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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Atlantic Canada Opportunities Agency
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Canada

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Abbreviations

AP	air pollutant
ATEI	Acadia Tidal Energy Institute
CAPEX	capital expenditures
CCS	carbon capture and storage
CGE	computable general equilibrium
CO_2	carbon dioxide
COMFIT	Community FIT
DPE	DP energy
DTI	Department of Trade and Industry
EC	European Commission
EMEC	European Marine Energy Centre
EPC	Engineering, Procurement and Construction
EU	European Union
FAST	Fundy Advanced Sensor Technology
FIT	feed-in tariff
FORCE	Fundy Ocean Research Centre for Energy
FTE	full-time equivalent
GDP	gross domestic product
GHG	greenhouse gas
GVA	gross value added
HAT	horizontal axis turbines
HVDC	high-voltage direct current
IEA	International Energy Agency
IMF	International Monetary Fund
IO	input-output
IPP	independent power producer
kW	kilowatt
LCOE	levelized cost of energy
LCICG	low carbon innovation coordination
MAC	marginal abatement cost
MRC	Marine Renewables Canada
MRE	marine renewable energy
MSP	marine spatial planning
MW	megawatt
MWh	megawatt-hour
N_2O	nitrous oxide
NSPI	Nova Scotia Power Inc.
NSERC	Natural Sciences and Engineering Research Council
O&M	operations and maintenance
OERA	Offshore Energy Research Association
OPEX	operating expenditures
PFOW	Pentland Firth and Orkney Waters
PV	present value
R&D	research and development
RDI&D	research, development, innovation and demonstration
RES	renewable energy standard
ROCs	renewable obligation certificates
ROV	remotely operated vehicle
SCC	social cost of carbon
SO_2	sulphur dioxide
SSE	Scottish and Southern Energy
TINA	technology innovation needs assessment
UK	United Kingdom
US	United States

Summary

1. Background

The world's oceans contain vast amounts of hydrokinetic energy. If harnessed, this resource has the potential to greatly reduce dependence on fossil fuels to meet increasing levels of electricity demand. In so doing, it also has the potential to create an entirely new industry, offering technical solutions to an emerging global industry and resulting in substantial socio-economic benefits for those nations with resource potential and a desire to support industrial and tidal project development.

The tidal energy industry is at an early stage of development. It relies heavily on various forms of public support for its research and development activities, and also on private investors. The industry benefits from feed-in tariffs in some jurisdictions (including Nova Scotia), as it moves to a commercial stage of development. Governments and industry recognize that support is needed for a period of years while costs are brought down to competitive levels with alternative renewable energy sources. Onshore and offshore wind energy serve as examples of how public support can contribute to both environmental and industrial objectives.

The value proposition for tidal energy over the long term rests on two key factors: its cost competitiveness with other energy sources, and the benefits it generates for the local economy through supply chain development. The two are connected. In the short term, support is needed to encourage industry to invest in the research, development, innovation and demonstration (RDI&D) needed to commercialize the technology. In the longer term, as the goal of commercialization is achieved, industry pays the economic dividend in the form of a national supply capability to develop and operate tidal energy facilities. For the early adopter, this capability could be exportable, offering the potential to add greatly to economic impacts.

2. Objectives

This report was produced on behalf of the Offshore Energy Research Association of Nova Scotia (OERA) to provide government and industry with a clear understanding of the value proposition for tidal energy in Canada, including the opportunities and challenges of creating a supply chain for a future tidal energy industry.

The main objective of the report is to produce a comprehensive assessment of the value proposition for tidal energy that provides an estimate of the potential value, broader benefits and potential economic impacts of tidal power development to Nova Scotia, the Atlantic Region and Canada. Meeting this objective requires casting the net widely for relevant information and lessons learned. The main elements are:

- An exploration of tidal resource potential and development in other jurisdictions: the key factors affecting the pace of development, forms and levels of public support, and the value propositions put forward by industry and government to justify these levels of support.
- Three tidal development scenarios in Canada that form the basis for assessing the value proposition and are contrasted with the Nova Scotia Marine Renewable Energy Strategic plan (Early adoption). The various factors affecting the scale of development are examined over a 25-year study period: 2015-2040. The competitiveness of tidal energy against other energy sources is assessed using a levelized cost of energy (LCOE) approach.

- A close examination of supply chain opportunities arising from tidal development in Canada. Demonstration/pre-commercial and commercial development phases are explored, with a description of how a supply chain would develop over time. Supply chain opportunities are described, with associated cost estimates.
- Quantification of the value proposition, beginning with an assessment of industry participation and leading to estimates of economic impact under each scenario. The benefits of avoided greenhouse gas (GHG) emissions and other pollutants form an important part of the value proposition.
- An assessment of areas of uncertainty, examining the impact of risk on the value proposition and offering options for risk mitigation. The report concludes with suggested steps governments and industry could take on a range of issues that would enhance the value proposition.

3. Findings

General

The world's oceans contain an immense renewable energy resource. Hundreds of millions of dollars globally have been spent to date on research and development of tidal and wave devices to harness this potential. Much of this activity has occurred in the European Union (EU), driven by the prospects for creating a supply chain to meet the needs of an emerging regional and global marine energy industry, while simultaneously reducing dependence on fossil fuels and increasing energy supply security. These prospective achievements form the essence of the value proposition.

Canada also possesses substantial sources of marine energy, including the tides of the Bay of Fundy, one of the world's largest and most accessible resources. The total potential market value to a tidal energy supply chain is a function of the market demand for tidal devices to meet electrical energy needs. In the absence of firm projections, a scenario approach is used to establish market demand. The scenarios incorporate changes in capital and operating costs over time, reflecting 'industry learning' – improvements in turbine efficiency, manufacturing processes, economies of scale and marine logistics.

