		http://www.tidaltesting.nl/ http://www.dutchmarineenergy.com/
MARETS (Smart Bay)	1/4 scale in-sea wave test site (Not Grid connected)	Ireland	Wave testing	Nursery testing site for smaller scale wave devices	http://www.smartbay.ie/
ORE Catapult NREC	Wind turbine blade testing Electicral sub systems testing in submerged environment Artificial seabed/still water test tanks (short term testing) Open access offshore wind turbine (Levenmouth)	UK	Wave, tidal. Wind	Multi-facility test environment beyond TRL3 Suited up to full scale systems testing prior to open sea tests	https://ore.catapult.org.uk/our-services/test-demonstration-assets/
AREG - EOWDC	European Offshore Wind Deployment Centre (Grid Connected)	UK	Offshore wind testing	Summer 2018 proposed first generation testing	http://www.aberdeenrenewables.com/about-areg/activities/european-offshore-wind-deployment-centre-eowdc/
WAVEC - Pico Plant	Fixed OWC wave test site (Grid Connected)	Portugal	Wave Testing OWC	WavEC administered	http://www.pico-owc.net/
EVE-MITRUKU Wave	Fixed OWC wave test site (Grid Connected)	Spain	Wave Testing OWC	EU OPERA project ongoing	http://www.power-technology.com/projects/mutriku-wave/
DanWEC (Nissum Bredning)	Full scaled wave test sites (Not Grid connected)	Denmark	Wave Testing		https://waveenergy.dk/afprovningsfaciliteter/ http://www.danwec.com/
WaveHub (Cornwall/Pembrokeshire)	Full scale Offshore Wave Energy test site (Grid connected)	UK	Wave Testing	Seatricity Carnegie CETO	https://www.wavehub.co.uk/
MarineEnergy Hub (Wales)	Marien research coordination in Wales	UK	Tidal Testing	Nova Inniovation Tidal testing/R&D hub	http://www.marinecentrewales.ac.uk/
Runde Environmental	Offshore wave test facilities (Not Grid connected)	Norway	Wave Testing	WaveEl buoy	http://rundecentre.no/en/
BiMEP	Full scale Offshore wave device testing site (Grid connected)	Spain	Wave Testing		http://bimep.com/en/
IslandBerg/Uppsala University	Full scale Offshore wave device testing site (Grid connected)	Sweden	Wave Testing	Lysekil Project	http://www.teknik.uu.se/electricity/research-areas/wave-power/lysekil/
FaB test (Falmouth) University of Exeter	Nursery test site for marine renewables (TRL4-8)	UK	Wave Testing	Polygen HDPE Volta WEC	http://www.fabtest.com/
PLOCAN	Mainly a WEC device testing site, some floating wind testing (Grid connected)	Spain	Wave/Wind Testing	Offshore Gran Canaria	http://www.plocan.eu/index.php/en/newsplocan/2016/245-diciembre/1632-plocan-instalada-en
QUB-Portaferry	Tidal test site for full scale devices (Not Grid connected)	Ireland	Tidal Testing	Strangford Lough tidal test site	https://www.qub.ac.uk/research-centres/cerc/Facilities/MarineFacilities/FieldTestSites/
MCTS 'El Bocal'	Mooring/Anchor systems Platform analysis/design Operation and Maintenance Ambient platform monitoring	Spain	Wave Testing	ACORN project conducted here 2015	http://ctcomponentes.es/en/mcts-marine-laboratory-bocal/

