ANNEXES

Value Proposition for Tidal Energy Development in Nova Scotia, Atlantic Canada and Canada

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Errors of fact or interpretation remain the responsibility of the report authors.

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Annex 1

Value Proposition in other Jurisdictions

1.1 State of the global industry

1.1.1 Introduction and background to tidal energy

In the search for secure, safe and economic energy supplies, attention has turned to renewable sources to meet future needs. Among these, tidal stream and ocean wave are the subjects of research and development for an emerging marine renewable energy (MRE) industry. A few large tidal barrages have been constructed and several major initiatives are planned (Table 1.1). However, this study is concerned with tidal stream – the exploitation of naturally occurring powerful tidal streams such as those that exist between islands and at constrained entries and exits to inlets and fjords.

Tidal stream resources suited to development are quite rare for the current state of technology and are often remote from existing energy markets. However, they could make a significant contribution to total demand. Transport or storage alternatives are essential considerations, as are socio-economic and environmental impacts. Commercial tidal stream technologies for large-scale power generation are less than ten years old and are at an early stage of development. Research and testing interest has focused on high-energy environments such as Strangford Lough in Ireland and the Orkney Islands in Scotland where prototype devices are successfully connected to the electricity grid. No commercial arrays are yet constructed, but are at an advanced stage of planning in Scotland and at feasibility study stage elsewhere, including the Bay of Fundy in Canada.

The EMEC (European Marine Energy Centre) ocean energy test centre in Orkney is a focal point for most testing and implementation activity in the world. Seabed fixed horizontal axis turbine (HAT) is the main technology of interest, although one floating HAT device is at an advanced stage of development. This floating device can exploit faster tidal streams close to the sea surface and could be deployed in river estuaries.

UK costs of electricity generation from tidal stream are currently estimated to be more than £300 per MWh compared to a CCGT (combined cycle gas turbine) unit cost at around £80-£100 per MWh [Mott 2010]. Pathways to tidal stream generation costs in the region of £100 per MWh are needed for commercial operation as the technology and industry matures. At this stage, the emerging industry is dependent on high levels of public funding, driven by international commitments to reduce carbon emissions and substitute for dwindling supplies of fossil fuels.

Table 1.1: Significant tidal barrage power stations

Station	Country	Capacity (MW)	Commissioned
Sihwa Lake	South Korea	254	2011
Rance	France	240	1966
Annapolis	Canada	20	1984
Incheon	South Korea	1000	Completion in 2017
Swansea Bay	Wales (UK)	240	Planned for 2020

1.1.2 Current state of the global 'in-stream' tidal industry

EMEC (www.emec.org.uk) maintains a record of companies with an active interest in power generation from tidal stream and the technologies with which they are working [Table 1.2]. The overwhelming private commercial interest is based in the UK and the US, although the governments of several countries have ambitious strategies in the sector. The US, Canada, China, Australia and New Zealand have all identified potential sites for development. South Korea is pursuing a large programme of tidal barrage construction with the world's largest station completed at Sihwa (254MW) in 2011 and the larger Incheon station (1GW) under construction for completion in 2017. It has identified several southern island areas suited to tidal stream energy development.

Table 1.2: Tidal stream developers by country and technology

Countries	Developers	Device Technologies (see key)							
		A	B	C	D	E	F	G	X
United Kingdom	32	13	4	1	2	0	0	5	7
United States	27	11	6	2	1	0	0	4	3
Norway	7	3	0	0	0	1	0	2	1
France; Canada: @ 5 each	10	3	2	0	2	0	0	1	2
Australia; Netherlands @ 4 each	8	4	1	0	1	1	1	0	0
Germany	3	3	0	0	0	0	0	0	0
Japan; Sweden: @ 2 each	4	1	2	0	0	0	1	0	0
China, Denmark, India, Ireland, Korea, Mauritius, Spain; @ 1 each	7	3	0	0	1	0	0	0	3
Totals from 17 countries	98	41	15	3	7	2	2	12	16

Device Technologies Key							
A	B	C	D	E	F	G	X
Horizontal axis	Vertical axis	Oscillating hydrofoil	Venturi	Archimedes screw	Tidal kite	Other	Not given

Source: EMEC www.emec.org.uk

Research and technology development in the tidal power sector is spread throughout the world but preparations for commercial deployment are most advanced in Europe and most of this is in the United Kingdom. The most comprehensive experiences and literature are to be found in this region. Four main headings of challenge to the emerging industry are identified as:

1. Technical development and innovation of devices capable of reliable operation at satisfactory cost;
2. Government policy towards financial support and the regulatory environment in marine space;
3. Identification of interactions with the ambient social, economic and environmental conditions and the management of conflicts; and
4. Business models demonstrating the level of financial security and return necessary to attract investment.

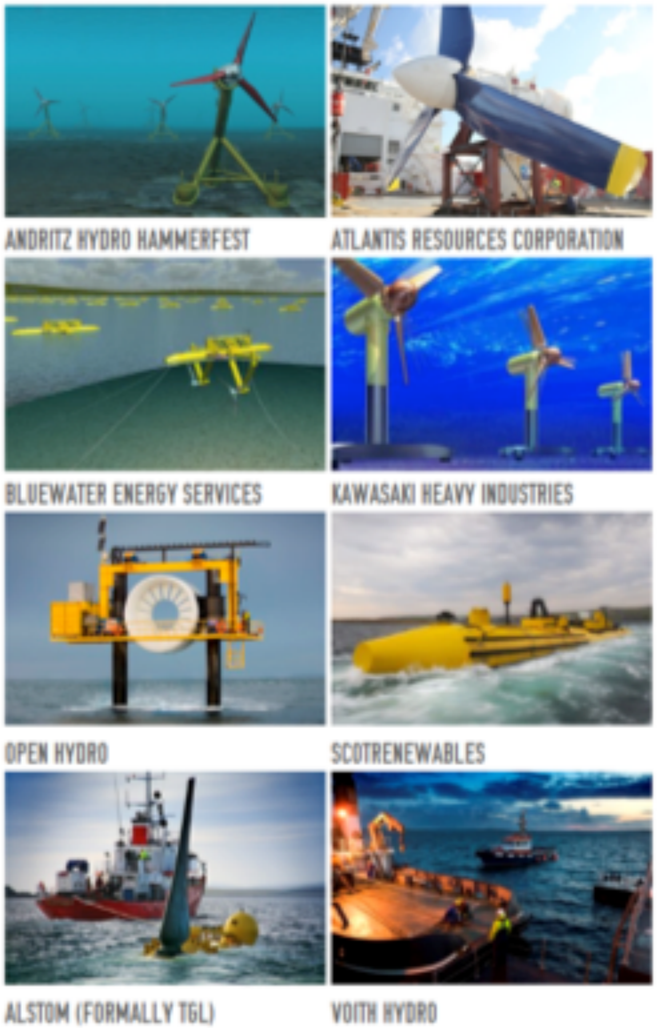
Major uncertainties remain in respect of all four headings of challenge and these are explored further in Section 2.1.4. In common with all industries, emerging marine industries can be expected to pass through several stages - concept, R&D, prototype, commercialisation, expansion, consolidation, maturity, post-maturity and decommissioning. On this scale, aquaculture, for example, might be considered to be at the consolidation stage and offshore wind power at the expansion stage. In contrast, wave and tidal power is very much at the prototype stage. Individual devices have been shown to work and power has been delivered to the grid. The first array of tidal stream devices in the world, 10MW in Islay Sound in Scotland, was consented in 2011. However, it is not yet installed. The emerging industry is going through a long period of gestation as the challenges are investigated and more certainty introduced. Important progress has been made but early estimates of the speed of commercialisation have proved to be over optimistic [see Chapter 2.3]. Ownership, private sector investment and the involvement of the major corporates are not yet secure.

Early indications were of interest from the international offshore oil majors looking to diversify their energy portfolio into renewables and use their offshore knowledge. This has not happened on a large scale although some like 'Statoil' have been prime movers for technologies such as floating wind power employing semi-submersible structures. In the UK, The Crown Estate, as administrator of the seabed, has been a main promoter of marine energy as a source of leasing income. The Pentland Firth and Orkney Waters (PFOW) leasing round in 2009 for wave and tidal sites attracted bids from major electricity utilities and most notably from E-ON and SSE (Scottish and Southern Energy). They were successful in obtaining agreements to lease tidal sites subject to government licence. However, E-ON announced their withdrawal from the sector in 2013 and SSE relinquished some of their interest soon after. In April 2014, SSE announced the transfer of some of their remaining interest to the renewables specialist company of DP Energy (DPE). Ireland-based DPE is a family-owned company formed with the specific objective of promoting the development and use of energy from renewable and sustainable resources. Similar transfers and hiatus have been made elsewhere such as the placing on hold of the Kaipara project in New Zealand and the transfer of ownership from Crest to oil/gas-based Todd Energy.

In summary, the emerging tidal stream power industry has made substantial technical progress but is still commercially uncertain. Development and ownership is mainly in the hands of specialist development companies supported by public funds. Some major corporate investors/operators have stepped back a bit after a show of initial interest. Global interest in tidal stream power remains strong albeit on a more modest path to growth than first envisaged. Considerable interest has been shown in emulating the EMEC example with the establishment of test centres in several jurisdictions including Canada (FORCE), China, Japan, United States, Australia and Chile. EMEC has made the strategic decision to support and advise the setting up of these new centres.

EMEC was established in Orkney in 2003 as the first and only centre of its kind in the world to provide developers of both wave and tidal energy converters with purpose-built, accredited open sea testing facilities. Start-up funding came from government development schemes and the local council. Orkney is an ideal base for the centre with a strong oceanic wave and tidal stream regime. Supporting infrastructure includes grid connection, sheltered harbours and a skilled workforce in a community engaged with renewable energy. A triple helix of government, industry and academic support is in place. EMEC provides fourteen full-scale test berths including grid connection and moorings - eight berths are dedicated to tidal stream. More sheltered smaller-scale berths are available for prototype devices not yet ready for open sea. As well as device testing, EMEC undertakes performance assessments and consultancy and research services. It works with government in the design of the consenting process and is at the forefront of the development of the first international standards for marine energy. Details of EMEC's tidal stream developer clients are shown in Fig 2.1.

Fig 1.1: EMEC Tidal Stream Device developer clients



1.1.3 Drivers

The main drivers for a tidal stream power industry relate to energy policy. The first is security and diversity of supply, where there is concern about dwindling supplies of fossil fuels and reliance on foreign sources. Locally available and renewable sources of natural energy will remain under the control of the domestic government. The second driver is the prospect in the future of reduced costs of useable energy, mainly in the form of electricity, but also in other forms such as hydrogen, combined with a high degree of gross value added to the national and local economy. The third driver is the need to control the emission of greenhouse gases and to mitigate the effects of climate change. Binding international and national agreements to reduce emissions can only be achieved with a significant contribution from the use of naturally renewable sources of energy along with other alternatives such as nuclear power.

These then are the most obvious and direct drivers. However, they also fit within a larger and wider ambition to achieve economic growth and employment by making use of marine resources. This is made possible by increasing knowledge of the resources themselves and the technical competence to exploit them on commercially viable terms. The European Union's 'Integrated Maritime Policy' (IMP) and 'Blue Growth Agenda' exemplify this approach [EU 2012]. The EU gives priority to energy and food security through the development of renewable energy and aquaculture, but also anticipates more oil and gas; mineral; biotechnology and recreational uses. However different in application, all these uses share with tidal stream the need for a marine jurisdictional and regulatory regime that allows them to co-exist, and to share space with the needs of the ecosystem and traditional uses such as fisheries and shipping.

1.1.4 Constraints and uncertainties affecting the development of the industry

The first and overarching constraints and uncertainties are the technical challenges - finding technologies that work at a consistent level of production in a hostile and frequently difficult to access environment, the sea. Tidal stream devices are currently producing electricity in the 1MW per unit range and 2MW units are an immediate prospect. Commercial tidal stream production in an area like the Pentland Firth and Orkney Waters (PFOW) is targeted at a capacity of 1GW by 2020, which, on current showing, will require 500-1000 individual devices in large arrays. Machines will have to demonstrate a very high degree of resilience and efficiency to operate and be maintained in this environment. Individual prototype machines have operated on test for three years or so. There are, as yet, no arrays and no long-term experience of operation.

The UK Low Carbon Innovation Coordination Group (LCICG) is a coordination vehicle for the major UK public sector backed funding and delivery bodies for the low carbon industries. In 2012, the LCICG produced a technical needs assessment (TINA) for marine energy [LCICG 2012]. The assessment is UK specific but with generic application to the emerging marine energy industry worldwide. In common with many such reports, the assessment combines wave and tidal considerations. The TINA assessment of technical innovation and its impact is summarised in Table 1.3. These technical and associated non-technical challenges feed directly to the tidal stream cost of energy (CoE) and are exacerbated by the FOAK (first of a kind) nature of the devices.

Table 1.3: Technical elements and innovation (wave and tide)

	Element of System	Description	Desired innovation outcome	Proportion of cost of energy (tidal stream)
1	Structure and prime mover	The fluid mechanical process whereby the device captures energy from the ocean.	Design optimisation for at sea performance; alternative materials; batch production to reduce manufacturing costs.	circa.15%
2	Power take-off	Conversion technology from kinetic energy to electrical energy.	Improvements in control systems and software. Next generation of power take off technologies.	circa.10%
3	Foundations and moorings	The means to hold the device in place by fixed structures and foundations or flexible or rigid moorings.	More durable and cost effective moorings and seabed structures. Improved station-keeping technologies.	circa.15%
4	Connection	The method whereby the energy is transferred from seas to shore (electrical or hydraulic).	Development of next generation cables, connectors and transformers. Improved ‘wet mate connectors’ for marine application.	circa.10%
5	Installation	The process of on-site construction and fixing.	Improved installation techniques and vessels. Drilling techniques better suited to working in tidal currents.	circa.35%
6	Operations and Maintenance	The lifetime process of keeping the device in operation.	Improved lifecycle design; retrieval systems and remote monitoring.	circa.15%

More constraints and uncertainties may be described as non-technical challenges such as the government regimes of policy and regulation. The European Ocean Energy Association (EU-OEA) has sponsored the Strategic Initiative for Ocean Energy (SI Ocean). Renewable UK has prepared the SI Ocean report on the policy and market conditions underpinning the development of ocean energy in Europe's Atlantic Arc Region. The report gives an overview of six European countries - Denmark, France, Ireland, Portugal, Spain and the United Kingdom. The analysis is country-specific but the headings are generic in application and will apply wherever tidal stream energy is proposed. A summary of results is described in Table 1.4.