The major challenge currently facing tidal device manufacturers is to prove the reliability of the technology, and also that tidal energy can become competitive with alternative renewable energy sources, particularly offshore wind. Prototype testing and demonstration are on-going in the EU and in the Bay of Fundy (the first deployment was in 2009, with the next expected as early as 2015). The first crucial steps on the 'path to market' – becoming competitive with alternatives to create a demand for tidal energy – have been implemented in the U.K., France and Nova Scotia. These take the form of various support programs, including feed-in tariffs (FIT). But as currently structured, these will provide long-term support for capacity installed before 2020; policy and support beyond 2020 remains to be established.

The nature and level of policy support for tidal after 2020 is not clear in any jurisdiction. What seems clear is that an indication of further support is going to be needed to ensure the global rate of installations is high enough to achieve the industry learning essential to reducing costs and improving competitiveness. In other words, device manufacturers need to see a role for tidal in the energy mix – an eventual market characterized by strong and consistent demand in order to sustain their commitment of resources to continue developing the technology. This kind of policy support played an important role in the development of wind (onshore and offshore) and solar energy technology. For their part, governments need to see that the industry is taking the steps needed to put tidal energy on a path leading to cost competitiveness.

The lack of an established global supply chain represents an opportunity for prospective suppliers, whether in Canada, the EU or elsewhere. Across a wide range of goods and services, it means there exist no barriers to entry from entrenched competition. The manufacture of tidal device components and supply of marine cable represent two notable exceptions, with the market for these items controlled by a few large industrial companies based mainly in the EU. But these items account for only 30-40% of capital costs, leaving the other 60-70% of the value of development open to an emerging supply chain. Most of this 60-70% consists of goods and services that would or could be supplied at or near the tidal development site. These include a range of environmental assessment and planning services, facilities and vessel construction, device assembly and installation, and cable installation. Local operation and maintenance expenditures would exceed 80% of total annual operations and maintenance (O&M) costs.

Suppliers in Nova Scotia, the Atlantic Region and Canada are in an excellent position to meet 60-70% of the goods and services required for tidal development in the Bay of Fundy. Decisions about whether to enter the market will depend on an assessment of the level of demand against supply-side factors including investment requirements and competitive conditions. Participation by domestic suppliers is assumed to be strong, resulting in positive economic impacts (gross domestic product (GDP), employment and income) varying more or less proportionately to assumed installed capacity under each scenario. The impacts are most intense during the development phase when tidal devices are installed, though on-going O&M also generates considerable on-site activity. That development in the tidal scenarios occurs in a largely rural area adds to the significance of the employment and income impacts because of the general scarcity of job opportunities and relatively low incomes.

Tidal developments outside Canada also provide opportunities for Canadian suppliers. Some estimates suggest this market could have a value in the $900-1,000 billion range by 2050. Even if Canadian suppliers were to compete in 10% of this market and secure just a 5% market share, it would be worth $4-5 billion over the period. Success in the export market would be enhanced if tidal development were to occur earlier, or at least no later, in Canada than in other jurisdictions. This would be the case under the Early Adoption Scenario, with 500MW installed in Nova Scotia by 2032.

In a world where addressing climate change is becoming increasingly urgent, investing in clean technologies that displace fossil fuels and contribute to the avoidance of GHG emissions (and other harmful pollutants) adds greatly to the tidal value proposition. Using conservative estimates of environmental costs per tonne, the value of avoided emissions ranges from about $200 million under the Demonstration Scenario to $1.0 billion under the Early Adoption Scenario.

Set against the benefits side of the value proposition – creating an industry, reducing GHGs and other emissions, improving energy security – are the costs embedded in the policy support needed to encourage tidal energy development. In Nova Scotia, primary support takes the form of a feed-in tariff for both distribution- and transmission-scale projects for up to about 20MW of installed capacity. The analysis indicates tidal cost parity with alternative renewable energy sources is expected to occur soon after 2040. Accordingly, implicit in each scenario is some form of public support needed to bridge the gap between the levelized cost of tidal energy and these alternatives.

The rate of tidal capacity installations globally forms a key determinant of the rate at which tidal costs are expected to decline. This in turn affects when cost parity would be reached and the level of support needed to bridge the energy cost gap. The assumption made about the global installation rate, then, becomes a major factor in the analysis. Considerable uncertainty surrounds this factor. This analysis adopts what seems to be a realistic assumption given available information. But if a higher rate were achieved, then costs would drop faster, parity with alternatives would be achieved sooner, and the level of public support would be less.

Specific

- **The value proposition (justification for public support) for tidal energy among EU member states hinges on its capacity to further policy in three key areas: economics, climate change and energy security.** Harnessing tidal energy is of interest to several nations with resource potential. Outside Canada, the EU – and the U.K. in particular – are the most advanced with respect to quantifying the resource potential and supporting technology RDI&D. The level of financial support directed by national governments and the European Commission (EC) towards tidal energy in the EU over the past several years amounts to several hundred million dollars. Support takes many forms including direct funding to device developers, to researchers at universities and institutes, and to fund test and demonstration facilities (e.g., the European Marine Energy Centre). Several countries have also introduced feed-in tariffs to subsidize energy producers (in anticipation of commercial production). Such support is the norm with technologies that hold promise to further key policy objectives – this is the essence of the value proposition. Wind energy serves as a good example of how public support has been used to good effect in bridging the gap between early development and commercialization, and in the process, creating dynamic industries in countries that were early adopters (e.g., Denmark, the U.S., Spain and Germany).

  In various industry (and some government) documents, considerable emphasis is placed on the opportunity for creating a new industry to supply the unique goods and services needed to develop the tidal resource. Impacts are quantified in terms of the value of industry output (potentially billions of dollars), jobs created, income earned, contribution to GDP, and export potential. The merits of the tides as a renewable energy source contribute to climate change commitments with respect to reducing GHG emissions and the related environmental/ economic costs associated with global warming. Last, but not least, tidal energy is also put forward as an important means of improving energy security and making a valuable contribution to price stability. The specific value proposition factors and measures used to quantify indicators are shown in Table S.1.