Table 23 – Possible project NeSSIE demonstration project testing facilities

Regulatory Organisation	Main Sectors	Country HQ	Main requirements	Website link
Health & SAFETY Executive (Energy Division)	O&G	UK	Offshore Installations (Offshore Safety Directive) (Safety Case etc) Regulations 2015 (SI 2015/398)	http://www.hse.gov.uk/offshore/law.htm
			Health and Safety at Work etc. Act 1974 (Application outside Great Britain) Order 2013 (SI 2013/240)	
			Offshore Installations (Safety Case) Regulations 2005 (S.I. 2005/3117)	
			Diving at Work Regulations 1997 (S.I. 1997/2776)	
			Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 (S.I. 1996/913)	
			Pipelines Safety Regulations 1996	
			Offshore Installations and Pipeline Works (Management and Administration) Regulations 1995 (S.I. 1995/738)	
			Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (S.I. 1995/743)	
			Offshore Safety (Repeals and Modifications) Regulations 1993 (S.I. 1993/1823)	
			Offshore Safety Act 1992 (c 15)	
			Offshore Installations (Safety Representatives and Safety Committees) Regulations 1989 (S.I. 1989/971)	
			Offshore Installations and Pipeline Works (First-Aid) Regulations 1989 (S.I. 1989/1671)	
			Regulation 5 of the Provision and Use of Work Equipment Regulations 2008	
International (UN)	Maritime	International	THE UNITED NATIONS LAW OF THE SEA CONVENTION 1982 (LOSC)	http://www.un.org/en/sections/issues-depth/oceans-and-law-sea/
OSPAR (North Atlantic Law)	Maritime	International	The Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (1992). (North Atlantic maritime areas pollution protection)	https://www.ospar.org/about
Bonn Agreement	O&G	International	The Bonn Agreement for Co-operation in Dealing with Pollution of the North Sea by Oil and Other Harmful Substances 1983 (North Sea and EU pollution from OIL protection)	http://www.bonnagreement.org/
Bern Convention	Environment	International	The Convention on the Conservation of European Wildlife and Natural Habitats	http://jncc.defra.gov.uk/page-1364
Bonn Convention	Environment	International	The Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention)	http://www.cms.int/en/legalinstrument/cms
Valletta Convention	Environment	International	European Convention on the Protection of the Archaeological Heritage, 2000	http://www.coe.int/en/web/conventions/full-list/-/conventions/treaty/143
IMO (International Maritime Org)	Maritime	International	International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78/97	
			International Convention for the Safety of Life at Sea (SOLAS), 1974	http://www.imo.org/en/about/conventions/listofconventions/Pages/Default.aspx
			Convention on the International Regulations for Preventing Collisions at Sea (COLREG), 1972	
			Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (LC), 1972 (and the 1996 London Protocol)	
			International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC), 1990	
			International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS), 2001	
European Union	All	International	Marine Directive Directive 2008/56/EC (Marine Strategy Framework Directive)	framework-directive/index_en.htm
			The Birds Directive 2009/147/EC	http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm
			The Habitats Directive 92/43/EEC	http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm
			Natura 2000	http://ec.europa.eu/environment/nature/natura2000/index_en.htm
			Renewable Energy Directive (2009/28/EC)	https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive
			EIA Directive (85/337/EEC) 1985 / Directive 2009/31/EC	http://ec.europa.eu/environment/eia/eia-legalcontext.htm
UK Government	Energy	UK	Section 36 (Electricity Act 1989) if > 1MW generation	https://www.gov.uk/guidance/consents-and-planning-applications-for-national-energy-infrastructure-projects
(Scottish Assembly) (Marine Scotland)			Section 25 (Marine Scotland Act 2010) for marine license consenting	http://www.gov.scot/Publications/2010/09/16112721/4
			Section 28 (Town and Country Planning Act 1997) for planning permission	http://www.legislation.gov.uk/ukpga/1997/8/contents
			Energy Act 2004 once consent give, Decomissioning Programme required	http://www.legislation.gov.uk/ukpga/2004/20/contents
			UK Post-2010 Biodiversity Framework	http://jncc.defra.gov.uk/page-6189
			Nature Conservation (Scotland) Act 2004	http://www.legislation.gov.uk/asp/2004/6/contents
			Wildlife and Countryside Act 1981	http://www.legislation.gov.uk/ukpga/1981/69
			Wildlife and Natural Environment (Scotland) Act 2011	http://www.legislation.gov.uk/asp/2011/6/contents
			Conservation (Natural Habitats, &c.) Regulations 1994	http://www.legislation.gov.uk/uksi/1994/2716/contents/made
			Methodology for Assessing the Marine Navigational, Safety Risks of Offshore Windfarms, 7th September 2005	bravo/SG_Phase1_Offshore_Project_Consent_Application_Document%20(September%2020
			MCA Marine Guidance Notice 371(M+F) – Offshore Renewable Energy Installations (OREIs)	installations-oreis
			The Protection of Wrecks Act 1973	http://www.legislation.gov.uk/ukpga/1973/33
			The Protection of Military Remains Act 1986	http://www.legislation.gov.uk/ukpga/1986/35/contents
			Section 73 (Marine Scotland Act 2010) for Historic Marine Protected Areas	http://www.gov.scot/Topics/marine/marine-environment/mpanetwork/historicmpas
			Scotlands Marine National Plan (EU Directive 2014/89/EU) Marine Spatial Planning Areas	http://www.gov.scot/Publications/2015/03/6517
			Water Environment and Water Services (Scotland) Act 2003	http://www.legislation.gov.uk/asp/2003/3/contents
			Water Environment (Controlled Activities) (Scotland) Regulations 2011	http://www.legislation.gov.uk/ssi/2011/209/contents/made
			Private Water Supplies (Scotland) Regulations 2006	http://www.legislation.gov.uk/ssi/2006/209/contents/made
			The Ancient Monuments and Archaeological Areas Act 1979 (AMAAA	http://www.legislation.gov.uk/ukpga/1979/46
			Planning Advice Note 1/2011: Planning and Noise	http://www.gov.scot/Publications/2011/02/28153945/0
			Scottish Environment Protection Agency (SEPA) Pollution Prevention Guidelines (PPG)	https://www.sepa.org.uk/regulations/water/guidance/
			The Fire Safety (Scotland) Regulations 2006	http://www.legislation.gov.uk/ssi/2006/456/contents/made

Table 24 – Regulatory compliance statutes for NeSSIE marine demonstration projects