All six countries recognise a future role for tidal stream but only the UK has a developed strategy and programme of implementation. The experience of Portugal and Spain demonstrates the dependence of the sector on public support and the sensitivity of the investment to periods of national austerity. The UK, which is so advanced in comparison to most countries in the tidal energy sector, is one of the most sensitive to difficulties of grid connectivity. The areas of potential tidal stream production are remote from population centres and existing grid capacity. Strengthening of the gird infrastructure is seen as one of the most significant constraints on tidal stream industry development in the UK. This is explored further in Chapter 2.3.

Planning and consenting regimes for marine energy and other marine activities are being rolled out in several jurisdictions. Europe is more advanced than many in the level of ambition, on the one hand, for 'Blue Growth' and, on the other, for ecosystem protection legislation. Marine spatial planning is seen as the tool to manage potential conflicts between uses and the environment. Domestic legislation for marine spacial planning (MSP) is in place in the UK with the objective to facilitate sustainable development. European-wide legislation is under preparation but few plans are yet complete, giving rise to another level of uncertainty. A number of recent reviews (e.g. Gill 2005, Inger *et al.* 2009, ICES 2010a, 2010b, Shields *et al.* 2011) have drawn together much relevant information for a qualitative appreciation of the perceived potential for environmental interactions involving marine renewable energy developments. Several types of interaction may be distinguished:

- Energy extraction impinging upon natural processes
- Operational effects on marine biota, acting through device operation, maintenance and decommissioning
- Provision of new ecological space through the physical presence of devices and other development structures
- Displacement of other human activities, modifying the locus and nature of their impacts

Table 1.4: Policy Drivers and European Status in 2013

	Policy Driver	Ocean Energy Status in Europe's Atlantic Arc (March 2013) (Denmark; France; Ireland; Portugal; Spain; UK)
1	Political will to develop Ocean Energy	Recognised as a future priority in all six countries. Actual progress in UK with strong sustained commitment close to commercialisation - especially Scotland. Identified for priority research in Ireland.
2	Government strategy on Ocean Energy	No dedicated strategies in Denmark, Portugal and Spain; 2013 government report in France; Range of OE strategic plans in UK and Ireland.
3	Market pull - public support to unit cost and purchase of energy produced	Support mechanisms initially in all six countries (FiT; ROCs, CfD) but halted or suspended in Portugal and Spain because of financial austerity cuts.
4	Technology push - public support to capital investment and technology development	Large capital support and grant schemes in the UK and Ireland. Relatively small schemes available in the other four countries.
5	Planning and consenting Regime	Streamlined ('one stop shop') consenting procedures in UK and for offshore wind in Denmark. Ireland to introduce 'one stop shop' later. Multi agency or regional case by case in France, Portugal and Spain. Statutory marine spatial planning in UK.
6	Seabed and marine space leasing process	All countries multi agency except for UK Crown Estate (CE). CE administers all seabed use in the UK territorial sea and renewables in the EEZ. Ireland arrangements under review.
7	Infrastructure focus and electricity grid connectivity	Strong grid availability in Denmark, Portugal and Spain. Upgrade in progress in Ireland and needed in France. Grid upgrades critical to progress of main UK tidal stream sites in remote Scotland.
8	Other issues of interest	Denmark target 100% renewable by 2050; 'France Energies Marines' established 2012; Ireland/UK 500MW interconnector completed 2012; Portugal MSP to facilitate fast consenting in future; In Spain, Biscay test facility due 2014; UK electricity reform to change revenue support from ROC to CfD.

1.2 Tidal development potential

1.2.1 Public Sector activity in support of marine renewables

The UK LCICG (2013) identified three broad categories of public sector activity in support of marine energy development, (1) Market Pull, (2) Technology Push and (3) Enabling Actions.

1. **Market Pull (demand side)** - actions, which increase private sector interest, generally improving profitability, reducing investor risk or otherwise increasing commercial confidence. Most significant are subsidies and price guarantees for electricity from marine sources. In the UK, the principal support mechanism for large scale renewable energy has been the Renewables Obligation which places retail suppliers under an annual obligation to demonstrate that a proportion of their energy sales is from renewable sources. They do this by purchasing Renewable Obligation Certificates (ROCs) that are issued to renewable energy generators. Failure to comply with this obligation results in the retailer being fined (making a 'buyout payment'). At the end of the year, accumulated fines (the buyout fund) are redistributed to retail suppliers in proportion to the number of ROCs they hold.

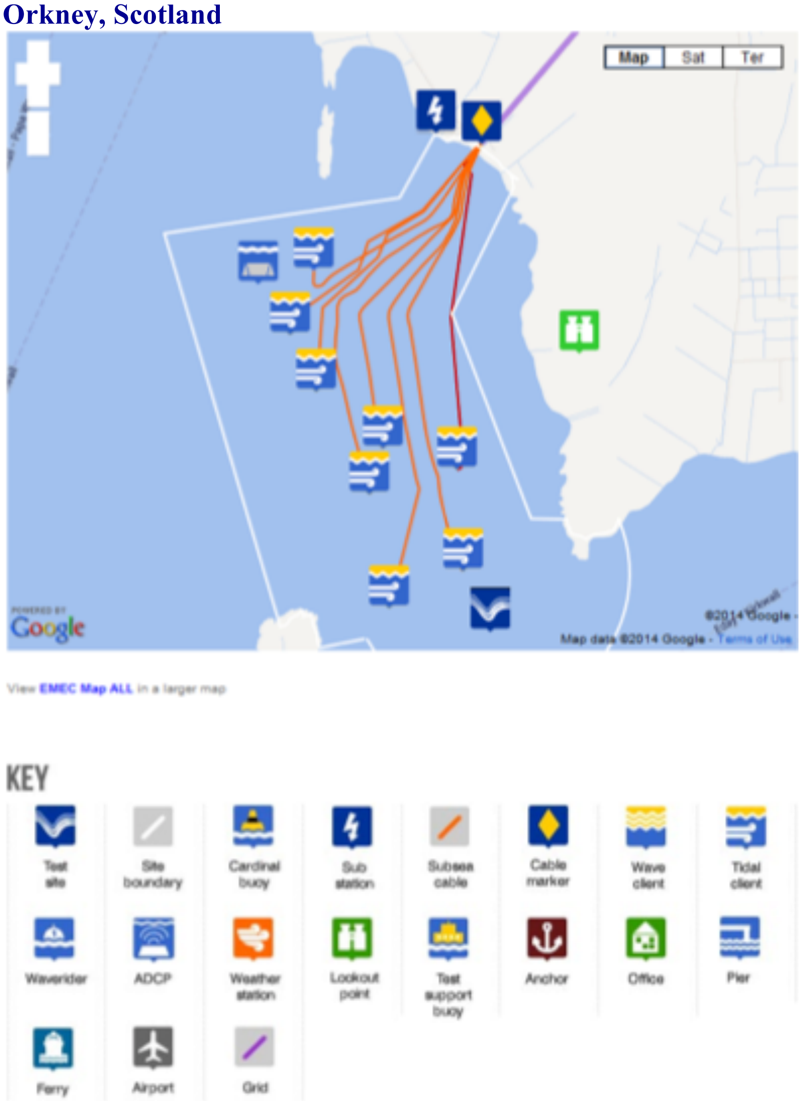
   Holding a ROC means a supplier both avoids the buyout payment and gets access to the buyout fund. ROCs are therefore a valuable commodity that suppliers purchase from developers. The ROC provides an income stream over and above electricity sales. The issue of ROCs varies according to technology. Tidal stream energy in the UK receives 2-5 ROC/MWh. In the UK, ROCs typically trade at between £45-£55 each (€54.45/€66.55). A UK tidal energy developer could be looking at receiving £200/MWh (€242/MWh), subject to market conditions.

   The UK ROC system will be replaced in 2017 by a guaranteed price system (contract for difference - CfD), similar to a feed-in tariff. Many other countries offering price subsidies for renewable energy offer a guaranteed price in the form of a feed-in tariff (FiT). Examples include: France €150/MWh (ocean energy); Spain €68.9/MWh (all renewables, recently withdrawn); Portugal €190-260/MWh (recently withdrawn); Denmark €80/MWh; and Ireland has proposed a FiT but the value has not been announced. The FiT schemes in Spain and Portugal have been suspended due to the financial crises.

2. **Technology Push (supply side)** - actions aimed at directly stimulating technology development. This includes capital grants for commercial demonstration projects and targeted research funding. Many examples exist. In the UK, R&D grants have included Supergen 2 (£5.5m), EPSRC Marine challenge call (£6m); Technology Strategy Board Marine Energy Programme (over £20m awarded), and funding for key research facilities, e.g. FLoWaveTT wave and current test facility (£9.5m). Various capital grant schemes in the UK have committed over £100m for marine energy demonstration activities. Other countries are also investing, for example, Ireland has a €10m prototype development fund and invests in test facilities.

3. **Enabling Actions** - actions intended to remove impediments, overcome barriers or speed up development. These might include test facilities, infrastructure development and permitting schemes, data collection and dissemination. The UK government has focused on enabling activities to help commercialise each activity. Key to this has been the establishment of test facilities for prototype devices. NaREC has received over £10m in funding and focuses on component testing with full-scale marine drive train test rig facilities. EMEC has received over £15m of funding to provide a grid-connected test facility for full-scale wave and tidal prototype devices. The wave test site has six grid connected berths. The tidal test site currently has eight test berths, all leased to tidal energy developers (Fig.2.2). This is the greatest concentration of full-scale tidal current deployment in the world. Other important enabling activities include the development of streamlined consenting processes and guidance.

Fig.1.2: Layout of the EMEC tidal energy test site at the Fall of Warness, Orkney, Scotland



1.2.2 Tidal development potential

Quantified projections for installed tidal stream energy capacity, globally and by country, are highly variable and speculative at this stage of the industry development. There are many forecasts but they are general in nature and frequently contradictory. They present an optimistic but confusing picture, made more difficult by the inclusion of wave and tidal power together in many cases. Best estimates of the global installed capacity might be 1GW (wave and tidal) by 2018 [IEA 2012]. A middle-case 2050 scenario by the UK Carbon Trust [2012] is 13GW (tidal only); their most optimistic case scenario is 52GW of tidal by mid-century. Potential may best be judged at this stage by the activities of test centres such as EMEC and the work that has gone on globally to identify developable tidal stream resources.

The European resource has been summarised by Aquaret and is shown in Fig 1.3 [www.aquaret.com]. The most promising sites, around Orkney, the Western Isles of Scotland and in Northern Ireland, are the early focus of testing and development. The first sites identified for large scale tidal arrays are in the Pentland Firth and Orkney Waters. Here, agreements to lease seabed areas have been made with developers and consenting applications are in progress. The target is to install a capacity of 1GW in five sites by 2020 (Fig 1.4). The main focus of the search for suitable sites elsewhere in the world is summarised in Table 1.5.