Table S.1: Value proposition in EU for tidal energy

Criteria	Value Proposition Motivators	Potential Measures
Economic growth	Supply chain development	National share of development expenditures
	Employment & income	GDP, employment and income created
	Regional disparities	Industry locating in rural areas of tidal potential
	First mover advantage & export potential	Inward investment & export capability
	Industrial location	Cost of electricity (relative)
Energy Security	Reducing fossil fuel dependence	Stable electricity price
	Depletion of conventional resources	TWh displaced/cost vs alternatives
	Age of existing generating capacity	Timescale for delivery
	Geopolitics	Uncertain supply/risk
	Increasing energy demand	Secure domestic source
Climate Change	Climate change commitments	% contribution to renewable energy supply (TWh)
	Renewable energy source	Tonnes CO_2e avoided
		Cost of carbon avoided (compared to alternative clean tech.)

- **Global tidal potential is substantial and developing it could require expenditures in the $1,000 billion range.** The theoretical global resource potential for tidal energy (in-stream and tidal range) is estimated to be approximately 1,200 million MWh per year, enough energy to supply the annual needs of 100 million households (slightly fewer than the number of households in the U.S.). The practical potential is considerably less, though nonetheless substantial. In 2013, the International Energy Association (IEA) indicated installed capacity could reach 23,000MW by 2035, while the UK's Carbon Trust projected 55,000MW by 2050. Reaching the latter capacity is expected to require cumulative expenditures in the CA$900-1,000 billion range. Though the timing of these projections may seem overly optimistic in light of the challenges the industry is facing in securing on-going support for developing the technology, they do provide a sense of the value of the global industry that would supply the goods and services.

- **Canadian tidal potential is likely to be developed initially where the value proposition is strongest: in the Bay of Fundy**. The theoretical potential of in-stream tidal energy in Canada is estimated to be 42,000MW at some 190 sites on the Atlantic, Pacific and Arctic coasts. The estimates of extractable power using today's technology vary, and considerably more analysis is needed to determine practical potential. Some high potential sites are favourably located, while others are remote, located some distance from transmission grids. Some accessible sites in Canada offer potential, but without FITs or other forms of support, the opportunity is likely to be limited to small-scale tidal technology to serve remote, off-grid communities now relying on expensive diesel generators.

  On the assumption that tidal development would occur first at those sites where the value proposition would appear to be strongest, the analysis is focused on the potential in Nova Scotia and specifically, the Bay of Fundy. This area meets three key criteria: excellent resource potential, relatively low cost for grid access, and a legislated requirement to meet carbon emissions and renewable energy targets (linked to energy diversity and security). Realizing this potential would require major investment in infrastructure, tidal arrays and a wide range of support services.

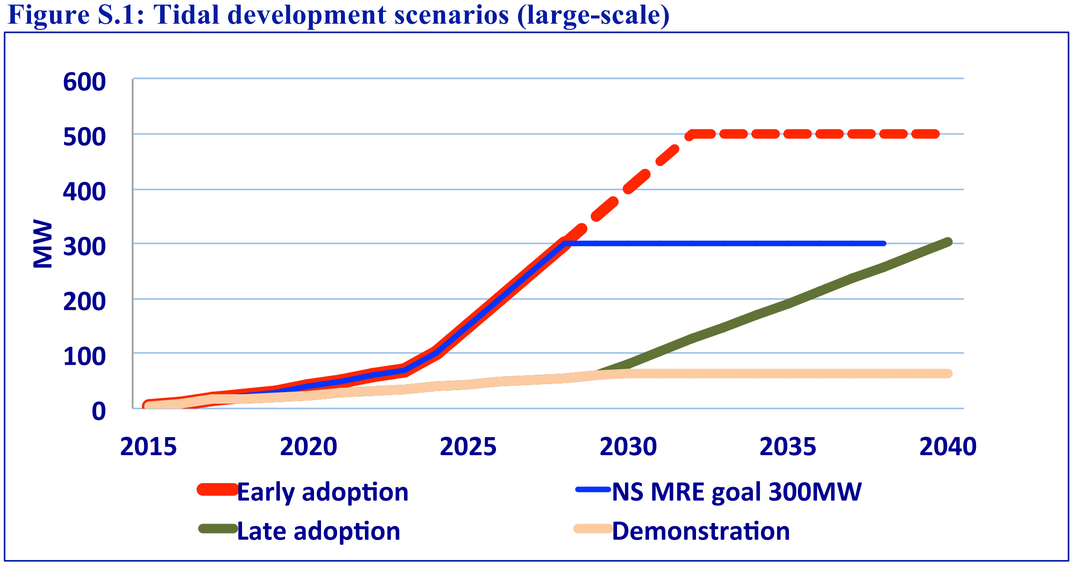
- **The scale of any potential tidal development in Nova Scotia depends on resource, environmental, market, economic and policy factors**. Preliminary research indicates that resource potential at the most attractive site, the Minas Passage in the Bay of Fundy, could yield 2,500MW of extractable power with minimal impact on tidal flow. Further study is needed to establish the full range of impacts turbines would have on the marine environment, and conversely, the impact that the marine environment would have on turbine performance. Tidal power has attractive marketability characteristics: like wind, it is renewable; though it has the great advantage over wind of being predictable. Nonetheless, there would be load-balancing challenges in absorbing large amounts of tidal energy, given current and future levels of wind capacity in the Nova Scotia electrical system. Certainly, 2,500MW would exceed the absorptive capacity of the Nova Scotia market, so access to electricity markets beyond the Province would be needed to realize this potential. This would require strengthening the transmission system between Nova Scotia and New Brunswick (likely to occur as the Maritime Link is built), and also between New Brunswick and New England. Accessing markets beyond Nova Scotia would be premised also on the competitiveness of tidal energy with alternative sources of electricity. Against the backdrop of these factors, Nova Scotia's Marine Renewable Energy Strategy sets out the elements for a 'phased and progressive' approach to achieving a long-term goal of producing 300MW of tidal power.