Standards Organisation	Main Sectors	Country HQ	Applicable ACS certifications/standard/guideline	Website link
Standards Norway (NORSOK)	O&G/Shipping	Norway	Norsok -M501 (Surface prep/coatings) Norsok -M001 (Materials Selection) Norsok -M101 (Steel fabrication) Norsok -M102 (Aluminium fabrication) Norsok -M503 (Cathodic Protection) Norsok -M506 (CO2 Corrosion rate model) Norsok -M601 (Pipe weld inspection) Norsok -M622 (GRP pipe fabrication) Norsok -M650 (Special materials manufactuers) Norsok -M710 (Non metallic materials manufactuers)	https://www.standard.no/En/
ISO	All sectors	Switzerland	ISO/TC 156/ WG 1-15 (Metals/alloys corrosion) ISO/TC 156/ WG 10 ISO21457 (O&G materials/corrosion controls) ISO13628 (O&G subsea systems design) ISO 12473 (CP steel in seawater) ISO 20340 (Offshore protective paints)	https://www.iso.org/standards.html
DNV-GL	O&G/Shipping	Norway	DNVGL-RP-0416 Corrosion rotection for Wind Turbines DNVGL-RP-F106 Factory applied external pipeline coatings for corrosion control DNVGL-RP-C302 Risk based corrosion management DNVGL-RP-B101 Corrosion protection of floating production and storage units DNVGL-OS-B101 Metallic Materials DNVGL-OS-D101 Marine and machinery systems and equipment DNVGL-OS-C101 Design of offshore steel structures, general- LRFD method DNV-OSS-312 Certification of tidal turbines and arrays DNV-OS-C401 Fabrication and Testing of offshore structures DNV-OS-J101 Design of FIXED Offshore Wind Turbine Structures DNV-OS-J103 Design of Floating Offshore Wind Turbine Structures DNV-OS-C105 Structurla design of tension leg platforms (LFRD Method) DNV-OS-E301 Positioning Mooring (for mooring line positioning) DNV-OS-J201 Offshore Substations for Wind Farms	https://www.dnvgl.com/rules-standards/index.html
EMEC	Marine Renewables	UK	1. Assessment of Performance of Wave Energy Conversion Systems* 2. Assessment of Performance of Tidal Energy Conversion Systems* 3. Assessment of Wave Energy Resource* 4. Assessment of Tidal Energy Resource* 5. Guidelines for Health & Safety in the Marine Energy Industry 6. Guidelines for Marine Energy Certification Schemes* 7. Guidelines for Design Basis of Marine Energy Conversion Systems* 8. Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems 9. Guidelines for Grid Connection of Marine Energy Conversion Systems 10. Tank Testing of Wave Energy Conversion Systems 11. Guidelines for Project Development in the Marine Energy Industry 12. Guidelines for Manufacturing, Assembly and Testing of Marine Energy Conversion Systems	http://www.emec.org.uk/standards/
Bureau Veritas	All sectors	France	Asset Integrity management Project development assistance Equipment and Certification Safety and Environmental management	http://www.bureauveritas.co.uk/
ASTM	All sectors	USA	ASTM A690/A690M-13a - standard specs for metal alloys in marine environment	https://www.astm.org/Standard/standards-and-publications.html
NACE	Oil & Gas	USA	SP0492-2006 Metallurgical and Inspection Requirements for Offshore Pipeline Bracelet Anodes SP0607-2007/ISO 15589-2 Cathodic Pipeline Protection SP0169-2013 Control of External Corrosion on Underground or Submerged Metallic Piping Systems SP0572-2007 Design, Installation, Operation, and Maintenance of Impressed Current Deep Groundbeds SP0185-2007 Extruded Polyolefin Resin Coating Systems with Soft Adhesives for Underground or Submerged Pipe SP0187-2008 Design Considerations for Corrosion Control of Reinforcing Steel in Concrete SP0387-2006 Metallurgical and Inspection Requirements for Cast Galvanic Anodes for Offshore Applications SP0290-2007 Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures SP0690-2009 Standard Format for Collection and Compilation of Data for Computerized Material Corrosion Resistance Database Input RP0104-2004 The Use of Coupons for Cathodic Protection Monitoring Applications SP0106-2006 Control of Internal Corrosion in Steel Pipelines and Piping Systems SP0108-2008 Corrosion Control of Offshore Structures by Protective Coatings SP0308-2008 Inspection Methods for Corrosion Evaluation of Conventionally Reinforced Concrete Structures SP0408-2008 Cathodic Protection of Reinforcing Steel in Buried or Submerged Concrete Structures TM0169/G31-12a-2012 Laboratory Immersion Corrosion Testing of Metals TM0174-2002 Laboratory Methods for the Evaluation of Protective Coatings and Lining Materials on Metallic Substrates in Immersion Service TM0499-2009 Immersion Corrosion Testing of Ceramic Materials TM0204-2004 Exterior Protective Coatings for Seawater Immersion Service TM0304-2004 Offshore Platform Atmospheric and Splash Zone Maintenance Coating System Evaluation TM0404-2004 Offshore Platform Atmospheric and Splash Zone New Construction Coating System Evaluation TM0106-2006 Detection, Testing, and Evaluation of Microbiologically Influenced Corrosion (MIC) on External Surfaces of Buried Pipelines	https://www.nace.org/uploadedFiles/Committees/NACEStandards_Detailed.pdf
IEC (International Electical Commission)			TC114 - IEC TS 62600-3/20/30/40/103/202/300/301 - ED1 (Performance and Resource Assessment, electrical power quality standards)	http://www.iec.ch/standardsdev/resources/?ref=menu

Table 25 – Certifications/Standards potentially applicable to Project NeSSIE demonstration