Fig. 1.3: Tidal stream resource sites in Europe

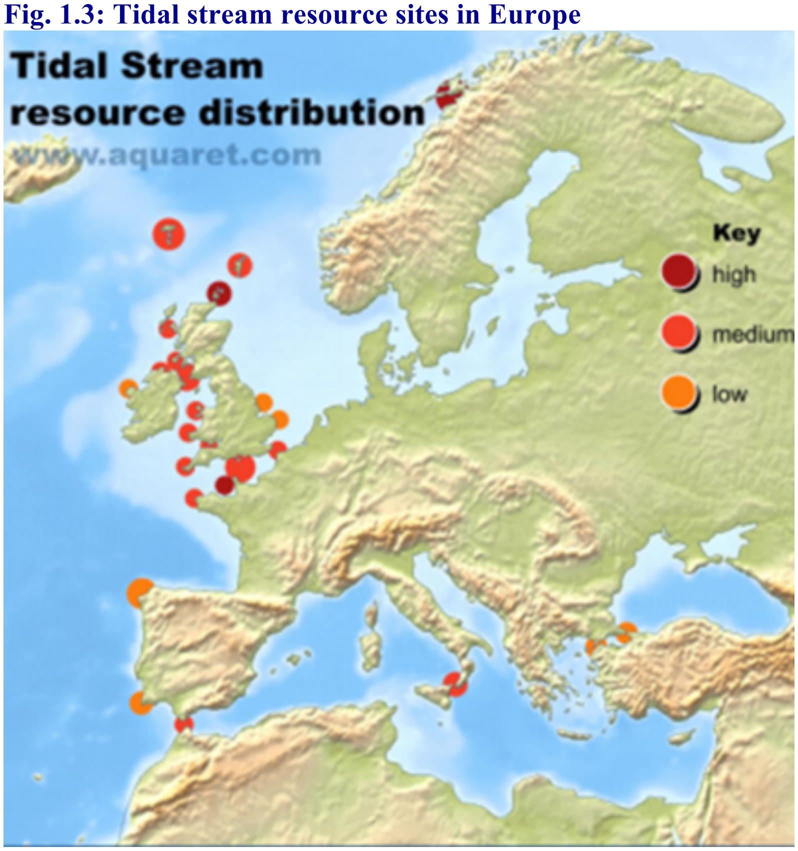


Fig. 1.4: Pentland Firth and Orkney waters Development Area

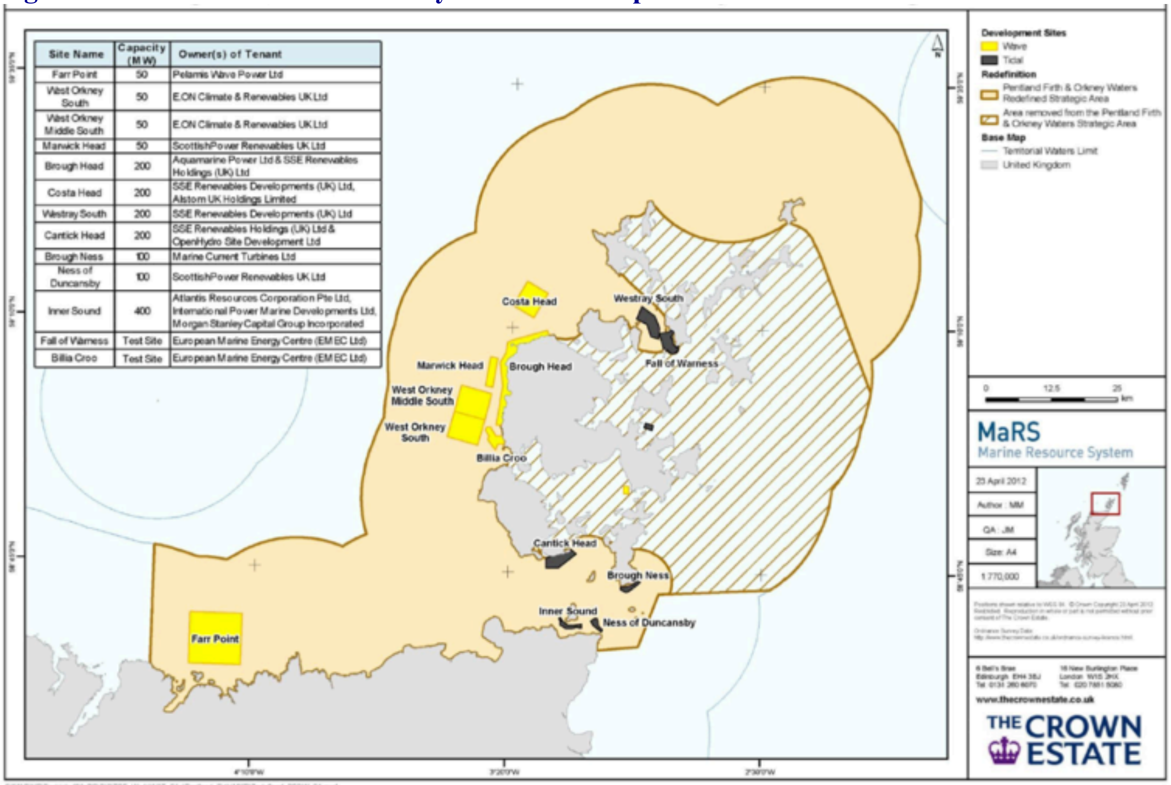


Table 1.5: Key tidal stream resource sites by country

Country	Key Sites	Description
Australia	Clarence Strait, Darwin; Port Philip Heads, Victoria and Banks Strait, Tasmania	10MW tropical test site planned at Clarence Strait by Tenax Energy. Future 500MW possibility.
Canada	Bay of Fundy, Nova Scotia	Research and studies underway.
China	Not named	Studies reported to be underway.
France	Brittany; St Malo	Major barrage at Rance (1966); tidal stream studies underway.
Netherlands	Not named	Studies underway for 50/100MW.
New Zealand	Kaipara Harbour	200MW project currently on hold.
South Korea	Uldolmuk (50/100MW); Daebang (10/20); Changjuk (100/200); Maenngol (200/300)	South Korea has largest installed and constructing capacity of barrage. Now focused on tidal stream sites in the south of the country.
United Kingdom and Northern Ireland	Pentland Firth and Orkney Waters; Islay Sound; Strangford Lough; Channel Islands	Full scale trial devices installed. Preparation and consenting in progress for large scale arrays.
United States	US potential tidal power sites mapped and published in 2012	Federal grant of $16m for 17 tidal energy projects announced in August 2013.

1.3 Value Proposition

1.3.1 Understanding Value Propositions

The aim of this section is to describe the value propositions that have been used in other countries (primarily the UK) to justify government expenditure and encourage private sector support for tidal stream. Before considering the results of various studies, it is necessary to consider the role of the value proposition (VP) in the development process.

In simplistic terms, renewable energy VPs are used to provide a picture of future benefits of an emergent industry, justifying government support for pump-priming initiatives and encouraging investor confidence. Whilst the rationale for private sector investment is generally focused on future profitability, the interests of the public sector are wider. Public sector interests in renewable energy generally fall under the headings of: economic growth, energy security, and climate change (see Table 1.6).

Table 1.6: Public sector interests in renewable energy

Criteria	Typical Motivators	Potential Measures
Economic growth	- Economic prosperity - Unemployment - Address regional disparities - First mover advantage	- Jobs potential (direct & indirect)) - GVA - Export market (electricity & tech.) - Inward investment - Cost of electricity (compared to existing commercial technologies)
Energy Security	- % of external supply - Depletion of conventional resources - Age of existing capacity - Geopolitics - Increasing energy demand	- TWh potential - Households supplied - Timescale for delivery - Cost of electricity (compared to alternative sources)
Climate Change	- Climate change commitments (national and international) - Lack of alternative solutions	- % contribution to renewable energy supply (TWh) - Tonnes CO2 avoided - Cost of carbon avoided (compared to alternative clean tech.)

The VP must address these criteria however the relative importance of each of these will vary. It is tempting to think of a VP as a flow of evidence, collated by industry and then presented to government in an attempt to release public sector funding. The reality is more complex. While some of the data presented in the following sections has been prepared specifically on behalf of industry, many studies are the results of private/public sector cooperation. Work that has been sponsored by public sector agencies often has a strong industry input. Other studies have been commissioned by joint industry/government working groups. Much of the published literature has been produced by relatively small number of engineering and economic consultancies. The academic community also plays an important role, providing baseline information (e.g. theoretically available resource) or core methodologies (learning curves, economic multipliers etc.).

This collaborative approach has advantages. In particular, it should allow the hands-on experiences of developers to feed into VPs. These relationships should also help public sector agencies target public funding and design appropriate support strategies. However, there is also potential for the recycling of information in different reports. Multiple studies producing broadly similar results may not represent a broad base of independent evidence but rather the recycling (or reworking) of the same information. Added to this, there is always a danger of an institutional *optimism bias* emerging. Indeed all-early predictions of the rate of deployment of wave and tidal energy have proved to be overly optimistic. This should become less of a problem as predictions are increasingly supported by evidence from real deployment.

1.3.2 Data sources and context

Most of the data in the following sections are taken from UK-based reports. The UK has the best developed understanding of its marine energy resource and is most advanced in terms of planning for future development and implementing practical support. Consequently, the UK leads the world in terms of device development and deployment. There are a multiple reasons for this, chief amongst these are:

- The largest wave, tidal current and offshore wind resources in Europe;
- An island nation with declining oil and gas resources, increasing dependency on imported energy and an ageing energy generation infrastructure;
- Commitments to CO2 emission reduction targets;
- Early academic research into device design and resource assessment;
- Negative experience from onshore wind where technology was developed in the UK in the 1980's followed by a failure to commercialise the technology (FREDS/MEG 2004). European wind energy manufacture is now focussed in Germany Netherlands and Spain.

It is noteworthy that, in Europe and the UK, there are multiple layers of government, each with slightly different priorities (see Table 1.7). These differences are reflected in different VP analyses, some of which take a broad perspective of national or European opportunities, while others are highly focused, even to the point of examining specific facilities or specific devices (see Westbrook 2012 and SQW2009).

Table 1.7: Policy Drivers and Actions for different levels of governance in the EU, UK and Scotland

	European Union	UK Government	Scottish Government	Local Government
Key Policy Drivers	CO_2 reduction targets - 20% by 2020 & 80% by 2050	Climate change & renewable energy targets (15% of energy from renewables by 2020)	UK marine energy resource is concentrated in Scotland	LG and regional development agencies focussed on local economic benefits and developing local supply chain to realise opportunities and retain benefits in local area
	As an energy importer, reliant on Russian gas, diversification of supply is a priority	Ageing generating capacity, increasing demand, and falling supplies of gas make energy security a priority	A nationalist SG wants to demonstrate that Scotland can be an energy exporter	Securing community benefit payments is a priority for some local authorities
	Integration of EU grid is to address intermittency of renewable energy supplies	The UK must identify a portfolio of energy sources to fill the emerging energy gap	Need to identify future employment opportunities and potential contributor of tax revenue	Balancing the space needs of existing sea users with incoming developers is an increasing concern
	Integrated Maritime Policy views the marine economy as key to EU growth	Aware of potential for jobs and technology exports. Aware of previous failure to exploit UKs research lead in wind energy	Status as global leader in wave and tidal power is symbolically important	
	Balancing environmental protection and development (e.g. Habitats Directive; Marine Strategy Framework Directive)		SG has its own CO_2 reduction targets; and a nuclear free energy policy	
Example Actions	Overarching policy infrastructure (binding CO_2 reduction targets)	Market rules and regulation and subsidy regime (e.g. RoCs, CfD, trading arrangements).	Planning and licencing regimes (e.g. development of one-stop-shop licencing, and Marine Spatial Planning)	Investing in local infrastructure (ports harbours)
	Market conditions (e.g. EU Emission Trading Scheme)	Direct grant funding	Financial support (enhanced ROCs, Saltire Prize, WATERS)	Encourage local supply chain
	Research funding (e.g. FP7, H2020, Interreg, KICs)	Research funding (EPSRC, NERC, UKERC etc)	Baseline environmental research to avoid regulatory delays and duplicated effort	Small business grants
	Infrastructure funding: ERDF (e.g. grid strengthening projects, ports and harbours)	Infrastructure investment (e.g. test facilities)	Infrastructure investment	Lobbying national institutions (e.g. grid and planning issues)
		Grid access rules (connection and transmission rules)		

1.3.3 UK and Irish tidal energy resource

It is something of a paradox that while tidal current technology is more advanced than wave technology, the extent and nature of the tidal resource is less well understood.

In the UK, the Carbon Trust commissioned a key tidal stream resource study in 2004-5. Phase I of this study estimated a 'Total Resource' of 110TWh/year and a 'Technically Extractable Resource' of 22TWh/year (Carbon Trust 2004). A phase II study reduced this to 18TWh/yr concluding that 12TWh/yr could be economically exploited. It was estimated this would require 3GW of installed capacity generating over 3% of UK electricity demand (Carbon Trust 2005). A recent update of this assessment has increased to 20.6TWh/yr (base case) and 30TWh/yr (optimistic) (Carbon Trust 2011). This represents about 10% of UK electricity consumption. Approximately 35% of this resource exists in deep-water sites in the Pentland Firth. The recent upgrade of resource is largely due to improved tidal modelling. Uncertainties still exist and other work has suggested that the UK tidal current resource may be larger by as much as an order of magnitude (MacKay 2007, Salter 2009). However, the 2011 Carbon Trust study is widely adopted as the best available assessment and more recent studies have produced broadly similar estimates for the Pentland Firth, the largest single resource in Europe (Draper et al 2014).

Most VPs take Carbon Trust (2011) figures as the best estimate of the UK resource. The 2012 Low Carbon Innovation Group (LCIG) study assumes a best case of 20-30TWh/year (LCIG2012). However, some industry reports have been significantly more optimistic. The Offshore Valuation Group produced estimates of practicable resource at 116TWh/yr (OVG 2010). OVG cite Mackay (2007) as corroborating evidence for their high estimate. This optimistic estimate then forms the base case of the OVG economic analysis (2.3.7).

An early study of the all-Ireland tidal energy resource estimated that the accessible tidal resource was in the order of 2.63TWh/y (6.3% electricity consumption), with an economically viable resource of 0.92TWh/y (2.2% electricity consumption) (SEI 2004). Building on this, DCENR (2008) suggest the practicable resources 914 GWH/y for all Ireland (541GWh/y located in Northern Ireland). This report also alludes to a potential 3.1Twh/y available of Ireland not accessible to first generation devices (DCENR 2008).

1.3.4 Estimates of installed capacity

In the UK, a 1993 Department of Trade and Industry (DTI) review of UK tidal resource concluded that resource was large but prospects of achieving economic viability were poor (DTI 1993). The report cited challenging locations with most of the resource in deep water as key constraints. This, combined with distance from the market, resulted in the conclusion that the sector did not warrant public support. However, continued private sector interest and changing political priorities resulted in a 2001 review of commercial prospects for tidal stream generation (ETSU 2001). The 2001 review concluded that, new designs offered a "*practical and robust method*" of exploiting tidal stream resources and that assumptions contained in the 1993 review had "*underestimated significantly*" the energy available from a single device (ETSU 2001).

This change in outlook stimulated a series of assessments and roadmaps with future growth projections and it is clear that deployment progress is not keeping pace with some of the earlier timelines suggested. The Scottish Government advisory group FREDS (Forum for Renewable Energy Development Scotland) roadmap report projected 1.3GW of wave and tidal energy capacity installed by 2020 (FREDS/MEG 2004). Using this figure as a guide and having surveyed marine developers they anticipated that 160MW of marine energy devices would be operational by 2010. The actual figure that had been deployed in the UK by the end of 2010 was 2.8MW. Table 1.8 below highlights some of estimates of future installed capacity that have been made for the UK.