- **The value proposition analysis relies on three scenarios for large-scale grid-connected tidal development and two scenarios for small-scale distribution system development implemented over the 2015-2040 period**. These alternative paths (illustrated in Fig. S.1) provide contrasting conditions against which to assess potential supply chain development, energy costs and economic impacts. Development in all scenarios benefits from Nova Scotia rate support under the FIT and community feed-in tariff programs (COMFIT).

Large-scale

- **Demonstration scenario** – **64MW**. Developers take full advantage of the infrastructure at Fundy Ocean Research Centre for Energy (FORCE) under various government or research initiatives, with installed capacity levelling off at 64 MW by 2030. A key assumption is that the tidal industry has not managed to achieve sufficient cost reduction to become competitive with alternative renewable energy sources in Nova Scotia, and public support to make up the difference is not available after 2030.
- **Early Adoption scenario – 300/500MW.** With indications that tidal energy costs are declining rapidly, the industry continues to receive support from governments until tidal energy is competitive with alternative renewable sources. Implicit in this scenario is that Nova Scotia and Canada accelerate the installation of tidal capacity, resulting in greater competitive opportunities for Canadian companies in the international supply chain, but with the higher costs associated with early development. Capacity expands rapidly after 2023 following regional transmission system investment, reaching the 2012 Nova Scotia Marine Renewable Energy Strategy (NS MRE Strategy) goal of 300MW by 2028. Capacity reaches 500MW in 2032, when the upper limit of regional market potential is reached.
- **Late Adoption scenario – 300MW**. Capacity development follows the Demonstration Scenario until 2029 and then increases to 300MW by 2040 as tidal technology approaches cost competitiveness with alternatives. Cost competitiveness is driven by the growth of tidal capacity internationally, but late entry into the marketplace reduces the competitive advantage for Nova Scotian and Canadian suppliers in accessing international supply chain opportunities. A key assumption is that the investment needed to integrate several hundreds of MW of tidal energy are made during the expansion of the bulk power system in Nova Scotia and New Brunswick to incorporate the Maritime Link.

Figure S.1: Tidal development scenarios (large-scale)



Small-scale

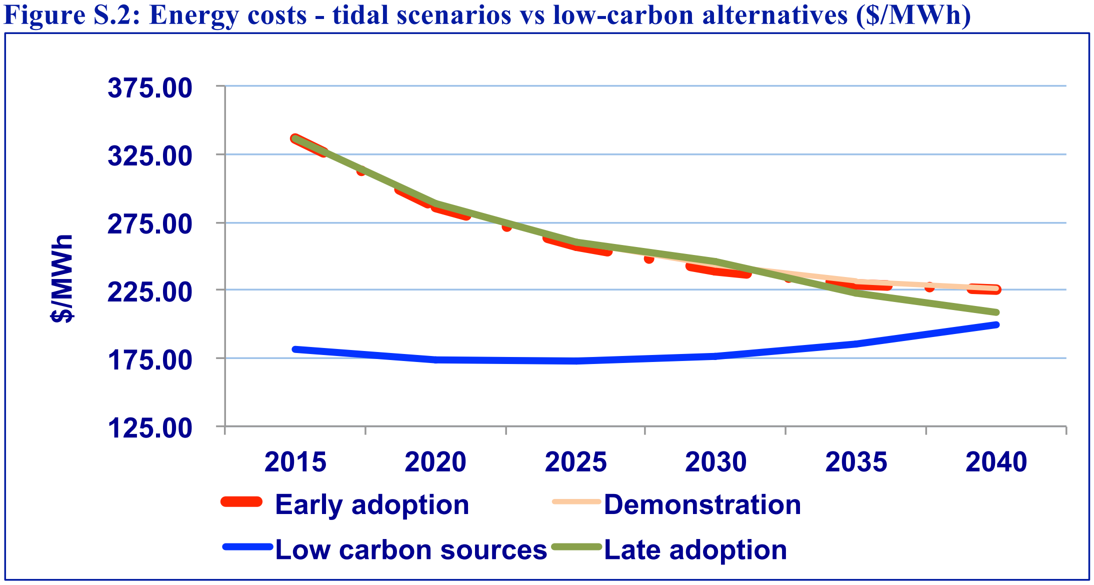
- **Low scenario – 3.5MW**. Approved developments range from 500kW to 1.95MW in Digby County (Digby Gut, Grand Passage and Petit Passage) and from 100 to 500kW in Cape Breton (Bras d'Or Lakes). The devices will be installed by 2017.
- **High scenario – 10MW**. Several sites in Canada offer tidal energy potential, but moving beyond the level of capacity supported by COMFIT requires sites that meet three key criteria: they are economic in their own right (because no other jurisdiction in Canada yet offers rate support); capacity can be absorbed by distribution systems; and they meet all regulatory and environmental assessments and are accepted following any First Nations consultations. In the absence of information on these considerations, no specific sites beyond those in the Low Scenario are identified for the High Scenario.

- **Assuming on-going public support, tidal energy costs will decline over the study period, becoming competitive with alternative renewables by the early-2040s.** Having reliable capital and operating cost estimates for tidal energy is important because it enables an analysis of competitiveness with alternative energy sources and also provides a basis for evaluating the prospective tidal energy supply chain and the economic impacts flowing from tidal development. Tidal costs now are relatively high because the technology is at an early stage of development. Costs will decline as manufacturing and installation processes are industrialized. The rate of decline depends on the rate at which tidal devices are installed.

  Industry learns from experience, technological innovation occurs, and scale economies are achieved. *The cost analysis in this report assumes installations are occurring globally to help drive costs down*. The rate of global growth is a critical assumption; a higher growth rate would cause costs to decline more rapidly and parity to be reached sooner.