Company name	Country HQ	Value Chain	SME/Employees	Marine Products/Projects	Status schedule	Website link
NorthLand Power	Canada	OFW Developer	No / > 250	Senvion SE 6.2M126 WTs	Nordsee 1 OFW - 23% of EU WF 2016	http://www.northlandpower.ca/What-We-Do/Development-Projects/Wind/Nordsee-One.aspx
DONG Energy	Denmark	OFW Developer	No / > 250	MHI Vestas V164 (example WT)	UK,Denmark OFW - 20% of EU WF 2016	http://www.dongenergy.co.uk/uk-business-activities/wind-power/offshore-wind-farms-in-the-uk
Siemens	Germany	OFW Developer	No / > 250	SWT-08 `154 (example WT)	North Sea OFW - 8% of EU WF 2016	https://www.siemens.com/global/en/home/markets/wind.html
(Gamesa)		(Wind Turbine Maker)			(96% of all Wind Turbines in EU)	
Vattenfall	Sweden	OFW Developer	No / > 250	MHI Vestas V164 (example WT)	North Sea OFW - 8% of EU WF 2016	https://corporate.vattenfall.com/about-energy/renewable-energy-sources/wind-power/wind-power-at-vattenfall/
SWM	Germany	OFW Developer	No / > 250		North Sea OFW - 7% of EU WF 2016	https://www.swm.de/erneuerbare-energien/energiequellen/wind.html
MHI Vestas	Denmark	Wind Turbine Maker	No / > 250	MHI Vestas V164 (example WT)	4% all EU WT - all Offshore	http://www.mhivestasoffshore.com/
Senvion	Germany	Wind Turbine Maker	No / > 250	Senvion SE 6.2M126 WTs	Commercial suppliers of WT	https://www.senvion.com/global/en/
			No / > 250			
VanOrd/HVC	Netherlands	Maritime/OFW designer	No / > 250	Gemini OFW designer		https://www.vanoord.com/
						https://www.hvcgroep.nl/gemeenten/energie/wind
Hexicon	Sweden	Floating OFW developer	Yes / <250	Dounreay Tri floating demonstration project	Commissioning offshore 2018	http://www.hexicon.eu/dounreay-tri/
Statoil	Norway	OFW Developer	No / > 250	Hywind I & II Norway/Scotland project	Commissioning 2017	https://www.statoil.com/en/how-and-why/innovate/the-hywind-challenge.html
KOWL (Atkins ltd)	UK	Floating OFW developer	Yes / <250	Kincardine offshore floating WF	Under consenting 2017	http://pilot-renewables.com/
IDEOL	France	Floating OFW developer	Yes / <250	FLOATGEN project	End 2017 commissioning	http://ideol-offshore.com/en/les-projets/floatgen-project
DCNS/ALSTOM	France	Floating OFW developer	No / > 250	SeaReed project	Full scale prototype testing 2018	https://www.naval-energies.com/en/news/dcns-energies-obtient-la-certification-du-bureau-veritas-pour-son-design-de-flotteur-deolienne-flottante/
SeaTwirl	Sweden	Floating OFW developer	Yes / <250	SeaTwirl S2 development	Full scale prototype testing 2015	http://seatwirl.com/technology/prototype-lysekil
GICON-SOF	Germany	Floating OFW developer	Yes / <250	GICON-SOF TLP Floating concept	2016 offshore testing programme	http://www.gicon-sof.de/en/sof-chronik.html
Alstom	France	TEC Developer	No / > 250	Tidal turbines - Oceade 18	EMEC - 2013/MeyGen test turbines	http://www.alstom.com/press-centre/2014/10/alstom-improves-the-performance-of-its-tidal-energy-solutions-with-oceade-18-14mw/
Andritz Hydro Hammerfest	UK	TEC Developer	Yes / <250	HS1000	MeyGen commercial testing 2017	http://www.andritzhydrohammerfest.co.uk/
Atlantic Resources	UK	TEC Developer	Yes / <250	AR1500/SeaGenS	MeyGen commercial testing 2017	https://www.atlantisresourcesltd.com/
Current2Current	UK	TEC Developer	Yes / <250	C2C	Prototype testing/R&D 2017	http://www.current2current.com/
EC-OG	UK	TEC Developer	Yes / <250	Subsea Power Hub	EMEC 2017 testing	http://ec-og.com/subsea-power-hub/
HydroQuest	France	TEC Developer	Yes / <250	HQ	EDF 2017 test	http://www.hydroquest.net/marine-current-turbine/?lang=en
NovaInnovation	UK	TEC Developer	Yes / <250	M100/Nova 30 Tidal turbines	Shetlands Tidal Array testing 2017	https://www.novainnovation.com/
					Bardsley Sound tidal array (AfL 2017)	
Openhydro /DCNS	Ireland/France	TEC Developer	Yes / <250	OpenCentre Turbine	Brimms Head array 2016	http://www.openhydro.com/
					Torr head tidal farm 2017	http://www.tidalventures.com/index.html
					Paimpol-Breht tidal array 2017	
ScotRenewables	UK	TEC Developer	Yes / <250	SR2000	EMEC testing 2017	http://www.scotrenewables.com/
SeaCurrent	Netherlands	TEC Developer	Yes / <250	TidalKite	Protoype test tank 2017	https://seaqurrent.com/
Sustainable Marine Energy	UK	TEC Developer	Yes / <250	PLAT-O (SIT Instream Turbine)	EMEC testing 2016	http://sustainablemarine.com/#news
SchottelHydro				SIT Instream turbine		https://www.schottel.de/schottel-hydro/sit-instream-turbine/
Tocardo	Netherlands	TEC Developer	Yes / <250	UFS - T2 turbines	InToTidal (EMEC commercial 2017)	http://www.tocardo.com/
Albatern	UK	WEC developer	Yes / <250	WaveNet /SQUID	FlowWave testing(WES)	http://www.waveenergyscotland.co.uk/programmes/details/novel-wave-energy-converter/wavenet-series-12/
AW Energy	Finland	WEC developer	Yes / <250	WaveRoller	EMEC 2005 (now commercial)	http://aw-energy.com/
CorPower	Sweden	WEC developer	Yes / <250	CP3	FullScale tests EMEC 2017	http://www.corpowerocean.com/
CrestWing	Denmark	WEC developer	Yes / <250	CRESTWING	Half scale tests 2017	http://crestwing.dk/
Carnegie	Australia	WEC developer	Yes / <250	CETO	Full scale testing WaveHub 2017	http://www.carnegiece.com/
Havkraft/HydroWave	Norway	WEC developer	Yes / <250	H-WEC	Commercial technology 2017	http://www.havkraft.no/latest-news/
Marine Power Systems	UK	WEC developer	Yes / <250	WaveSub	Scale testing/1:4 Falmouth 2017	http://marinepowersystems.co.uk
Polygen Ltd	UK	WEC developer	Yes / <250	Volta Wave Flex	HD PolyEthylene WEC testing	http://www.polygenlimited.com/index.php/volta/
SWEL	UK/Cyprus	WEC developer	Yes / <250	Magnet 9.1	Prototype testing 2016	http://swel.eu/its-here-waveline-magnet-9-1-deployed/
Seatricity	UK	WEC developer	Yes / <250	Oceanus2	Testing WaveHub suspended 2017	http://seatricity.com/
Seabased	Sweden	WEC developer	Yes / <250	Seabased WEC s2.7	Sotenas Wave Power Plant	http://www.seabased.com/en/newsroom
Waves4Power	Norway	WEC developer	Yes / <250	WaveEL Buoy	Runde Test site Norway 2017	https://www.waves4power.com/
Wello OY	Finland	WEC Developer	Yes / <250	Penguin	EMEC - 2017	http://www.wello.eu/en/
Wavetricity	UK	WEC Developer	Yes / <250	OceanWaveRower	Sea Testing Phase 2017	https://wave-tricity.com/
		WEC Developer				
WETFEET	Netherlands	WEC Developer	Yes / <250	Wave energy transition to future	Ongoing 2017	http://www.wetfeet.eu/partners/
(Teamwork BV)				(Set up Tocardo, Darwind, WES new start ups)		
(WavEC)				OWC/Symphony WECs development focused		