Table 1.8: Estimates of Future Tidal Current installed Capacity (MW)

Source & date of estimate	Prediction date	Estimated capacity MW low	medium	high	Notes
ETSU (1999)	****	***	10,000	11,000	Estimate of “accessible” resource
Scottish Executive (2001)	2010	***	1,607	***	Constrained capacity Scotland
	2020	***	1,274	***	Constrained capacity Scotland
FREDS (2004)	2020		1,300		Wave & tide in Scotland
Marine Energy Group (2009)	2020	500	1,000	2,000	Development scenarios selected for supply chain analysis
Renewables UK (2010)	2021	1,300	***	2,000	UK wave and tide
OVG (2010)	2050	2,000	9,000	21,000	Based on high estimate of resource (2.3.x)
LCICG (2012)	2050	0	2,500	5,000	Notes potential for all or nothing
Renewables UK (2013)	2023	56	238	676	UK wave and tide

A number of reasons exist for the high level of variation in the figures presented above. OVG (2010), for example, used a very high estimate of the available resource. It is important to note that the understanding of the total resource has changed significantly in recent years. The LCICG (2012) figures are based on the most up-to-date estimates of total resource (Carbon Trust 2011b).
It is noteworthy that RenewablesUK has downgraded their 20-year projections. This reflects a change in the anticipated pace of development rather than reassessment of ultimate capacity. While UK investor confidence in in tidal current technology remains high relative to wave, a recent Crown Estate review highlights a number of issues emerging after a decade of experience (Crown Estate 2013). Chief amongst these are:

- Market confidence: the government needs to signal its continued long-term support for the wave and tidal sector in its new Electricity Market Reform package.
- Readiness of Technologies: investment required in research, which focusses on project design installation and integration.

- Progress is required to enhancing grid capacity. A circular delaying effect has emerged where project developers require guaranteed grid availability to proceed and the grid company requires certainty over development delivery in order to invest in upgrades.
- Environmental impacts and consenting needs to address remaining uncertainties concerning science and data collection. Resources should be out in place to speed up consenting processes.

Outside the UK, detailed assessments of future installed capacity have been fewer. In Ireland, a DCNER (2008) study suggested that all island installations might "credibly range" between 2MW (2010), 12MW (2012), 20MW (2015) and 70MW (2020). The highest estimates in this study, based on most optimistic estimates of cost reductions, suggest that 200MW could be developed by 2020 (DCNER 2008). The European Ocean Energy Association has suggested that total European wave and tide installed capacity would be 3.6GW in 2020 rising to 188GW in 2050 (EU-OEA 2010).

1.3.5 The Cost of Electricity (CoE)

The levelised cost of electricity (CoE) is the metric used in most VPs to describe the cost of generating electricity from tidal current technologies. CoE is also a tool widely used to compare the costs of different generating technologies and has been adopted by the International Energy Agency (IEA) to make comparisons between technologies, regions and countries. The CoE methodology utilises the standard investment appraisal technique of discounting to convert all costs (over the expected life of the project) into a single present value. Future expected annual generation (MWh) is also discounted and summed to produce a present value. The two values are combined producing a cost/MWh. The CoE method is used *inter alia* to demonstrate that renewable energy technologies are increasingly competitive, or have the potential to become competitive compared to conventional technologies. Consequently, this has become an important metric for government, investors and developers. Significantly, the IEA now include the cost of carbon in their estimates of CoE for conventional technologies. This improves the relative performance of low carbon technologies compared to coal, gas and oil. The use of CoE raises a number of issues that are relevant to the following discussion:

- Renewable Energy Technologies (RETs) typically exhibit high capital and installation costs and low future costs. In the case of onshore wind, investment costs typically account for 70-90% of the CoE, the remainder being operations and maintenance (O&M). In the case of gas, the situation over 70% of the CoE may be attributed to the cost of gas making electricity prices highly susceptible to gas price volatility. Electricity prices from renewable technologies should be relatively stable.
- The CoE from RETs may be <u>highly location specific</u>. With conventional technologies (gas coal, nuclear etc.), the load factor (device efficiency) is a known quantity and largely independent of the location. The load factor of RETs may be intimately linked to the energy availability at a specific location. Onshore wind developments across Europe may exhibit load factors between 15 – 45% which explains the wide variation in the reported CoE from wind (110-245 USD/MWh, IEA 2010). While many studies generalise about CoE from wave and tidal, actual CoE will be significantly influenced by resource availability at specific locations.
- Discounting reduces the PV of future values. This means that relatively less emphasis is placed on far future costs (e.g. decommissioning).
- Higher discount rates will tend to make RETs (with high investment expenditure in the short run) look relatively less attractive compared to conventional technologies (with future or ongoing costs – e.g. fuel or decommissioning).
- Exchange rate fluctuation can have a significant impact on CoE in any particular country where component parts or entire devices are being imported.

1.3.6 Future CoE reduction and learning rates.

It is generally not current CoE for tidal energy that interest governments and investors but the potential for costs to be reduced in the future. For example, offshore wind current costs in the UK are £140-£180/MWh with potential to fall to £100/MWh by 2020 and then £60/MWh by 2050 which is cost competitive with conventional technologies (LCIG 2012a). These future projections have a significant influence on support for the sector. CoE may fall over time through a combination of reduced cost and increased yields. Cost reductions may be achieved through:

- *Economies of scale*: this relates to the size of individual devices; the scale of individual developments; and the mass production of devices.
- *Technical innovation*: this includes improvements in component design, improvements in procedures (e.g. installation); innovation in manufacture.

Actual costs reductions observed over time may be represented graphically as a *learning curve*. Alternatively they may be described as a *learning rate* i.e. a % reduction in costs each time installed capacity (experience) doubles. There is great interest in applying values estimated for existing technologies to estimate future cost reductions in emerging technologies. In the case of onshore wind there is wide variation in published learning rates with some as high as 30% (Lindman and Soderholm 2012). While referring to learning rates in other energy sectors does provide a starting point, it can also be misleading (Jamasb and Kohler 2007). Some technologies are more suited to mass production (e.g. photovoltaic) than others. Also learning experience that has already happened in one sector (e.g. offshore wind) cannot necessarily be repeated in another. The Low Carbon Innovation Group argued that the greatest scope for innovation driven cost reductions in tidal energy will be associated with (i) moorings & foundations and (ii) installation processes (LCIG 2012b). In the UK, the Carbon Trust (2011b) adopted 12% as a mid-range learning rate value for tidal current technologies.

1.3.7 CoE estimates for tidal current technologies

The 1993 DTI UK tidal stream review concluded that tidal stream technologies were not economically viable (DTI 1993). However a reappraisal of this work in 2001 concluded that the best sites around the UK may be capable of producing electricity at a cost of £40-60/MWh and that these figures were the "*right order of magnitude to encourage commercial interest"* (ETSU 2001). At the same time investigations of the Scottish renewable resources were making assumptions about future capacity based on assumptions of £70/MWh in 2020 and £50/MWh. Most recently, the Low Carbon Innovation Coordination (LCICG 2012) suggest that CoE from existing tidal energy technologies are £200-300/MW and that a pathway way to £100/MWh is required for viability of the sector. Achieving this kind of reduction in cost can only be achieved through large-scale arrays of at least 200MW. A summary of five analyses carried out between 2006 and 2011 is given below:

(1) In 2006 the Carbon Trust published an assessment of the cost competitiveness of tidal stream technologies (Carbon Trust 2006). This analysis used current estimates of prototype CAPEX (4,800 – 8,000/KW) to produce estimates of CAPEX for first commercial deployments (£1400-4,800/KW). Then adding operation and maintenance estimates and then applied learning rates to various development scenarios to estimate future CoE.

Date of Study 2006	First commercial farms (2006)	Future estimates (based on 10% learning and various installed capacities)
Pessimistic	£180/MWh	£70/MWh
Base	£120-150/MWh	£50/MWh
Optimistic	£90/MWh	£30/MWh

(2) As part of an analysis of the likely future subsidy required by wave and tidal energy technologies Ernst and Young (2010) made the following assessment of future levelised cost for tidal current technology.

Date of Study 2010	2050 estimates with learning. Deep water	2050 estimates with learning. Shallow water
Pessimistic	£129/MWh	£166/MWh
Base	£102/MWh	£138/MWh
Optimistic	£82/MWh	£111/MWh

Source Ernst and Young (2010)

(3) In 2010 Offshore Valuation group gave current CoE for tidal stream in the range £135-£241/MWh a judgement based upon literature and "expert interview." It should be noted that a 10% discount rate was used which is advantageous (OVG 2010). After learning and based on their middle case scenario estimate of resource and rate of deployment:

Date of Study 2010	2050 estimates with learning.
Pessimistic	£106/MWh
Base	£79/MWh
Optimistic	£59/MWh

Source: OVG (2010)

(4) As part of a general 2011 review of all renewable energy technologies in the UK and building on the Ernst and Young (2010) study, the Department of Energy and Climate Change (DECC) estimated CoE from tidal current as follows:

Date of Study 2011	2030 estimates with learning. Deep water	2030 estimates with learning. Shallow water
Pessimistic	£161/MWh	£196/MWh
Base	£140/MWh	£171/MWh
Optimistic	£121/MWh	£149/MWh

Source DECC (2011)

(5) Carbon Trust (2011b) produces a range of results based on an analysis of the 30 most productive sites around the UK. Base case costs without learning were assessed for each site these ranged from £170-900/MWh. However costs are highly location specific with resource availability as a dominant variable (see 2.3.x). Based on practical resource estimates, with learning taken into account, at a 15% discount rate, a range of future average tidal current CoE were established for the UK.

Date of Study 2011	Average UK CoE with Learning
Pessimistic	£452/MWh
Base	£210/MWh
Optimistic	£155/MWh

Source: Carbon Trust (2011b)

It is important to note that these averages are for electricity production across 30 UK sites. Whilst the values for Pentland Firth sites dominate (with 35% of the resource) other UK sites are more expensive to develop and therefore increase average values. Within these calculations the best projections for the Pentland Firth deep-water sites are below £100/MWh.

1.3.8 Employment

The prospect of generating employment from tidal energy is, of course, a key driver behind public support for the sector. The prospect of new employment is part of a wider interest in the potential for economic growth associated the maritime economy. It is estimated that the EU 'Blue Economy' already employs 5.4 million people (Ecorys 2012). 'Blue Growth', the sustainable expansion of the blue economy, including marine energy, is at the heart of the EU's Integrated Maritime Policy (IMP) and the Europe 2020 strategy (EU 2012). Increasing pressure on land-based resources and the opportunities created by new technology is causing many countries to consider growing their blue economies (e.g. Zhao 2014).

While all analyses agree that tidal energy development will create employment, placing a figure on this is challenging. There is already considerable uncertainty concerning the scale and timing of future development (see 2.3.4). While uncertainty is high in all estimates of future employment, uncertainty tends to increase as the geographic unit decreases in size. At the local level, a decision about where to locate a supply base may create an all-or-nothing situation. At a regional level, the capacity of the supply chain to respond to the opportunities created by tidal generation will determine how much employment is captured. Competition between fabrication facilities in different countries may create a strong international dimension to the eventual distribution of employment. There are several factors which make estimating employment challenging:

- Predictions of installed capacity;
- Timeline for development;
- Estimates of construction costs;
- Capacity of local/regional supply chains to capture market;
- The development profile of the industry – e.g. will generation be distributed or are economised of scale important;
- Logistics – will the industry centralize operations and maintenance;
- The strength of any income/employment multiplier effect;
- Will fabrication be close to the deployment site or distant (overseas);
- Are there export opportunities – if so, what are predictions for deployment elsewhere?

Despite the inherent difficulty in making such predictions, a number of estimates have been made and again the UK is the focus of this work. It is worth noting that much of the literature considers wave and tidal development together. While there is a strong argument for treating the two sectors separately, not least because the development of tidal technology is ahead of wave, it is the case that in Europe that the resources are geographically coincident (e.g. PFOW). There has also been a working assumption that the fabrication processes; supply chains; support needs and regulatory control of wave and tidal come under one umbrella. Consequently, the two sectors are often considered together.

Most of the studies that have examined marine energy employment have adopted an assumed ratio of jobs/MW during the build period and then again for operations and maintenance (O&M) going forward. These ratios have been derived through consultation with developers and comparison with other sectors (onshore wind). Multipliers may be added to provide an assessment of indirect employment. More sophisticated econometric approaches have been attempted with the use of Input-Output (IO) models and Computable General Equilibrium (CGE) methods (Grant et al 2014). All approaches are, of course, subject to many of the same underlying assumptions mentioned above – not least of which are predictions of resource and installed capacity.

Summaries of various employment predictions for the UK and Scottish marine energy sectors have been set out below. There is significant variation based on starting assumptions (in particular installed capacity). The least and most optimistic estimates suggest between 1,000 and 20,000 jobs, with the medium cases in most studies falling between 5,000 and 10,000 jobs.

(1) In 2004, the Scottish Executive Forum for Renewable Energy Development's Marine energy Group stated a belief that by 2020, "*we could see 1300 Megawatts of marine installed capacity in Scottish waters*" and that "*7,000 direct jobs could be created*" (FREDS/MEG 2004).

(2) A 2007 report, prepared for the Scottish Executive, suggested that a total of 17.4 jobs/£m capital investment at the installation stage for wave and tidal energy. Based on scenarios of 330MW and 650MW installed by 2020, this could create a net gain of between 2,340 and 630 jobs in Scotland, peaking around 2015 (Scottish Executive 2007).