  A conventional LCOE approach is used to determine how costs are expected to change over the 2015-2040 study period. A comparison of costs for each scenario with the average for a mix of low carbon alternatives indicates that grid-parity would be reached soon after 2040 (Fig. S.2).

Figure S.2: Energy costs - tidal scenarios vs low-carbon alternatives ($/MWh)



The rate at which costs decline has a direct bearing on the level of support the tidal industry would need before the technology is competitive with relevant alternatives. This level of support (illustrated by the wedge between tidal and the low-carbon alternatives) may be characterized as the tidal 'learning investment' governments make to meet economic and energy policy objectives.

- **The emergence of a tidal energy supply chain is contingent on the industry moving successfully through RDI&D into commercial development**. From the perspective of market pull and push, the industry path would appear to be set for the next 4-5 years. Locations where the resource is most promising (U.K., France and Nova Scotia) have mechanisms in place to support prototype and developmental grid-connected installations. Industry observers suggest that a minimum of two years continuous performance would be needed to meet the reliability and operability criteria established by Independent Power Producers (IPPs), insurers, lenders, investors and utilities. This suggests 2018-2019 at the earliest for the first pre-commercial arrays (reliable technology, but not yet cost-competitive).

  The FITs in the various jurisdictions are essential to industry development to this stage. There is uncertainty about the industry development path after 2019, because policy everywhere is unclear about future levels of public support for technology development. The basis for the uncertainty lies in tidal energy costs that will still be too high in 2020 to be competitive with alternative renewable sources. This threshold may not be reached until 2030 at the earliest, in large part because it has taken the device developers much longer than anticipated to conduct the RDI&D. In the meantime, device developers are urging governments to continue the support they say is essential to maintaining industry interest – support to encourage the deployment of the additional arrays that are essential to achieving the industry scale, supply chain specialization and efficiencies that will bring costs down.

  The nascent tidal industry, then, finds itself at a critical juncture. Costs must come down to be competitive, but costs can only come down if the rate of capacity installation increases. And while industry looks to government for support, government is looking to industry to do more to resolve some of the outstanding challenges. Assuming the combination of factors needed to break the logjam emerges over the next few years, the tidal industry could enter a commercial phase of development by about 2020. *Implicit in this assumption is the global installation of some 150MW of tidal capacity in small arrays between 2015 and 2020.* This rate of installations is essential to force a reduction of tidal costs to about $290/MWh by 2020. Limited supply chain development is likely to occur up to this point.

  Assuming delivered tidal energy can enter electrical grids at a cost competitive with alternative renewables (including public support), the global industry would be characterized by a rapid build-out of capacity in locations worldwide. This could exceed 500MW by 2030. This expansion could only occur as a result of important changes in the structure and operation of key aspects of the tidal industry as we know it today.

  - IPPs would emerge to take responsibility for project design, implementation and operation, much as they do in the mature onshore and offshore wind energy industry.
  - Technology developers would transition to their typical role as technology suppliers.
  - IPPs would have access to conventional sources of finance and insurance based on devices meeting accepted reliability criteria and manufacturer's warranties.
  - A convergence of technologies would be expected, given the need to achieve production and installation efficiencies. Purpose-built vessels would enter service to deploy and retrieve tidal energy conversion devices.

- The projected pace of development, coupled with the size of the devices, would require investment in facilities close to tidal sites for assembly, fabrication and installation.
- With a strong and consistent level of demand for tidal energy, an industry supply chain would develop leading to the production of 'off the shelf' goods and services typical of mature technologies (such as wind energy).

- **Supply chain development in Nova Scotia and elsewhere in Canada is contingent on expectations for strong and consistent demand for tidal energy and the goods and services tidal development projects require.** Common to each large-scale Scenario is a test phase, 2015-2017, when the berth holders at FORCE deploy their devices. Small-scale projects are implemented over the same period. At FORCE, one or more of the developers deploy small arrays, bringing total capacity to 20MW by about 2018. To this point, with deployments spread across several developers and some uncertainty about support beyond the current FIT, it is likely that assembly of the large-scale devices and any structural fabrication would take place in existing facilities in Halifax, with devices towed to the Bay of Fundy for deployment. In other words, before 2018, there is still likely to be insufficient clarity around tidal competitiveness (including reliability and financing) and the prospect of a rapid build-out to warrant investment in assembly/fabrication facilities.

  For large-scale tidal, the nature and extent of supply chain development would depend greatly on what happens after 2018. This is when the scenarios begin to diverge.

  - **Demonstration Scenario:** the market pull for tidal capacity beyond the level of FORCE capacity does not arise. Tidal development is assumed to benefit from a reduced FIT available during the 2020s, but tidal energy does not reach the level of competitiveness needed to expand beyond 64MW. There is insufficient justification for dedicated assembly/ fabrication facilities in the Bay of Fundy; this work is staged from Halifax.
  - **Early Adoption Scenario:** through a combination of declining costs and public support, there is sufficient market pull for up to 500MW of tidal capacity to be installed by 2032. The first phase consists of 300MW, meeting the NS MRE Strategy goal. With sufficient regional demand for renewable energy, development is assumed to continue to 500WM. Nova Scotia Power Inc., (NSPI) would signal its intent to issue RFPs for specified blocks of power. This level of certainty provides the basis for the market entry of IPPs and investment in a Bay of Fundy facility for device assembly and fabrication. The expectation of strong and consistent demand over a decade also provides a strong incentive for domestic supply chain development.
  - **Late Adoption Scenario:** the market pull in Nova Scotia for tidal capacity beyond 64MW does not arise until 2030, after on-going tidal development in other jurisdictions has caused costs to decline to levels approaching competitiveness with low-carbon alternatives. Industry has converged on one or two designs. There is justification for a dedicated assembly/fabrication facility in the Bay of Fundy, though the facility is not constructed until the late 2020s. A domestic supply chain would begin to emerge in the 2030s.