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http://www.emec.org.uk/marine-energy/tidal-developers/
https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2016.pdf

Table 26 – Fixed/Floating OWE, TEC,WEC developers with relevant projects

Company Name	Model	Operational Testing	Country	Website
Alstom Hydro/Tidal Generation Limited	TGL series	Full-scale	France/UK	www.alstom.com/power/renewables/ocean-energy/tidal-energy
Andritz Hydro Hammerfest	HS series	Full-scale	Norway/Austria	www.hammerfeststrom.com
Aqua Energy Solutions	AES tidal devices	Part-scale	Norway	www.aquaenergy.no
Atlantis Resources Corporation	AN series, AR series, AS series	Full-scale	Singapore/UK	www.atlantisresourcesltd.com
BioPower System Pty Ltd	bioStream	Full-scale	Australia	www.biopowersystems.com
Bluewater	BlueTEC	Part-scale	Netherlands	www.bluewater.com/new-energy/tidal-energy/
Clean Current Power Systems	Clean Current Turbine	Full-scale	Canada	www.cleancurrent.com
Deepwater Energy BV	Oryon Watermill	Part-scale	Netherlands	www.deepwater-energy.com
EEL Energy	EEL Tidal Energy Converter	Small-scale	France	www.eel-energy.fr/en
Elemental Energy Technologies	SeaUrchin	Small-scale	Australia	www.eetmarine.com
Flumill	Flumill	Part-scale	Norway	www.flumill.com
Hydra Tidal Straum AS	Hydra tidal	Part-scale	Norway	www.hydratidal.info
Hyundai Heavy Industries		Part-scale	South Korea	www.hyundaiheavy.com/news/view?idx=332
IHC Tidal Energy/ Tocardo[a]	OceanMill	Part-scale	Netherlands	www.ihctidalenergy.com
Kawasaki Heavy Industries Ltd		Full-scale	South Korea	www.khi.co.jp/english/news/detail/20111019_1
Marine Current Turbines	SeaFlow, SeaGen	Full-scale	UK/Germany	www.marineturbines.com
Magallanes Renovables	Atir	Part-scale	Spain	www.magallanesrenovables.com
Minesto	Deep Green	Part-scale	Sweden	www.minesto.com
Nautricity	CoRMaT	Full-scale	UK	www.nautricity.com
New Energy Corporation	EnCurrent Turbine		Canada	www.newenergycorp.ca
Nova Innovation	Nova-I	Part-scale	UK	www.novainnovation.co.uk
Ocean Flow Energy	Evopod	Small-scale	UK	www.oceanflowenergy.com
Ocean Renewable Power Company	TidGen	Small-scale	USA	www.orpc.co
Oceana Energy Company	Oceana	Small-scale	USA	www.oceanaenergy.com
OpenHydro (DCNS)	Open Centre Turbine	Full-scale	Ireland/France	www.openhydro.com
Sabella SAS	Sabella D03	Part-scale	France	www.sabella.fr
Schottel Group	STG series	Full-scale	Germany	www.schottel.de
Scotrenewables	SR series	Part-scale	UK	www.scotrenewables.com
Tidal Energy Ltd	DeltaStream	Part-scale	UK	www.tidalenergyltd.com
TidalStream Limited	Plat-O	Part-scale	UK	www.tidalstream.co.uk
Tidalys	Electrimar1800, 4200	Part-scale	France	www.tidalys.com
Tocardo Tidal Turbines	T series	Full-scale	Netherlands	www.tocardo.com
Uppsala University: The Ångström Laboratory		Small-scale	Sweden	
Verdant Power	Free Flow System	Full-scale	USA	www.verdantpower.com
Voith Hydro	HyTide	Full-scale	Germany	www.voith.com/en/products-services/hydro-power-377.html
Vortex Hydro Energy	VIVACE	Small-scale	USA	www.vortexhydroenergy.com