(3) The Scottish Marine Energy Group's 2009 report adopted a base case with 1,000MW installed wave and tidal capacity by 2020 (MEG 2009). The report estimates that 5,020 jobs will be created with 53% retention in Scotland (2,647). This is based on 20 jobs /MW capacity in development phase plus 0.5 jobs/MW for O&M of installed devices. Indirect and induced jobs were not fully included in this study.

(4) The Offshore Valuation Group produced estimates of direct jobs in the marine energy sector by 2050 (OVG 2010). These are summarised below.

	Low	**Medium**	**High**
All Marine (inc. wind)	71,000 (78GW)	145,000 (169GW)	342,000 (406GW)
Wave	2,000 (2GW)	4,000 (5GW)	4,000 (14GW)
Tidal Current	2,000 (2GW)	8,000 (9GW)	19,000 (21GW)

The Offshore Valuation Group estimates appear to be made with reference to estimated fabrication costs and experiences from other sectors. This includes people working in the installation, operation and maintenance but not elsewhere in the supply chain. While the estimates of installed capacity are high compared to other studies, the ratio of jobs/MW is lower than other analyses.

(5) Considering wave and tidal energy together, in 2013, Renewables UK estimated the following direct and indirect employment in 2023 for three development scenarios.

	Low (56MW	Medium (328MW)	High (676MW)
Direct	649	5,631	9,148
Indirect	1,447	6,476	13,873

These figures are a downgrade from an earlier study that estimated the marine energy sector could employ 19,500 individuals (Renewables UK 2011).

(6) Allan et al (2014) used IO and CGE methods to estimate Scottish employment peaks of between 5,700 and 12,200. Total employment, over the study period, ranged from 35,835 to 50,212 person years, depending on method used. These estimates were based on the 1.6GW of wave and tidal development planned for the PFOW being completed by 2020 and assuming a total spend of £5.4bn (£2.2bn of expenditure in Scotland) (see Crown Estate 2011). Previously, an alternative model (AMOSENVI) was used by the same group. This analysis looked at the impacts of expenditure required to deliver 3GW of capacity by 2020, estimating a net growth in employment in the region of 15,500 jobs (Allan 2008).

While most published work has focussed on the UK, a recent all-Ireland study estimated employment associated with wave and tidal energy as follows:

Employment 2030

	Low	Medium	High
Market capture	(577 MW)	(800 MW)	(800 MW)
High (technology exporter)	852	8,465	17,259
Medium	368	3,642	7,679
Low (technology importer)	92	887	1,986

Source: SQW 2010

This assessment was based on different estimates of installed capacity and three predictions of market capture. The installed capacities adopted are based on the highest predictions given in an earlier resource assessment (see DCENR 2008). The least optimistic prediction of market capture assumes that all manufacture would take place overseas and employment would be limited to operations and maintenance. The most optimistic scenario assumes that Ireland becomes a major exporter of tidal energy technology. This study illustrates how the level of market capture has a significant impact on estimates of employment.

At the wider level, the European Ocean Energy Association has predicted, by 2020, the EU ocean energy sector will generate over 40,000 direct indirect jobs and predict, by 2050, this will increase to 471,320 (EU-OEA 2010).

Annex 2

Levelized Cost of Tidal Energy and Cost Reduction

The costs of tidal energy are not yet well known. There have been pre-commercial installations of TEC devices but no arrays as of yet. Costs are quite high at this stage of development. Developers consider cost information proprietary, so publically available information is scant. There are several reasonably well-informed estimates, however. These are described in this review of the literature.

2.1 The Cost of Electricity (LCOE)

The levelized cost of electricity (LCOE) is the metric used in most value propositions to describe the cost of generating electricity from tidal current technologies. LCOE is also a tool widely used to compare the costs of different generating technologies and has been adopted by the International Energy Agency (IEA) to make comparisons between technologies, regions and countries. The LCOE methodology utilises the standard investment appraisal technique of discounting to convert all costs (over the expected life of the project) into a single present value. Future expected annual generation (MWh) is also discounted and summed to produce a present value. The two values are combined producing a cost/MWh. The LCOE method is used *inter alia* to demonstrate that renewable energy technologies are increasingly competitive, or have the potential to become competitive compared to conventional technologies. Consequently, this has become an important metric for government, investors and developers. Significantly, the IEA now include the cost of carbon in their estimates of LCOE for conventional technologies. This improves the relative performance of low carbon technologies compared to coal, gas and oil. The use of LCOE raises a number of issues that are relevant to the following discussion:

- Renewable energy technologies typically exhibit high capital and installation costs and low future costs. In the case of onshore wind, investment costs typically account for 70-90% of the LCOE, the remainder being operations and maintenance (O&M). In the case of gas, over 70% of the LCOE may be attributed to the cost of gas, making electricity prices highly susceptible to gas price volatility. By contrast, electricity prices from renewable technologies should be relatively stable.
- The LCOE from renewable energy technologies may be highly location-specific. With conventional technologies (gas, coal, nuclear, etc.), the load factor (device efficiency) is a known quantity and largely independent of the location. The load factor of renewable energy technologies may be intimately linked to the energy availability at a specific location. Onshore wind developments across Europe may exhibit load factors between 15 – 45% which explains the wide variation in the reported LCOE from wind (110-245 USD/MWh, IEA 2010). While many studies generalize about LCOE from wave and tidal, actual LCOE will be significantly influenced by resource availability at specific locations.
- Discounting reduces the present value of future costs. This means that relatively less emphasis is placed on far future costs (e.g. decommissioning).
- Higher discount rates will tend to make renewable energy technologies, with high investment expenditure in the short run, look relatively less attractive compared to conventional technologies, with future or ongoing costs (e.g. fuel or decommissioning).
- Exchange rate fluctuation can have a significant impact on the LCOE in any particular country where component parts or entire devices are being imported.

2.1.1 LCOE estimates for tidal current technologies – UK and Europe

The 1993, DTI UK tidal stream review concluded that tidal stream technologies were not economically viable (DTI 1993). However, a reappraisal of this work in 2001 concluded that the best sites around the UK may be capable of producing electricity at a cost of £40-60/MWh[1] and that these figures were the "*right order of magnitude to encourage commercial interest"* (ETSU 2001). At the same time, investigations of Scottish renewable resources were making assumptions about future capacity based on assumptions of £70/MWh in 2020 and £50/MWh. Most recently, the Low Carbon Innovation Coordination (LCICG 2012) suggest that LCOE from existing tidal energy technologies are £200-300/MW and that a pathway to £100/MWh is required for viability of the sector. Achieving this kind of reduction in cost can only be achieved through large-scale arrays of at least 200MW. A summary of four analyses carried out between 2006 and 2011 is given below:

(1) In 2006, the Carbon Trust published an assessment of the cost competitiveness of tidal stream technologies (Carbon Trust 2006). This analysis used current estimates of prototype CAPEX (4,800 – 8,000/KW) to produce estimates of CAPEX for first commercial deployments (£1,400-4,800/KW). They added operation and maintenance estimates and then applied learning rates (discussed later) to various development scenarios to estimate future LCOE.

Date of Study 2006	First commercial farms (2006)	Future estimates
Pessimistic	£180/MWh	£70/MWh
Base	£120-150/MWh	£50/MWh
Optimistic	£90/MWh	£30/MWh

(2) As part of an analysis of the likely future subsidy required by wave and tidal energy technologies, Ernst and Young (2010) made the following assessment of future levelized cost of energy for tidal current technology.

Date of Study 2010	2050 estimates Deep water	2050 estimates Shallow water
Pessimistic	£129/MWh	£166/MWh
Base	£102/MWh	£138/MWh
Optimistic	£82/MWh	£111/MWh

Source Ernst and Young (2010)

(3) In 2010, the Offshore Valuation Group estimated current LCOEs for tidal stream in the range £135-£241/MWh, a judgement based upon literature and "expert interview." It should be noted that a 10% discount rate was used, which is advantageous (OVG 2010). After learning and based on their middle case scenario estimate of resource and rate of deployment, they derived the following:

[1] £1=CA$1.83
[2] US$1-CA$1.10

Date of Study 2010	2050 estimates
Pessimistic	£106/MWh
Base	£79/MWh
Optimistic	£59/MWh

Source: OVG (2010)

(4) As part of a general 2011 review of all renewable energy technologies in the UK and building on the Ernst and Young (2010) study, the Department of Energy and Climate Change (DECC) estimated LCOE from tidal current as follows:

Date of Study 2011	2030 estimates Deep water	2030 estimates Shallow water
Pessimistic	£161/MWh	£196/MWh
Base	£140/MWh	£171/MWh
Optimistic	£121/MWh	£149/MWh

Source DECC (2011)

(5) Carbon Trust (2011b) produces a range of results based on an analysis of the 30 most productive sites around the UK. Base case costs without learning were assessed for each site. These ranged from £170-900/MWh. However, costs are highly location specific with resource availability as a dominant variable. Based on practical resource estimates, with learning taken into account, at a 15% discount rate, a range of future average tidal current LCOE was established for the UK as follows:

Date of Study 2011	Average UK CoE
Pessimistic	£452/MWh
Base	£210/MWh
Optimistic	£155/MWh

Source: Carbon Trust (2011b)

It is important to note that these averages are for electricity production across 30 UK sites. Whilst the values for Pentland Firth sites dominate (with 35% of the resource), other UK sites are more expensive to develop and therefore increase average values. Within these calculations, the best projections for the Pentland Firth deep-water sites are below £100/MWh.

2.1.2 LCOE estimates for tidal current technologies – North America

Black and Veatch/NREL

Black and Veatch (2012) produced a report on the cost and performance data for various power generation technologies with data drawn from their database, built from years of consulting in the energy industry. The costs they report are from the period 2009 to 2010 and are in US$2009.[2] They project a broad breakdown of costs and performance data for various energy generation technologies in 5-year increments to 2050.

For tidal energy conversion, Black and Veatch/NREL draw on a modest amount of experience in tidal energy and published data in the UK and Europe. Their estimated costs begin with a 2015 installation of 10-MW farm and assume 50MW of capacity has been installed worldwide. All values varied with the quality of the resource where devices would be installed. Assuming the best (high-band resource) locations would be developed first, the base case estimates by Black and Veatch/NREL are as shown in Table 2.1.

Table 2.1: Base Case Estimates by Black and Veatch/NREL

Base case Year	Cap cost (US$/kw)	Fixed O&M (annual cost per kW)	Cap. Factor	LCOE US$/MWh	Quality of location
2015	$5,940	$198	26%	$358	High-band resource
2020	4,401	147	26%	$358	High-band resource
2025	3,498	117	26%	$358	High-band resource
2030	3,267	112	23%	$444	Medium-band resource

NREL/B&V 2013, p. 89.

FERN Engineering Challenges Subcommittee

In 2012, the Engineering Challenges Subcommittee of the Fundy Energy Research Network produced estimates of the cost of a 1 MW turbine installation in the Minas Passage. They are summarized in both the MacDougall (2013) and SLR (2013) reports.

UARB/Synapse

In Nova Scotia, the most recent and complete estimates of tidal energy costs is the 2013 submission to the Nova Scotia Utilities and Review Board by Synapse Energy Economics for the development of feed-in tariffs. Synapse consulted with potential project developers and staff at the Fundy Ocean Research Centre for Energy (FORCE). For a 10 MW farm, Synapse estimated the capital costs to be CA$71.3 million and annual operating and maintenance costs of $5.3 million per year and a decommissioning cost, net of salvage, of $5.2 million (15 year economic life, 2% inflation, 10% after-tax discount rate). Synapse estimated the 2013 LCOE to be approximately CA$465/MWh.

2.2 Cost Centers

There are very few breakdowns of the CAPEX or OPEX estimates publically available. Cost centers include: design, engineering, permitting; structure and prime mover; power takeoff; station keeping; grid connection, installation, operation and maintenance.

The UK Low Carbon Innovation Coordination Group (LCICG) is a coordination vehicle for the major UK public sector backed funding and delivery bodies for the low carbon industries. In 2012, the LCICG produced a technical needs assessment (TINA) for marine energy [LCICG

[2] US$1-CA$1.10

2012]. The assessment is UK specific but with generic application to the emerging marine energy industry worldwide. In common with many such reports, the assessment combines wave and tidal considerations. The TINA assessment of technical innovation and its impact is summarised in Table 2.2. These technical and associated non-technical challenges feed directly to the tidal stream cost of energy (LCOE) and are exacerbated by the FOAK (first of a kind) nature of the devices.

Table 2.2: Technical elements and innovation (wave and tide)

	Element of System	Description	Desired innovation outcome	Proportion of cost of energy (tidal stream)
1	Structure and prime mover	The fluid mechanical process whereby the device captures energy from the ocean.	Design optimisation for at sea performance; alternative materials; batch production to reduce manufacturing costs.	circa.15%
2	Power take-off	Conversion technology from kinetic energy to electrical energy.	Improvements in control systems and software. Next generation of power take off technologies.	circa.10%
3	Foundations and moorings	The means to hold the device in place by fixed structures and foundations or flexible or rigid moorings.	More durable and cost effective moorings and seabed structures. Improved station-keeping technologies.	circa.15%
4	Connection	The method whereby the energy is transferred from seas to shore (electrical or hydraulic).	Development of next generation cables, connectors and transformers. Improved 'wet mate connectors' for marine application.	circa.10%
5	Installation	The process of on-site construction and fixing.	Improved installation techniques and vessels. Drilling techniques better suited to working in tidal currents.	circa.35%
6	Operations and Maintenance	The lifetime process of keeping the device in operation.	Improved lifecycle design; retrieval systems and remote monitoring.	circa.15%

In the various reports, the cost centers are broken down differently, making comparisons difficult. However, some similarities are evident. They are summarized in Table 2.3 below.
The percentages vary across studies. Part of this is due to the particular device design being used in the analysis and whether it is held in place by a gravity base or pile.