  Small-scale tidal projects differ in number, size, complexity and duration, and as a consequence, most requirements are likely to be served by suppliers who adapt their goods and services, rather than the emergence of a dedicated supply chain. The small scale of projects favours use of local assembly, fabrication and installation facilities. Turbines are an exception; supply chains for the efficient manufacture of standard components and parts would be expected to emerge as demand increases.

- **Tidal energy development would create opportunities for suppliers covering a wide range of goods and services, with the nature and scale of opportunities dependent on the level of demand.** Many of the activities comprising a tidal project would be familiar to those companies with experience planning and building for, and operating in, the marine environment. For some suppliers, meeting the domestic tidal energy goods and services requirements would be fairly straightforward because they currently have the direct capability and capacity. For others, it would be a matter of adapting their offering and expanding their capacity in anticipation of, or in response to, demand. Interviews conducted with prospective suppliers indicate that many would be taking a 'wait and see' approach, holding off decisions on investing in adaptation or expansion until it becomes clear a strong and consistent demand exists or can be safely anticipated.

  Nova Scotian, regional and other Canadian suppliers have the capability and experience to supply 60-70% of the goods and services required for large-scale development. This content estimate is tied to site-specific inputs or activities and is fairly consistent across scenarios. A breakdown of requirements, costs and an estimate of local content is shown in Table S.2.

  Supply capability is expected to be high for most inputs, with the exception of turbines, ancillary equipment and marine cables. These components are likely to have high import content. Device developers are most likely to rely on existing manufacturing facilities (mainly in Europe), allowing them to refine operations and extend production runs to minimize costs. Nonetheless, as confidence in the continued prospects for tidal development grows, domestic industry could adapt and compete effectively in the supply of some of the goods and services that initially are likely to be imported (e.g., certain device components, turbine blades). In the case of small-scale development, tidal devices are manufactured in Canada. Supply content would approach 100% if domestically manufactured devices were used.

  Tidal development outside Canada provides an export opportunity for domestic suppliers. The capability and capacity developed by Canadian suppliers in tidal projects in the Bay of Fundy would provide an excellent foundation for participating in this global market. Among the promising areas of global opportunity for Canadian suppliers are:

  - Resource modelling and site characterization (directly applicable);
  - Constructing purpose-built vessels and work boats (directly applicable);
  - Fabricating support structures (directly applicable);
  - Sensors, acoustics, instrumentation and monitoring (some adaptation required);
  - Manufacturing composite turbine blades (innovation and adaptation required); and
  - Marine cable installation, interconnection and electrical systems (innovation required).

Penetrating the export market would present a challenge because the same logic that drives the relatively high potential local content reflected in Table S.2 also applies to other jurisdictions, especially the EU with its industrial strength and long history of offshore oil & gas development and marine capabilities. *Export opportunities would be strengthened to the extent the timing, pace and scale of tidal development here places Canada in the position of an early adopter. This would be the case under the Early Adoption Scenario only.*

Table S.2: Tidal development costs by scenario and domestic content estimate, 2015-2040

Cost centre (1)	Supplier	Total Expenditures: 2015-2040 Demo	Early adoption NS MRE	Early adoption Maximum	Late adoption	% of total	% spent in Canada (2) %	NS MRE Case (3) $000 (2012)
MW		67	300	500	300			
1. Pre-project planning								
Site screening								
Resource assessment	Consultant	320	1,305	2,025	1,153	0.1%	100%	1,305
Constraints analysis	Consultant	128	522	810	461	0.0%	100%	522
Health & safety analysis	Consultant	256	1,044	1,620	922	0.1%	100%	1,044
Grid connection assessment	Consultant	192	783	1,215	692	0.1%	100%	783
Logistical analysis	Consultant	320	1,305	2,025	1,153	0.1%	100%	1,305
Technology assessment	Consultant	256	1,044	1,620	922	0.1%	100%	1,044
Preliminary feasibility analysis	Consultant	128	522	810	461	0.0%	100%	522
Environmental & technical assessment								
Environmental scoping	Consultant	639	2,610	4,049	2,305	0.2%	100%	2,610
Physical surveying	Consultant	1,278	5,219	8,099	4,610	0.3%	100%	5,219
Meteorological & resource assessment	Consultant	959	3,914	6,074	3,458	0.3%	100%	3,914
Grid infrastructure assessment	Consultant	639	2,610	4,049	2,305	0.2%	100%	2,610
Marine infrastructure assessment	Consultant	1,278	5,219	8,099	4,610	0.3%	100%	5,219
Sub-total		6,392	26,095	40,494	23,052	1.7%		26,095
2. Project implementation								
Planning								
Public consultation	Consultant	1,203	4,912	7,622	4,339	0.3%	100%	4,912
Mi'kmaq ecological knowledge	MEKS services	1,203	4,912	7,622	4,339	0.3%	100%	4,912
Environmental assessment	Consultant	3,610	14,736	22,867	13,018	1.0%	100%	14,736
Permitting and regulatory approval	Legal	6,016	24,560	38,112	21,696	1.6%	100%	24,560
Sub-total		12,032	49,120	76,224	43,392	3.2%		49,120
Design								
Front-end engineering design	IPP/Engineer*	4,512	18,420	28,584	16,272	1.2%	75%	13,815
Procurement	IPP*	1,504	6,140	9,528	5,424	0.4%	75%	4,605
Detailed design	IPP/Engineer*	9,024	36,840	57,168	32,544	2.4%	90%	33,156
Sub-total		15,040	61,400	95,280	54,240	4.0%		51,576
Procurement & assembly								
Construct operations facilities	IPP/Contractor	1,000	1,500	2,000	1,500		100%	1,500
Develop site for device assembly/maint.	IPP/Contractor		75,000	100,000	75,000		100%	75,000
Mechanical (turbine & power take-off)	OEM*	38,822	158,489	245,942	140,007	10.3%	0%	0
Electrical (generator & transformer)	OEM*	66,552	271,695	421,614	240,012	17.7%	0%	0
Subsea cabling	OEM*	30,832	125,870	195,324	111,192	8.2%	0%	0
Control system	OEM*	8,648	35,305	54,786	31,188	2.3%	0%	0
Grid connector	IPP/Contractor	7,896	32,235	50,022	28,476	2.1%	100%	32,235
Device framing & foundation	IPP/Contractor	89,112	363,795	564,534	321,372	23.7%	100%	363,795
Final assembly	IPP/Contractor	29,704	121,265	188,178	107,124	7.9%	75%	90,949
Transportation services	IPP/Contractor	5,546	22,641	35,135	20,001	1.5%	100%	22,641
Sub-total		277,112	1,131,295	1,755,534	999,372	73.7%		586,120
Installation & commissioning								
Mobilize logistical equipment	IPP/Contractor	6,542	26,709	41,447	23,594	1.7%	50%	13,355
Install foundation/moorings	IPP/Contractor	26,170	106,836	165,787	94,378	7.0%	90%	96,152
Load-out and install devices	IPP/Contractor	9,814	40,064	62,170	35,392	2.6%	90%	36,057
Install marine electrical systems	IPP/Contractor	16,356	66,773	103,617	58,986	4.4%	50%	33,386
Commission facilities	IPP/Contractor	6,542	26,709	41,447	23,594	1.7%	50%	13,355
Sub-total		65,424	267,090	414,468	235,944	17.4%		192,305
Total		376,000	1,535,000	2,382,000	1,356,000	100.0%		905,216
Average cost per MW		5,432	5,117	4,612	4,375			
3. Operation & maintenance (4)								
Management	IPP	125,341	450,879	621,807	243,080	29.6%	90%	405,791
Maintenance	IPP/Facility	293,027	1,054,082	1,453,684	568,281	69.2%	75%	790,562
Decommissioning	IPP/Contractor	5,081	18,279	25,208	9,855	1.2%	100%	18,279
Total		423,450	1,523,240	2,100,700	821,215	100.0%		1,214,632