[a] Tocardo acquired IHC Tidal in November 2014 — Companies shortlisted by IRENA

Table 27 – Complete shortlisting of Tidal Developers *[90]*

Name	Capacity (MW)	Status	Project Developer
Bluemull Sound	0.5	In planning	Nova Innovation Ltd
Brough Ness	100	In planning	Sea Generation (Brough Ness) Ltd
Cantick Head	200	In planning	Cantick Head Tidal Development Ltd
Esk Estuary	0.6	In planning	GlaxoSmithKline Montrose plc
Inner Sound (MeyGen)	392	In planning	MeyGen Ltd
Isle of Islay	30	In planning	DP Marine Energy Ltd
Kyle Rhea	8	In planning	Sea Generation (Kyle Rhea) Limited
Mull of Kintyre	3	In planning	Argyll Tidal Ltd
Ness of Duncansby	100	In planning	ScottishPower Renewables UK Ltd
Sanda Sound	0.035	In planning	Oceanflow Development Ltd
Sound of Islay	10	In planning	ScottishPower Renewables UK Ltd
St David's Head	10	In planning	Tidal Energy Developments South Ltd
Westray South	200	In planning	Westray South Tidal Development Ltd
Afsluitdijk	3	In development	Tocardo, Tidal Test Centre
Fair Head	100	In development	DP Marine Energy & DEME Blue Energy
Lashy Sound	30	In development	Scotrenewables Tidal Power
Nepthyd	5.6	In development	Alstom/GDF Suez
Normandie Hydro	14	In development	OpenHydro/DCNS/EDF/ADEME
Perpetuus Tidal Energy Centre	20	In development	Isle of Wight Council
Ramsey Sound	1.2	In development	Tidal Energy Limited
Fromveur	1	In development	Sabella/IFREMER/Veolia Environnement/Bureau Véritas
Norway	2	In development	Flumill
Raz Blanchard	12	In development	GDF Suez/Voith Hydro/CMN/Cofely Endel/ACE
Inner Sound (Meygen)	6	In construction	MeyGen Ltd
Strangford Lough (Minesto 2)	0.003	In construction	Minesto AB
EMEC Shapinsay Sound	n.a.	Nursery facilities	European Marine Energy Centre Ltd
Lynmouth	1.6	Interrupted	Pulse Tidal Ltd
Skerries, Anglesey	10	Interrupted	Sea Generation Ltd
EMEC Fall of Warness	10	Operational	European Marine Energy Centre Ltd
Ness of Cullivoe	0.03	Operational	Nova Innovation Ltd
Strangford Lough (Minesto 1)	0.003	Operational	Minesto AB
Strangford Lough (SeaGen)	1.2	Operational	Sea Generation Ltd

Sources: The Crown Estate 2014; France Energies Marines 2014

Projects expected to become operational by the end of 2016 | Projects of uncertain status | Interrupted projects

Table 28 – Complete shortlisting of leased Tidal Developments [90]

Company Name	Model	Operational Testing	Country	Website
40South Energy	R115, Y series, D series	Full-scale	Italy/UK	www.40southenergy.com
Albatern	SQUID	Part-scale	UK	http://albatern.co.uk/
AquaGen Technologies	SurgeDrive	Small-scale	Australia	www.aquagen.com.au
Aquamarine Power	Oyster	Full-scale	UK	www.aquamarinepower.com
Atargis Energy		Small-scale	USA	www.atargis.com
AW Energy	WaveRoller	Full-scale	Finland	www.aw-energy.com
AWS Ocean Energy	AWS-III, Archimedes Wave Swing	Full-scale	UK	www.awsocean.com
BioPower Systems Pty Ltd	bioWave	Small-scale	Australia	www.biopowersystems.com
Bombora WavePower	Bombora WEC	Small-scale	Australia	http://www.bomborawavepower.com.au/
Carnegie Wave Energy Ltd	CETO	Full-scale	Australia	www.carnegiewave.com
Columbia Power Technologies	Manta, SeaRay	Part-scale	USA	www.columbiapwr.com
COPPE Subsea Technology Laboratory		Part-scale	Brazil	www.coppenario20.coppe.ufrj.br/?p=805
DexaWave A/S	DexaWave	Small-scale	Denmark	www.dexawave.com
Eco Wave Power	Wave Clapper, Power Wing	Part-scale	Israel	www.ecowavepower.com
Floating Power Plant AS		Part-scale	Denmark	www.floatingpowerplant.com
Fred Olsen Ltd	FO3, Bolt, Bolt 2 Lifesaver	Full-scale	Norway	www.fredolsen-renewables.com
Intentium AS	ISWEC, IOWEC	Full-scale	Norway	http://www.intentium.com/
Kymaner	Kymanos	Part-scale	Portugal	http://www.kymaner.com/
Langlee Wave Power	Rubusto	Full-scale	Norway	www.langlee.no
LEANCON Wave Energy	MAWEC	Small-scale	Denmark	http://www.leancon.com/
Neptune Wave Power	Neptune WECD	Part-scale	USA	http://www.neptunewavepower.com/
Ocean Energy Ltd	OEBuoy	Part-scale	Ireland	www.oceanenergy.ie
Ocean Harvesting Technologies		Full-scale	Sweden	http://www.oceanharvesting.com/
Ocean Power Technologies	PowerBuoy	Full-scale	USA	www.oceanpowertechnologies.com
Oceantec	Oceantec WEC	Small-scale	Spain	www.oceantecenergy.com
Offshore Wave Energy Ltd (OWEL)	OWEL WEC	Small-scale	UK	www.owel.co.uk
Oscilla Power	Wave Energy Harvester	Small-scale	USA	www.oscillapower.com
Pelamis Wave Power [a]	Pelamis	Full-scale	UK	www.pelamiswave.com
Perpetuwave	Wave Harvester	Part-scale	Australia	http://www.perpetuwavepower.com/
Pico Plant EU Consortium	Pico Plant OWC	Full-scale		
RESEN Waves	LOPF Buoy	Small-scale	Denmark	http://www.resen.dk/resen_standard.asp?pageid=120
Resolute Marine Energy Inc.	SurgeWEC	Full-scale	USA	www.resolute-marine-energy.com
SDE Energy	Sea Wave Power Plants	Full-scale	Israel	http://www.sdeglobal.com/
Seabased AB	Seabased	Full-scale	Sweden	www.seabased.com
Seatricity	Oceanus	Full-scale	UK	www.seatricity.net
Spindrift Energy	Spindrift	Small-scale	USA	http://www.spindriftenergy.com/
Trident Energy Ltd	PowerPod	Full-scale	UK	www.tridentenergy.co.uk
Voith Hydro Wavegen	Limpet OWC, Mutriku OWC	Full-scale		
Wave Dragon	Wave Dragon	Part-scale	Denmark	http://www.wavedragon.net/
Wave Energy Technology New Zealand (WET-NZ) [b]	WET-NZ	Part-scale	New Zealand	www.waveenergy.co.nz
WaveRider Energy	WaveRider Platform	Part-scale	Australia	www.waveriderenergy.com.au
WaveStar Energy	WaveStar	Part-scale	Denmark	www.wavestarenergy.com
Wedge Global		Part-scale	Spain	www.wedgeglobal.com
Wello OY	Penguin	Full-scale	Finland	www.wello.fi
WePTO	WePTO WEC	Part-scale	Denmark	www.weptos.com