Table 2.3: Cost Centers

Cost Center	UARB/ Synapse 2013	Cost Center	Carbon Trust 2011	TINA 2012	SI Ocean 2013
	% Total Cost		% LCOE	% Total Cost	% lifetime costs
Design, engineering, permitting	6%	Station Keeping/Foundations & moorings	13%	10%	14%
Structure	21%	Structure & Prime Mover	12%	15%	13%
Power/Electrical	19%	Power takeoff	9%	10%	10%
Subsea connection	5%	Connection	10%	15%	5%
Grid connection*	-				
Installation	11%	Installation	30%	35%	27%
Monitoring and Control	1%	Control	11%		12%
Decommissioning	1%				
Total capital costs	65%	Total capital costs	85%	85%	81%
O&M (PV annual costs)	35%	O&M (PV annual costs)	15%	15%	19%
Total	**100%**	**Total**	**100%**	**100%**	**100%**

*Subsea cable to shore and connection to the transmission grid will be installed by FORCE with a capacity of 64MW.

The most recent and regionally relevant cost breakdown was provided by Synapse Energy Economics to the Nova Scotia Utility and Review Board in 2013. This study will begin with those weightings and cost centers as the base case for this analysis.

2.3 Cost reductions over time

The cost of energy from tidal energy, which is function of expenditures and energy yield from devices, is expected to decrease over time. Learning-by-doing, learning-by-research, and economies of scale all play a role in the decrease. Learning-by-doing occurs as experience is gained through practice. Subsequent TEC devices, installation, operations and maintenance become less costly and more efficient. The cost reductions and energy yield arising from learning-by-doing can be improved upon through research and development (learning-by-research) activities to improve the technology and procedures. Economies of scale are generated as more devices are placed in a tidal farm allowing for common costs to be spread over more units, such as cables to shore, substations, connections to the grid, operations and greater utilization of dedicated fixed assets such as vessels used for installing and retrieving devices for repair. These cost reductions will also arise from the supply chain as it develops and gains experience, works with developers and operators to improve products and processes, undertakes research and development, benefits from economies of scale and the supply industry becomes more competitive.

The historical costs of wind energy serve as an example of cost reductions that are possible over time. Lantz, Hand and Wiser (2012) report on historical costs of wind energy in Denmark and the US for the period 1980 to 2009. From the 1980s to 2004, the capital costs declined approximately 55% in Denmark and 65% in the US. This, along with improved turbine performance, reduced the LCOE of wind energy by a factor of 3, from approximately US$150/MW in the 1980s to $50/MW in the early 2000s. From 2004 to 2010, turbine prices rose due to supply chain constraints, material and labour prices, and exchange rates. This trend has moderated since. Citing their earlier study, Lantz et al project continued capacity factor improvements. Furthermore, advances in the technology have improved the viability of low wind speed sites such that the land area that could achieve a 35% capacity factor or better increased by 270 %, compared to the technology available in the 2000s (Lantz et al 2012, pp. 1-3).

There are various approaches to estimating cost reductions (LCOE) over time. A top-down approach applies learning rates. A bottom-up approach looks at what particular costs can be reduced. A hybrid of these two would be learning rates by cost category. The latter two yield a closer look at where in the process of developing tidal energy the best gains in cost reduction per unit of energy can be derived but details are scant at this stage.

Bottom-up

The Brattle Group (2013), in analyzing the economic potential of offshore wind in the United States, highlighted areas where cost reductions would occur, citing reports generated by the Crown Estate in the UK. They project a 39% reduction in LCOE between 2011 and 2020. They note the largest contributors to this reduction are advances in technology and supply chain improvements. Supply chain improvements will come from scale-related learning, increased productivity, changes in planning and permitting activities, and the entrance of more competitors. They also note other areas where improvements will lower costs: array optimization, improved ex-ante site characterization, better use of surveys, earlier involvement of the supply chain, optimized installation methods and standardization (p. 17). Finally, they note the impact of financing costs on the cost of energy, stating a 1% decrease in capital cost could to lead to a 6% reduction in LCOE (p.18). It is reasonable to expect these types of improvements would also impact the LCOE of tidal energy conversion over time.

Some factors put upward pressure on costs. For instance, working in deeper water and further from shore can raise the cost of energy. Intensity of competition, bottlenecks in the supply chain, availability of specialized vessels, ports and labour, commodity prices, and exchange rates can also cause costs to rise, as was experienced by the UK offshore wind industry (Brattle Group, 2013).

Learning rates

The application of a learning rate to estimate cost of energy reductions due to industry experience generally begins after 50MW of capacity has been installed worldwide. The estimated cost is then reduced by the learning rate percentage with every subsequent doubling of cumulative global capacity (e.g. 100, 200, 400, 800 MW, etc.)

Black and Veatch/NREL (2012) project a learning rate for tidal energy ranging from 7-15%, using 11% as their mid-range estimate. Learning rates for other, more developed, technologies are summarized in their report (p.71). SI Oceans (2013) estimates a 12% learning rate for tidal energy conversion. The European Commission (2014) estimates a 5-10% learning rate. In the UK, the Carbon Trust (2011b) adopted 12% as a mid-range learning rate value for tidal current technologies.

The use of learning rates, though common, is more multifaceted and prone to bias than it appears. Learning rates are drawn from studies of past technologies: their cost decreases and the global installed capacity over time. However, a many other variables, besides global installed capacity, are at play: raw material prices, scale effects (economies of scale), design differences (e.g. larger turbines), policy impacts, research and development activities, and innovations. The effects of these other variables are difficult to discern and even more difficult to predict. Economies of scale are generally blended into the cost decreases from which the learning rate is derived so tend to lead to an overstatement of what is actually the learning-by-doing rate. For instance, their empirical analysis of wind power installations in Europe, Soderholm and Sundqvist (2007) found an observed learning-by-doing rate of 5% was reduced to 1.8% when savings due to economies of scale were measured.

Thus, the suitability of a learning rate from another time, location and technology, such as past onshore or offshore wind power in the UK, may be poor. Accordingly, learning rates and the resulting cost reductions should be applied and interpreted with caution.

Hybrid Approach

Two recent reports have broken down estimated learning rates by cost center. The Technology Innovation Needs Assessment 2012 Marine Energy Summary Report (noted earlier) does this to emphasize where research and development can have bigger impact. The Carbon Trust (2011) does a similar breakdown, describing what cumulative cost reductions can be generated. The learning rates/cost reductions by cost center in the two reports are summarized in Table 2.4 below.

Table 2.4: Learning Rates/Cost Reductions by Cost Center

	Learning Rates		
	Carbon Trust 2011	TINA 2012	
Component/Sub-area	Learning Rate	Cumulative Cost Reductions	
		by 2020	by 2050
Structure and prime mover	12%	35%	55%
Power takeoff	13%	20%	35%
Station-keeping/foundations & moorings	12%	40%	60%
Connection	2%	15%	30%
Installation	15%	55%	80%
O&M	18%	35%	55%

Carbon Trust (2011) p.23; TINA (2012) p.7.

2.3.1 Potential for LCOE reductions in Nova Scotia

The learning rates by cost center, when weighted by the proportion of total costs of TEC development, show some areas where significant gains can be made. They highlight areas where focused R&D support could have greater impact on the costs of energy from tidal energy conversion. Much of the work summarized by of these cost centers also can also be sourced locally. These suggest where the fertile ground is for both cost reductions in Nova Scotia/Canada and innovations that would benefit the global tidal energy industry. The cost centers of the base case used in this study (Synapse 2013) and the Carbon Trust (2011) learning rates are juxtaposed in Table 2.5 below.

Table 2.5: Learning rates by cost center

Cost Center	Base case - Cost centers as % of total costs	Learning rates (Carbon Trust 2011)
Design, engineering, permitting	6%	
Structure	21%	12%
Power/Electrical	19%	13%
Subsea connection	5%	2%
Monitoring and Control	1%	
Installation	11%	15%
Decommissioning	1%	
Total capital costs	65%	
O&M	35%	18%
Total costs	**100%**	

Carbon Trust (2011), Low Carbon Innovation Coordination Group (2012), Renewable UK (2013) describe activities in these target areas that can be effective in reducing the cost of tidal energy. Closer to home, SLR (2013) reports on the key cost reduction measures the Nova Scotia ocean technology sector could address through innovation and collaboration.

Annex 3

Estimating the Plausible Installed Capacity for Nova Scotia's Tidal Energy Industry

3.1 Assessing Tidal Potential

The discussion below establishes that the Early Adoption scenario of 500 MW for Nova Scotia is reasonable based on the development of Minas Passage alone.

Assessing the potential of a tidal resource is still a developing science. Researchers have made considerable progress in measuring and modeling the raw potential of tidal resources, but there remains considerable challenges in estimating how much of this resource can be converted into generated electricity by arrays of tidal turbines. Many factors must be considered from the efficiency of the turbines, to practicality of deploying turbines in a shared resource, to the environmental impacts of removing energy from the system. Estimating each of these factors for each potential location is beyond the scope of this work. We will simply build on previous works (Karsten et al 2008, Karsten et al 2012, Karsten 2012) and similar analysis of resources in the U.K. (Carbon Trust 2012; TINA 2012). What is clear from these previous works is that only a fraction of the potential tidal resource can be considered for plausible development

In order to discuss how one can calculate the plausible resource for a given tidal stream, we will adapt the terminology and discussion found in the Carbon Trust discussion of the U.K resource. Here are definitions from Carbon Trust (2011):

- Theoretical Resource – Maximum energy that can be harvested from tidal currents in the region of interest without consideration of technical, economic or environmental constraints.

- Technical Resource – The energy that can be harvested from tidal currents using envisaged technology options and restrictions (including project economics) without undue impact on the underlying tidal hydrodynamic environment. The technical resource is hence a proportion of the theoretical resource.

- Practical Resource – The energy that can be harvested from tidal currents using envisaged technology options and restrictions (including project economics) without undue impact on the underlying tidal hydrodynamic environment, and allowing for the impact of key external constraints excluding grid constraints (e.g. shipping, fishing, MOD etc.). The practical resource is hence a proportion of the technical resource.

The Carbon Trust document estimates that the technical resource is between 12.5% and 43% of the theoretical limit of the resource. They applied a restriction of a reduction of tidal flow or tidal range that was less than 10%. In Karsten 2013, a similar calculation for Bay of Fundy passages found that the extractable power was in the range of 25%-58% of the theoretical limit. It was estimated that installed capacity was 70% of the extractable power, while the actual electricity generated was only 40% of the of the extractable power (this assumed a very efficient turbine, and resulted from a very high capacity factor of over 55%). Therefore the estimate of technical power in Karsten 2012, is in the range 10% to 23% of the theoretical limit, or roughly in line with the U.K. estimates.

In the two tables below, we give the estimates for each resource level for Minas Passage (and for comparison for the resource for Pentland Firth, likely the most similar tidal resource in terms of scale and potential development in the foreseeable future, and the entire U.K. as taken from CT 2011 and Draper et al. 2013).

It is worth noting that of the 20 TWh/y practical U.K. resource, only about 3.7 TWh/y can be realized with current technology - that is technology that can be deployed in shallow waters. Much of the remaining resource lies in deep waters (35-75 m) and would require the development of 2nd generation turbine technology capable of extracting energy from the mid-depths of these deeper waters.

Pentland Firth represents over 1/3 of the U.K.'s tidal resource, with the vast majority of the resource in deep waters. While the resource contained in the deep waters of Pentland Firth are considered the most difficult resource to develop, they are also the resource that can produce the lowest Cost of Energy, due to the speed of the flow and large size of the turbines. Thus, this resource is critical to any development of the U.K. tidal energy industry.

Minas Passage plays an even more important role in the development of Canada's tidal energy industry, at least for the next 25 years. The other potential large resource locations, the west coast of Canada or Hudson Strait, are unlikely to be developed until large commercial farms are established in Minas Passage.

Table 3.1 Estimated Resource in terms of mean power generation for Minas Passage and Pentland Firth

Location	Theoretical Limit	Technical Resource	Practical Resource	Plausible Installed Capacity
Minas Passage	6000-8000 MW	1600-2500 MW	800-1000 MW	500 MW
Pentland Firth	4000 MW	1000-1500 MW	680-800	
All U.K.		3300 MW	2350 MW	

Table 3.2 Estimated Resource in terms of Annual Energy Production for Minas Passage and Pentland Firth

Location	Theoretical Limit	Technical Resource	Practical Resource	Plausible Installed Capacity
Minas Passage	50-70 TWh/y	14-22 TWh/y	7.0-8.8 TWh/y	4.4 TWh/y
Pentland Firth	35 TWh/y	8.8-13 TWh/y	6-7 TWh/y	
All U.K.		29 TWh/y	20.6 TWh/y	

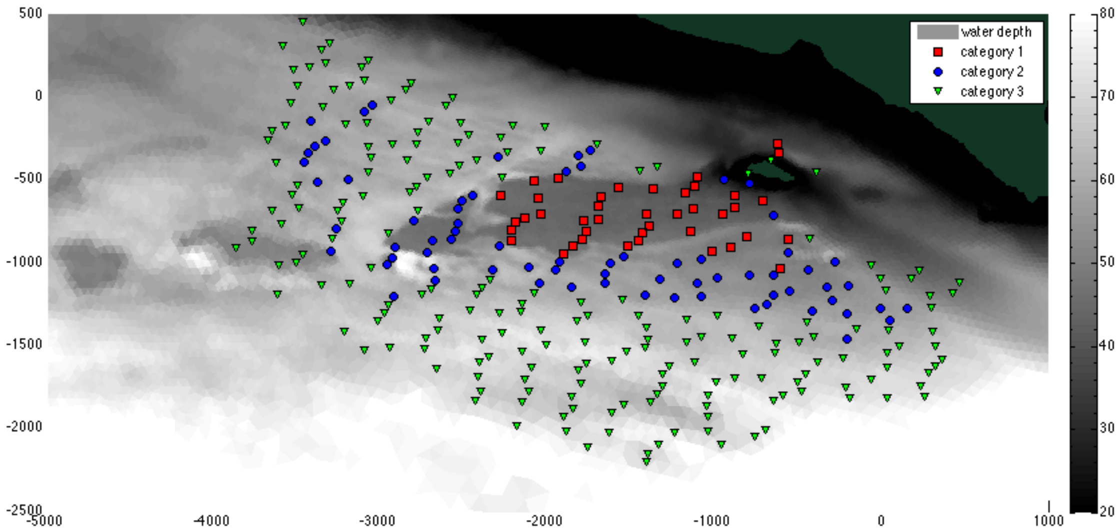
3.2 Minas Passage turbine deployment

We extend the previous analysis of Karsten et al. (2008, 2012, 2013) to estimate a plausible turbine deployment array in the region surrounding the FORCE site. In doing so, a plausible installed capacity for Minas Passage and a capacity factor for these turbines can be calculated. The locations are shown in Figure 3.1.