1. Cost breakdown based on Synapse 2013. Cost for operations facilities and device assembly/maintenance estimated by consultant. All costs in 2012 dollars.
2. Indicates initial share of expenditures by input assumed to be procured in Canada (mainly Nova Scotia). Share is assumed constant across scenarios and over time.
3. The percentage share of expenditures is applied to the Early Adoption Scenario (MRE 300MW) spending to illustrate the dollar content
4. O&M and decomissioning costs expressed as percentage of total annual costs (2015-2040).
* Indicates requirements that need not be produced or conducted locally

4. Value proposition

In-stream tidal energy is an emerging technology with the potential to form the basis for a new industry in Canada and other jurisdictions. The three tidal development scenarios examined produce widely differing economic impacts across the selected indicators. This is because the scenarios are based on different assumptions regarding the scale and timing of development – two of the main factors determining the economic impact.

Tidal development can be expected to have a substantial impact on the economy of Nova Scotia, and also the economies of the Atlantic Region and Canada. Because most of the in-stream tidal development in each of the large- and small-scale scenarios occurs in Nova Scotia waters, the direct impacts are concentrated in Nova Scotia, with spill over effects in the Atlantic Region and elsewhere in Canada. The economic impacts summarized in Table S.3 present cumulative (2015-2040) and average annual values for each Scenario (including the NS MRE Strategy 300MW phase of the Early Adoption Scenario). The economic impact values are based on Nova Scotia tidal development only, and exclude the potentially substantial impacts arising from export market opportunities.

The interpretation of the values in Table S.3 follows the NS MRE Strategy 300MW phase of the Early Adoption Scenario (use the corresponding values to interpret the Scenarios):

- **Tidal Expenditures:** Total capital expenditures (CAPEX) of $1,535.0 million plus operating expenditures (OPEX) of $1,523.2 million refer to total cumulative spending over 25 years. Nova Scotia content (where direct expenditures occur) is 60% of CAPEX ($921.0 million) and 80% of OPEX ($1,218.6 million) for a total of $2.139.6 million. All values are expressed in 2013 dollars (excluding inflation).
- **Gross Domestic Product:** The NS MRE Strategy 300MW installation generates an overall GDP impact of $1.7 billion, including a direct impact of $1.1 billion. The average annual direct GDP impact is $42.9 million.
- **Employment:** Almost 22,000 full-time equivalent (FTE) jobs would be created, 15,000 of these engaged in direct activities at the assembly facility and in marine logistics, initially in planning and device assembly, construction and deployment, and within 4-5 years in maintenance activities as well. Average direct employment per year would reach about 600 FTEs, with an average of about 880 FTEs when indirect and induced effects are included.
- **Income:** Tidal development and operations would generate about $815 million in direct labour income, with an overall impact of $1.1 billion including spinoff impacts. The average annual direct income impact would be $32.6 million.
- **Tax revenues:** though difficult to quantify, the construction and operation of the tidal energy facilities would generate millions to tens of millions of dollars annually (depending on scale) through corporate and personal income, sales, excise, and municipal property taxes.

It is important to note that these impacts would *primarily affect the rural economy bordering the Bay of Fundy*. Because of limited economic opportunities, the rural economy tends to be characterized by relatively high unemployment rates and generally lower income levels than more urban areas. An industry offering the employment and income levels indicated in Table S.3 would provide a much-needed economic infusion.