[a] Pelamis filed for administration in November 2014 [b] WET-NZ sold its technology to a US-based company in 2014
Companies shortlisted by IRENA

Table 29 – Complete shortlisting of Wave Developers [90]

Project Name	Device	Capacity	Type	Expected Completion Date	Updates
Western Australia	Carnegie CETO5	0.72 MW	Demo array	2014	The project is currently under construction, with the first device having started operations (ReNews 2014b).
EMEC – Oyster	Oyster 801	0.8 MW (up to 1.6 MW)	Single device/ Demo array	2015	Oyster 801 represents an improvement on the existing Oyster 800, deployed currently at EMEC. The two devices will be installed closely and connected to the same power station. Oyster 802 will be also installed, with the total array capacity expected to be 2.4 MW once completed. Oyster 800 underwent significant upgrades in summer 2014.
Sotenas	Seabased	10 MW	Array	2016	The construction of the array is currently underway with the first 10 devices out of a total of 340 already installed.
Wave Hub	Seatricity Oceanus	10 MW	Demo array	2016	The first Oceanus device was installed at Wave Hub in June 2014. Electricity generation will begin in 2015. Seatricity aims to deploy 60 devices at Wave Hub to a total of 10 MW. Oceanus devices are being fabricated in Falmouth.
Garden Island	Carnegie CETO6	3 MW	Demo array	2016	Carnegie is currently upgrading its CETO5 technology from 204kW to 1MW, and is expected to install in Garden Island in 2016.
Swell	Wave Roller	5.6 MW	Demo array	01/01/2018	16 Wave Roller devices should be installed off the coast of Peniche. The project has received NER 300 funds.
Wave Hub	Carnegie CETO6	3 MW	Demo array	N/A	Carnegie was awarded a berth at Wave Hub in June 2014. They plan a 3 MW installation of its CETO6 devices, with an option to expand up to 10 MW. The development of the project is to be carried out in parallel with the Garden Island 3MW demo array.
Wave Hub	Wello Oy Penguin	5 MW	Single device	N/A	In February 2014 Fortum signed a lease with Wave Hub for a berth. It later announced that it would be used for testing the upscaled version of the Penguin device, developed by Wello.
West Wave	Wave Roller Pelamis Oyster	5MW	Demo array	30/06/2018	In September 2014 it was announced that Wave Roller and Pelamis were shortlisted as the wave energy technologies to be deployed at the site.
Canary Islands	Langlee Robusto	0.5 MW	Demo array	N/A	Langlee has announced plans for the construction of devices in the Canary Islands and is also pushing forward testing and potential development in the Canary Islands, including a 500kW array.

Table 30 – Complete shortlisting of 2014 upcoming demonstration Wave projects *[90]*