The turbines have been classified into three categories, based on a rough assessment of the difficulty to install the turbines and the amount of energy they would produce. Category 1 is easy to install and high power generation; Category 2 is more difficult to install or lower power generation; Category 3 is the most difficult to install. The first category should be plausible with today's technology. The deeper locations of categories 2 and 3 would require 2nd generation turbines suitable for deeper water (similar to the requirements for development of the deep locations in Pentland Firth).

Some of the locations shown in Figure A3.1 would be undesirable for turbine deployment due to other reasons not considered here (seabed conditions, cable connections, high turbulence in flow, wake interactions, environmental reasons). For example the deployment locations near Black Rock may not be suitable. Therefore, we consider the Early Adoption scenario of 500 MW to be a plausible installed capacity for Minas Passage.

Figure 3.1: Plausible turbine locations in Minas Passage



The markers indicate the possible locations of turbine that have been spaced appropriately. The gray shading indicates the mean water depth. The distances are shown in metres.

Category	Minimum Capacity Factor	Depth Range	Distance from FORCE Power Station	Number of turbines	Installed Capacity	Mean capacity factor	Mean Power Generated
1	40%	30-50 m	2500 m	41	82 MW	45%	37 MW
2	35%	30-60 m	3000 m	112	224 MW	41%	96 MW
3	30%	30 – 75 m	4000 m	315	630 MW	37%	247 MW

Table 3.3: Standard turbine design

Rated Power	2 MW
Rated Speed	2.5 m/s
Cut in speed	1.0 m/s
Cut out speed	5.0 m/s
Diameter: single turbine	28 m
twin turbines (each)	20 m
Cross flow spacing	50 m from turbine centre to turbine centre, roughly 1 turbine diameter between turbines
Along flow spacing	250 m in each direction – allows for a wake that is 10 turbine diameters in length

A few notes on the calculation presented. The water speed used comes from a high-resolution, month-long, 2D numerical simulation of flow through Minas Passage. In practice, turbines could be designed to match the conditions at each deployment location, possibly increasing or decreasing the rated speed and power, as necessary. However, the flow in the FORCE region is much stronger on the flood than ebb. This makes it difficult to design a turbine that generates a large amount of power and a high capacity factor.

This analysis does not account for the effect of the turbines on the strength of the flow through the passage. Previous work has shown that, for the amount of power generated by these turbines, the effect on the overall flow through Minas Passage will be minimal (approximately a 1% decrease in flow).

The distance used is the distance to the current location of the FORCE power station. If additional land-based power stations were constructed, a few other locations along Minas Passage or Minas Channel could become possible Category 3 sites.

Finally, we comment on the development potential in other sites in Nova Scotia. As discussed in Karsten 2013, the Digby Neck passages could support an installed capacity of about 65 MW. However, most of this is located in Digby Gut and would require the development of a second or third generation of turbine that could extract power from lower water speeds and be deployed in deep water. A plausible development for the Digby Passages would be in the 5-15 MW range.

Annex 4

Details of Tidal Development Supply Chain Requirements and Opportunities

Source: Acadia Tidal Energy Institute, Community and Business Toolkit for Tidal Energy Development, Opportunities and Strategies for Businesses

4.1. Pre-Project Planning

SITE SCREENING			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
• Energy conversion technology • Energy storage/usage • Prototype testing • Investment	• Universities • Government and industrial labs Research granting agencies	• Tidal/wave tanks	• Technical expertise (technology choice assessment) • Electrical engineer • Research support • Financial services
• Desktop screening exercise based on available data to identify sites • Early stage resource assessment • Constraints analysis including preliminary identification of First Nations interests, conservation areas, archaeological sites, infrastructure, and other marine environment users such as fishing, commercial transportation, recreational transportation, defence • Analysis of financial feasibility • Identification of high-level site-related health and safety hazards for future assessment and to inform design of Safety Plan • Identification of a suitable grid connection point and determination of availability • Logistics analysis – identification of suitable harbours, associated services, and infrastructure • Identification of marine renewable energy technology that will best fit the project objectives and identified sites	• Engineering and environmental consulting • Financial services • Universities • Government	• Desktop modeling tools • Acoustic Doppler Current Profiler (ADCP)	• Technical expertise (technology choice assessment) • Electrical engineer • Research support • Health & safety expertise • Financial services

ENVIRONMENTAL & TECHNICAL ASSESSMENT			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Environmental Scoping and Surveys • Environmental surveys are used to assess whether a project could have an impact on a species that live in, use, or frequent the marine environment, both in the sea and air. Surveys address benthic species, fish, marine mammals, birds, and onshore species. • Planning for multiple surveys • Operation of vessels for use and management of survey equipment • Aerial surveying where coverage of larger area is required • Collection and evaluation of data to provide information on project development issues • Analysis and interpretation of survey data	• Technical/research consultancy • Universities/researchers • Offshore/marine survey vessel business	• Vessel (range of vessels can be used including local fishing crane, 30m long vessels, and specialist physical surveying vessels for environmental surveying) • Surveying, trawling, and imaging equipment • Aircraft (helicopter) for aerial survey)	• Vessel operator • Helicopter/ aircraft operator • Marine biologist, ecologist, environmental scientist, and/or local knowledge from fishers, etc. (should have knowledge of local species)
Physical Surveys • Coastal process surveys and seabed surveys are used to examine the subsea environment and potential impact of tidal energy projects, particularly on sedimentation and erosion. Existing bathymetry and seabed geomorphology (geophysical and geotechnical conditions) are investigated to further refine the location and extent of the deployment area, assess the fixing and mooring requirements, and outline a corridor for the cable route. The geomorphology of the seabed can also provide an indication of the likely benthic habitats in the area. • Onshore geotechnical conditions should also be assessed in order to identify technical requirements for onshore works and cable installation. These use a mix of desktop studies and on-site investigations. • Planning for multiple surveys • Operation of vessels for installation and management of survey equipment • Collection and evaluation of data to provide information on project development issues	• Offshore/ marine survey vessel business • Technical/ research consultancy • Universities/ researchers	• Specialized vessel • Surveying, trawling, and imaging equipment	• Vessel operator • Knowledge of sediment transfer • Geotechnical engineer

ENVIRONMENTAL & TECHNICAL ASSESSMENT, CONTINUED			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Meteorological and Resource Assessment/Monitoring • Measurement of meteorological and metocean conditions are necessary to enable detailed model of resource characteristics (wave heights, wave periods, tidal speeds, and direction of both waves and tides). Data collected is used alongside historical and modeled outputs to inform project design. The final resource assessment stage is completed once the technology is chosen and serves to determine the exact location of each device. • Planning for the deployment of instruments • Operation of vessels for installation and management of subsea deployment of acoustic profilers (ADCP) • Deployment and collection of ADCP measurements • Collection and analysis of weather patterns in the area • Collection and evaluation of acoustic data to provide information on project development issues	• Technical and research consultancy services to interpret and advise on modeling data (data analysis and resource modeling, site conditions and device suitability analysis)—metocean • Ocean technology supplier (instruments, ADCPs, etc.) • Offshore/ marine survey vessel business • Universities/ researchers	• Meteorological instruments and packaged instruments (ADCPs) • Dynamic positioning vessel • Remotely operated vehicles (ROV)	• Meteorology expertise • Vessel operator • ROV operator • Diver
Electrical Connection The availability of a suitable grid connection with sufficient capacity for the proposed project is integral for moving forward with the project. After identifying suitable grid connection points, a developer must begin discussions with the operator of the electrical grid. • Discussion with System Operator of the electrical grid • Identification of technical and contractual agreements for connection and associated costs	• Technical/ engineering consultancy • Legal services		• Electrical engineer • Technical expertise • Lawyer

4.2 Project Implementation

PLANNING			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Public and Stakeholder Consultation Developers will engage with the local community throughout the life of the project. Extensive consultation with stakeholders, especially those more likely to be affected by the project, is typically undertaken during the preparation of an Environmental Assessment (EA). • Design of a consultation strategy and plan • Identification of potential stakeholders • Ongoing and formal engagement with First Nations • Production of materials for public consumption that provide project details and future development plans • Arrangements for public event/meetings • Collection of stakeholder input and analysis to inform project design, preparation of permit/approval applications, and EA	• Public relations firm/consultant • Consultants with existing EA expertise	• Meeting/conference space (local community centre or hotel)	• Consultant with knowledge of key local stakeholders and their relevant interests in a project may be required • Public Relations expertise
Mi'kmaq Ecological Knowledge Study (MEKS) There are sites in Nova Scotia that have particular cultural significance for the Mi'kmaq of Nova Scotia, who may use them to support traditional or current practices for food, social, or ceremonial purposes. A MEKS should be conducted to identify areas of historical and current use in the project area and to help to ensure that traditional knowledge informs project design and development. • Determine MEKS scope in consideration of project requirements and proposed site	• MEKS services[1]	• Geographic Information Systems (GIS) technology • Geographical Positioning Systems technology.	• Mi'kmaq traditional knowledge experts

[1] There are currently three MEKS firms in Nova Scotia: The Confederacy of Mainland Mi'kmaq, Mi'kma'ki All Points Services and Membertou Geomatics Consultants.

PLANNING, CONTINUED			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Environmental Assessment (EA) Although EAs have basic requirements and common elements, they should be project and site specific. They are informed by scoping and surveying conducted during the feasibility stage of project development. The EA considers the impacts of the project through the installation, operation, and decommissioning phases. Parameters assessed include: coastal and sedimentary processes, marine ecology (including benthic ecology, marine mammals, and cetaceans), fish resources and commercial fisheries, marine navigation, cultural heritage and archaeology, ornithology, terrestrial ecology, landscape and visual impact, road traffic and access, tourism and recreation, water/sediment/soil quality, noise and air quality, and socio-economics. • Surveys and specialist investigations to provide a description of current environmental features (baselines) • Data gathering according to criteria defined by the previous surveying and scoping • Modeling and specialist studies to predict potential environmental impacts and evaluation, identification mitigation measures, identification of uncertainties, assessment of cumulative effects, and identification of monitoring requirements/plans • Input from stakeholders/consultees from continued dialogue on scope of surveys and studies, likely impacts, and mitigation measures • Design of potential monitoring program	• Consultants with existing EA and related specialist experience	• Physical and biological environmental monitoring and data processing equipment (E.g. ADCP’s)	• Environmental/ resource management expertise (background in planning, environmental studies, biology, ecology, etc.)

PROJECT DESIGN AND IMPLEMENTATION			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Other Legal, Permitting, and Approval Requirements Project developers will need to prepare applications and documentation for all legal and permitting requirements including: land lease, power purchase agreement, regulatory approvals, financial agreements, and insurance. • Preparation of land lease document, permits/approvals applications • Preparation of application for negotiation of electrical grid connection conditions including modeling of device and array power quality output (if applicable), power project interconnection studies • Design of Safety Plan (addressing operational and occupational health and safety issues) • Determination of financing options and building of a financial team • Clarification of required insurance during the construction and operating phases covered by plant suppliers, construction, and installation contractors	• Detailed experience in the permitting and approval of projects within the marine environment • Legal services • Financial services • Insurance supplier • Health & safety consultant		• Legal expertise • Consulting services (health & safety expertise) • Electrical engineer • Technical expertise • Health & safety expertise • Legal expertise • Financial expertise
Project Design The project design is developed and refined in parallel to the EA. Findings from the environmental surveys and studies should feed back into the design and technical specification. This process should also set the basis for the preparation of suitable procurement and contract strategies. Technical specifications and drawings will assist in the drafting of the contract documents. • Evaluation of design options and outline of selected design using the following pre-set criteria: functionality, flexibility, operability, costs, proven performance, safety issues, environmental and socio-economic impacts, ease of installation, project risks, reliability, maintainability, and survivability. • Techno-economic analysis to determine the expected costs and revenues arising from the project to facilitate eventual financial investment decisions.	• Engineering consultant • Logistical support – marine architect		• Marine architect • Engineer

PROJECT DESIGN AND IMPLEMENTATION, CONTINUED			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Development of a Procurement Strategy A strategy for the procurement of services and materials to serve project lifecycle needs will be developed. Strategies are designed to select suppliers that provide value for money over the expected life of the project while ensuring supplier competence and quality of service. Design of a strategy typically takes the following factors into consideration: • Analysis of current market status and projected market trends • Research and consideration of rules and procedures for procurement applicable to project development • Analysis of risk between parties involved and development of management techniques for uncertainty • Development of procurement process timescales and integration with overall project program	• Consultant may be required depending project developers procurement and contract management experience.		• Financial, business administration expertise

PROJECT DESIGN AND IMPLEMENTATION, CONTINUED			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Detailed Design A detailed design of the project will commence once a project receives the necessary approval from regulatory authorities and the predicted technical and commercial performance of the project remains feasible and in line with project objectives. Technical studies will be undertaken to refine project design. • Assessment and detailed design of electrical equipment and cables (subsea and onshore) • Detailed design of Supervisory Control and Data Acquisition (SCADA) System, communications, and control equipment • Detailed design of onshore facilities and auxiliary equipment • Development of generation profiles and quality of generation based on selected technology to inform grid connection studies • Grid connection feasibility study and integration with network • Specification of safety features, navigational marking, and lighting • Detailed review of the selected technology • Marine logistics studies to optimize installation methods, vessel, and port requirements • Failure Modes, Effects, and Criticality Analysis (FMECA) to ensure the integrity and survivability of the project infrastructure and to optimize its reliability, availability, and maintainability. • Review and refinement of cost estimates and program • Update of the design risk register • Preparation of a Quality Plan	• Logistical support (inform on marine safety and standards requirements) • Consultants – Engineering, technical, OHS, planning (deployment) • Financial services • Universities/ researchers		• Marine architect • Marine engineer • Subsea electrical expertise • Health & safety expertise • Technical knowledge in marine renewable energy or parallel sectors including pressurized vessels, marine equipment, and aquaculture. • Electrical engineer • Financial expertise

ASSEMBLY AND FABRICATION			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Hydrodynamic System The hydrodynamic system is composed of the blades or hydrofoils and moves directly under the influence of forces applied by water. **Activities:** • Precision fabrication of blades and hydrofoils • Moulding and finishing of composite materials • Casting of metal structures used in providing buoyancy • Assembly of components with fasteners, welding, or other means • Design and production of pressure vessels for marine environment • Provision of coatings and treatments to control corrosion and marine growth • Workshop testing and verification	• Steel fabrication • Composites manufacturing	• Raw materials and parts: steel, composites	• Welders • Engineers
Reaction System The reaction system keeps the device in position and provides a static reference point for oscillating devices (mooring arrangement, gravity base, foundation, or foundation fixed to sea bed via piles). **Activities:** • Design of dynamic structure in the marine environment under frequent waves • Procurement, fabrication, and handling of large scale steel and concrete structure of up to over 1000 tonnes • Design, manufacturing, and installation of wire ropes, chains, and anchors	• Steel fabrication • Manufacturer • Concrete supplier	• Raw materials: steel, concrete	• Engineers • Procurement specialist • Expertise in corrosion and marine growth prevention • Local knowledge of marine conditions

ASSEMBLY AND FABRICATION			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Power Take-Off System The power take-off system converts the motions of a device's hydrodynamic system into electrical energy. This can be done in two ways – 1) with hydraulic actuators or a linear electrical generator, or 2) constraining movement with speed-up gearboxes or direct drive electric generators. • Production of gearboxes, bearings, and power transmission components	• Engineering/ technical consultancy	• Subsea connectors from device to inter-array cabling with voltage rating of 11kV and above.	• Electrical engineer • Mechanical engineer • Technical expertise
Control System The control system provides both supervisory and closed-loop control. It also includes auxiliary systems. • Design and production for high reliability applications	• Engineering/ technical consultancy	• Specialist sensors and data collection systems related to the marine environment to indicate pressure, movement, electrical characteristics, or environmental conditions. • Hydraulic actuators, valves, or other equipment. • Bearings and actuation components for use in yawing or pitching	• Experience in design and use of supervisory control and data acquisition (SCADA) systems • Engineers
Subsea Cabling and Connectors An electrical collector system is needed to connect individual devices to a common device interconnection point. There are two types of cables that are necessary for the operation of an in-stream tidal energy project. Array cables are required to connect strings of devices (if the project consists of an array) to an offshore substation and higher voltage cables are necessary to connect the substation to the onshore grid connection point. There is already very high demand for these types of cables from other industries and if manufacturing capacity does not increase, bottlenecks will likely occur. • Advise on selection of cable • Specify protection requirements	• Subsea cable supplier • Cable installer	• Large-scale and high precision cabling extrusion and assembly equipment • Cable armouring products to protect against extreme forces and ensure life of the conductor	• Electrical design knowledge • Mechanical engineer • Expertise in the production of insulation for cables to provide thermal and electrical protection

ASSEMBLY AND FABRICATION			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Electrical Equipment Transformers, switchgear, and other electrical equipment are likely to be based on conventional electrical power engineering products, but adapted to meet the needs of specific applications.	• Offshore electrical manufacturing		• Knowledge and understanding of design requirements of distributed generation and impacts of wave and tidal supply characteristics. • Electrical engineer
Foundations, Anchoring Systems, and Moorings In-stream tidal devices are anchored to the seabed. There are different types of systems for anchoring depending on device design. The following is a generalization of activities and supplies required to design and produce a foundation and anchoring system. • Production of large scale concrete structure • Fabrication of steel frame structure weighing up to over 500 tonnes • Assembly of various components	• Concrete supplier • Steel fabrication • Corrosion and marine growth prevention products	• Concrete • Cranes: lifting of various components into place for assembly and lifting assembly into barge for testing and deployment.	• Marine engineer • Expertise in the design of dynamic structures for the marine environment • Technical expertise • Welders • Marine architect
Other Project Stage Service and Supply Requirements: • Insurance: protection of owner from accidental damage to the components during fabrication and assembly • Transportation of component parts to site for final assembly	• Insurance supplier • Transport company	• Trucks	• Truck drivers and machinery operators

INSTALLATION & COMMISSIONING			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Procurement and Assembly Logistics • Identification of permitting requirements • Movement of materials procured from other jurisdictions	• Marine consultant • Customs broker for importing materials and guidance in obtaining proper permits for temporary use of barge		
Barge Requirements Supply vessels such as jack-up barges and crane barges will be required for lifting heavy loads. • Inspection of barge and associated equipment for compliance with regulations • Towing of barge through test program prior to deployment activities	• Marine consultant • Customs broker		
Deployment and Installation of Device • Preparation of device at port and float-out and install devices using general purpose vessels where possible • Marine logistics planning • Towing of barge and tidal assembly into place for deployment (and recovery) • Monitoring movement of marine life (lobster, fish, mammals, birds) during deployment for indication of change from normal behavior • Explore fish monitoring technologies at the turbine site (2-D and 3-D sonar) and follow fish patterns • Identification of acoustic signatures • Passive monitoring of acoustic noise from marine mammals to determine any effect or risk • View turbine in operation using side scan SONAR and camera on tether • Monitoring and analysis of anticipated wind and sea state during expected deployment/recovery window	• Engineering and environmental consultancy • Universities/ researchers • Diving services	• Fishing boats for transporting additional personnel and emergency response • Personal protective and safety equipment • Radios for communication between all parties involved in deployment • Instrumentation for communication with the assembly during deployment and recording of forces experienced on the assembly and other data to further understand environmental conditions and optimize design • Specialist tooling and ROVs • Marker buoys and navigational lighting	• Marine consultant for review and inspection and knowledge of local conditions and constraints • Electrical Engineer • Mechanical Engineer • System Engineers • Power Engineers • Certified welders (CWB Class 47.1) • Journeyman machinists • Customs broker to provide guidance in obtaining proper permits for temporary use of barge • Tugboat operator • Health and Safety/Emergency Response preparedness • Biologist, ecologist, or marine biologist • Diver

INSTALLATION & COMMISSIONING, CONTINUED			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Installation of Foundations and Moorings In-stream tidal devices are anchored to the seabed. The method by which it is anchored depends on device design (pin-piled, concrete gravity, multipoint mooring). • Offshore installation and assembly of various components	• Diving services	• Cranes • Specialist tooling • ROV • Support vessels • Specialist vessels (installation) • Drilling and piling operations	• Vessel operators • Divers • Marine drilling • Marine construction • Environmental monitoring • Construction supervision • ROV and tooling operator
Installation of Offshore Electrical Systems (including Cable Installation) • Grid connection upgrades • Procurement of cabling/electrical contractors and storage/testing of cables • Procurement of bespoke winches and drums for cable • Draw-through and installation of several kilometers of subsea cabling to avoid geohazards • Cable protection and securing using rock dumping (and potentially ROVs for pinning and active positioning around seabed features) • Directionally drilled pipelines from shore out to the location of devices • Installation and connection of the offshore substation and array cabling between devices (if applicable)	• Cabling/electrical contractors • Drilling contractor	• Power conditioning equipment (converters, generators) • Underwater substation pod—(transformers, switchgear) • Bespoke winches and drums for cable • Cable laying vessel • Special drilling equipment (carbon steel pipeline, fabricated-coated-assembled-welded) • ROV (optional)	• Electrical engineer • Technical expertise • LV Dynamic cable and MV Static Cable (with fibre optics) • Geotechnical knowledge • ROV operator • Subsea cable armouring/burial vessels and skills
Onshore Structures (if needed) Projects will likely include an onshore substation and control building. This could also be built to house some essential operations and maintenance staff. Given the remote location of some of these projects, it is also possible that a road may need to be built to provide for site accessibility. • Construction of building • Preparation of applications for any planning permits or approvals required by regulatory authorities	• Building contractor • Concrete supplier • Electrical contractor • Window installation • Telecommunications • Metalworks • Plumber	• Concrete • Building supplies • Windows • Plumbing supplies • Electrical	• Carpentry • Building design and construction • Electrician • Metal works • Plumbing • Telecommunications

INSTALLATION & COMMISSIONING, CONTINUED			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Other Project Stage Service and Supply Requirements: • Insurance: protection of owner from accidental damage to the components during fabrication and assembly • Project certification	• Insurance supplier		• Certification – permitting requirements

4.3. Operations and Maintenance

MANAGEMENT			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Operations • Review, monitoring, auditing, and managing environmental performance to ensure compliance with permit/approval conditions • Provision of information on environmental impact to stakeholders and regulatory authorities • Monitoring performance • Inspection of operations and activities • Planning and management of maintenance activities • Administrative activities related to customer, regulatory, and legal requirements	• Diving services • Consultants—engineering, technical, environmental • Administrative services • Port services and facility	• Computing systems • Navigation systems and data	• Dedicated operations staff and control centre • Marine engineer (class 4 or higher) for offshore and onshore maintenance work • Power Engineer (Class 1 and Class 4) • GIS services • Subcontractor support services • Vessels for ongoing environmental monitoring activities and inspection • Ecologists and marine biologists • Mechanical technicians • Electrical technicians • Health & Safety/Emergency Response • Business administration

MAINTENANCE			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Maintenance • Planned maintenance including retrievals using tugs and workboats • Management of unplanned maintenance	• Port facility • Consultants – engineering, technical	• Support vessels including tug boats and workboats • Portside lifting capability to lift the device to shore if needed (crane) • Local workshop facilities to allow for strip-down, refurbishment, re-assembly, and testing of devices. • Storage for replacement parts/PTO systems	• Dedicated maintenance staff and control centre • Mechanical technicians • Electrical technicians • Marine engineer (class 4 or higher) for offshore and onshore maintenance work • Welding and machining • Health & Safety/Emergency Response

DECOMMISSIONING			
Activities	**Suppliers**	**Equipment & Instruments**	**Skilled Workers & Knowledge Workers**
Decommissioning Plan • Prepared as part of the permitting conditions and revised over the life of the project • Consultation with regulatory authorities and stakeholders to determine decommissioning methodology and potential mitigation needs • Consideration of potential environmental impacts • Contains provisions for safe removal of the project infrastructure and disposal of removed equipment • Preparation of a suitable procurement strategy for the elements of the decommissioning work to be outsourced • Site surveys pre- and post-decommissioning	• Engineering and environmental consulting • Government		• Technical expertise • Engineers • Research support • Health & Safety expertise • Financial services
Decommissioning Fund • Fund set aside over life of the project to ensure that decommissioning and other costs will be covered	• Financial services		

Annex 5

Suppliers Contacted

Tidal Developers		
Large Scale	Minas Energy	www.minasenergy.com
	DP Energy	www.dpenergy.com
	Meygen	www.meygen.com
	Emera	www.emera.com
	Scottish Power	www.scottishpower.co.uk
	Open Hydro	www.openhydro.com
	Schottel	www.schottel.de
	Andritz	www.andritz.com
	Siemens	www.siemens.com
	Voith	www.voith.com
Small Scale	Clean Current	www.cleancurrent.com
	Tocardo	www.tocardo.com
	Ocean Renewal Power Company	www.orpc.co
	Fundy Tidal Inc.	www.fundytidal.com
Suppliers		
	Envirosphere Consultants Ltd	www.envirosphere.ca
	A.F. Theriault & Sons	www.aftheriault.com
	Aspin Kemp	www.aka-group.net
	Claire Machine Works	www.claremachineworks.com
	Akoostix	www.allswater.com
	Geospectrum Technologies	www.geospectrum.ca
	JASCO Research	www.jasco.com
	MacArtney (BC)	www.macartney.com
	Ocean Sonic Instrument Concepts	www.oceansonics.com
	Oceans Ltd	www.oceansltd.com
	Open Seas Instrumentation	www.openseas.com
	Rockland Scientific	www.rocklandscientific.com
	Allswater	www.allswater.com
	Hatch	www.hatch.ca
	Lengkeek Vessel Engineering Inc.	www.lengkeek.ca
	Matrix Consulting Inc	www.matrixconsultinginc.ca
	Stantec Inc	www.stantec.com
	Canadian Seabed Research Ltd	www.csr-marine.com
	McGregor Geoscience	www.mcgregor-geoscience.com
	Seaforth Engineering Group Inc.	www.seaforthengineering.com
	Dommінion Diving	www.dominiondiving.com
	Romor	www.romoroceansolutions.com
	Dynamic Systems Analysis, Ltd.	www.dsa-ltd.ca