11. Annex III

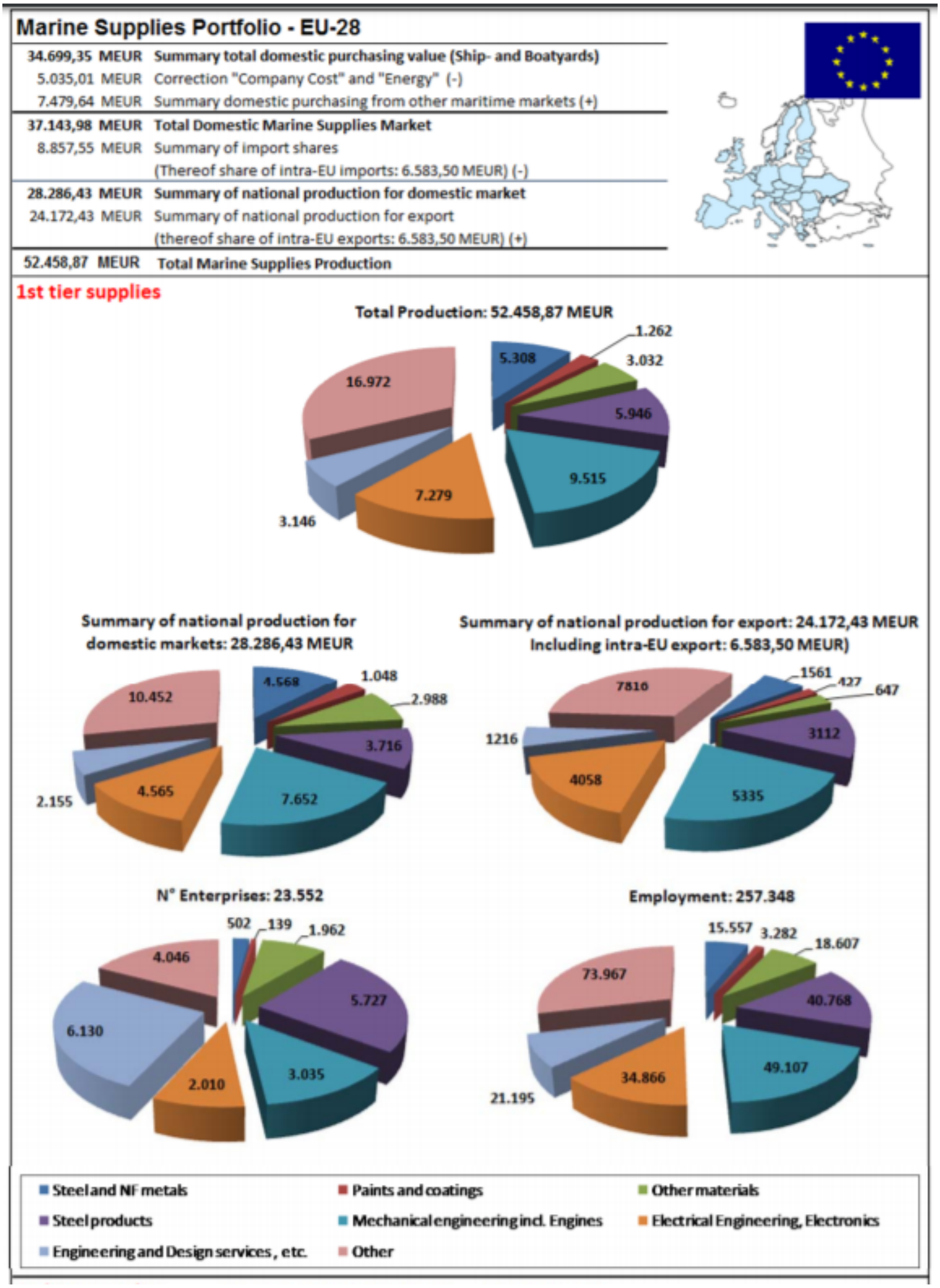

Figure 46 – EU28 marine supplies portfolio estimation 2013 *[114]*

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NeSSIE

North Sea Solutions for Innovation in Corrosion for Energy

Co-funded by the European Maritime and Fisheries Fund

Innovative corrosion solutions and new materials in wave, tidal and offshore wind energy sectors

THE PROJECT IN NUMBERS

8 PARTNERS
5 Countries

3 DEMONSTRATION
Cases

DURATION
2017 - 2019

TOTAL BUDGET
860.000 €

VANGUARD INITIATIVE
New growth through smart specialisation

*All partners are members of the **Vanguard Initiative** and involved in the pilot "**A**dvanced **M**anufacturing for **E**nergy **R**elated **A**pplications in **H**arsh **E**nvironment"*

WHAT IS NESSIE

The **NeSSIE** project will tap into the existing knowledge of **anti-corrosion technology** / **novel materials** solutions in the maritime sector supply chain to develop demonstration projects for offshore renewables in the North Sea.
The corrosion solutions, when developed and commercialised, will provide global growth and job creation opportunities across the European Union.

NeSSIE WILL

- Develop and scope 3 offshore renewable energy **demostration projects** relating to corrosion issues by drawing on existing maritime supply chain expertise.
- **Accelerate the deployment and cost reduction of wave**, tidal and offshore wind devices.
- Support the demonstration projects developed to access **public and private investment**.
- Create **economic opportunities in the North Sea Basin**.

FURTHER INFORMATION:
www.nessieproject.com

IF YOU WANT TO KNOW MORE ABOUT THE NESSIE PROJECT PLEASE CONTACT

Scottish Enterprise

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KEY ACTIVITIES

Learn → Connect → Demonstrate → Commercialise

Assessment of **innovative corrosion solutions in wave, tidal and offshore wind**, through:

- **Technology roadmap**
- **Supply chain analysis**
- Supporting consortia to scope and develop **investable demonstration projects**

EXPECTED IMPACT

- Greater collaboration within the value chain
- Market focused demonstration projects on marine renewables on offshore renewable
- New opportunities for SMEs to create jobs and growth in the Blue Economy

EU ADDED VALUE

- Building a new model applicable to other cluster partnerships
- Fostering the transfer of technology solutions to new sectors
- Strengthening regional cooperation through the Vanguard Initiative

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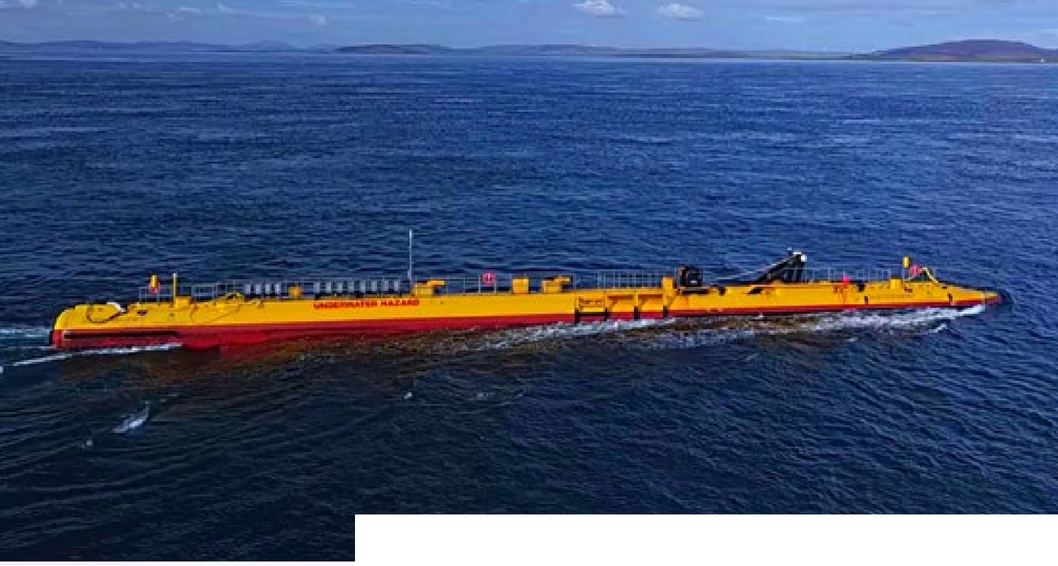

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