Table S.3: Tidal development value proposition – benefits and costs (2015-2040) (1)

	Demonstration (67MW)		Early adoption NS MRE (300MW)		Early adoption Maximum (500MW)		Late adoption (300MW)	
	Cumulative	Average/yr	Cumulative	Average/yr	Cumulative	Average/yr	Cumulative	Average/yr
Total spending in NS ($000s) (2)	**568,425**	**22,737**	**2,139,592**	**85,584**	**3,133,580**	**125,343**	**1,484,132**	**59,365**
Economic impacts								
GDP ($000s)								
Direct	283,245	11,330	1,073,263	42,931	1,559,919	62,397	737,669	29,507
Indirect	77,602	3,104	294,045	11,762	427,376	17,095	202,102	8,084
Induced	86,649	3,466	328,327	13,133	477,202	19,088	225,664	9,027
Total	**447,495**	**17,900**	**1,695,635**	**67,825**	**2,464,497**	**98,580**	**1,165,434**	**46,617**
Jobs (FTE)								
Direct	3,948	158	14,958	598	21,740	870	10,281	411
Indirect	949	38	3,594	144	5,224	209	2,470	99
Induced	892	36	3,381	135	4,914	197	2,324	93
Total	**5,788**	**232**	**21,933**	**877**	**31,879**	**1,275**	**15,075**	**603**
Labour income ($000s)								
Direct	215,027	8,601	814,774	32,591	1,184,222	47,369	560,006	22,400
Indirect	45,981	1,839	174,228	6,969	253,230	10,129	119,750	4,790
Induced	36,325	1,453	137,641	5,506	200,052	8,002	94,603	3,784
Total	**297,333**	**11,893**	**1,126,643**	**45,066**	**1,637,504**	**65,500**	**774,358**	**30,974**
Emissions avoided								
Tonnes: 000s	4,795.5	191.8	9,738.2	389.5	24,158.0	966.3	9,738.2	389.5
$millions	198.4	7.9	402.9	16.1	999.6	40.0	402.9	16.1
Present value: $millions	92.7	3.7	161.6	6.5	415.7	16.6	161.6	6.5
Learning investment								
Energy price gap: PV$000s	255,500		813,000		1,030,000		305,250	

Source: Statistics Canada Inter-Provincial Input-Output Model (2010)

1. These are the expected economic impacts in Canada. They will be concentrated in Nova Scotia with spillover effects in the Atlantic Region and elsewhere in Canada. See Table 5.1 and Annex 4.

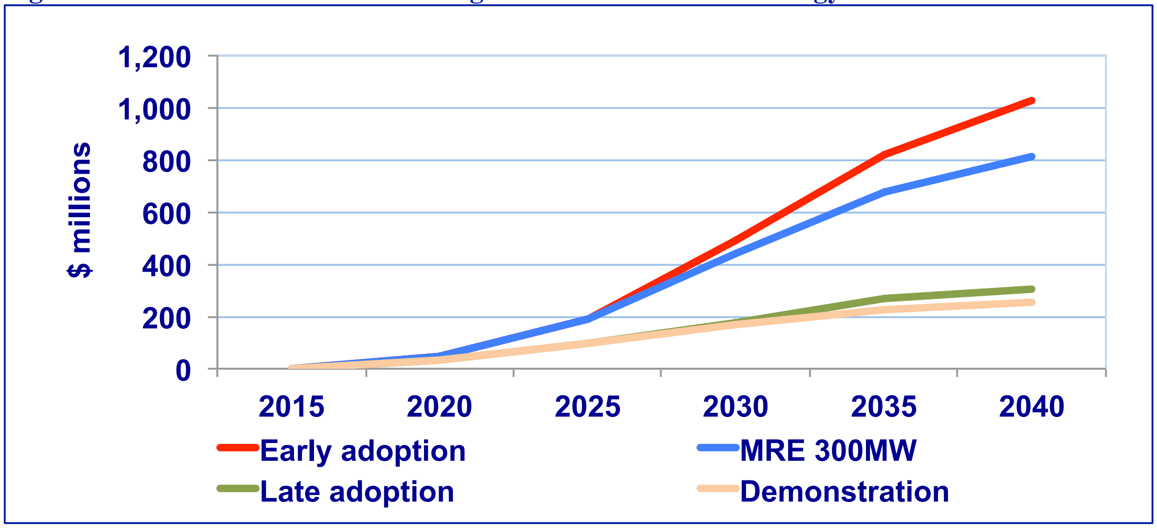
2. See Tables 3.7 and 5.2

Export potential adds to the value proposition. Even a market share of 5% in the supply of inputs accounting for just 10% of the estimated CA$1,000 billion global market could amount to an export value in the CA$5 billion range by 2050. The latter exceeds cumulative tidal development spending in Canada, even under the Early Adoption Scenario. As noted, because of timing and scale, export potential for Canadian suppliers would be greatest under the Early Adoption Scenario. Under the high market share assumptions, the economic impacts flowing from this level of participation could exceed the cumulative economic impacts arising from domestic tidal development by a factor of two to three (based on the not unreasonable assumption that impacts would be roughly proportional to levels of spending shown under the Early Adoption Scenario in Table S.3).

In addition to the GDP, jobs and income impacts, tidal development would also produce benefits in the form of reduced costs arising from avoided GHG and pollutant emissions. These benefits range from about CA$200 million under the Late Adoption Scenario to almost CA$1.0 billion under the Early Adoption Scenario.

Set against these benefits are the costs of generating them. The analysis indicates that the tidal LCOE is not expected to achieve parity with low-carbon alternatives in Nova Scotia until after 2040. The gap in each Scenario, referred to in Table S.3 as the 'learning investment', would be covered through some form of public support as illustrated in Fig. S.3.

Figure S.3: The Cumulative 'Learning Investment' for tidal energy



The level of support varies widely by Scenario. It is lower in the Late Adoption Scenario than in the equivalent capacity NS MRE Strategy (a present value of about CA$305 million versus CA$800 million) because most of the capacity in the former is installed after 2030. This allows the system to benefit from greatly reduced capital and operating costs. The investment is greatest under the Early Adoption Scenario (a present value of about CA$1,028 million) because most of the capacity is installed before 2030, resulting in limited benefit from cost reductions due to industry learning. It is worth repeating that implicit in these scenarios is the trade-off between energy costs and industrial opportunity: the lower costs associated with the Late Adoption Scenario come at the expense of lost first mover advantages and related supply opportunities both domestically and in export markets. These advantages and supply opportunities are greater under the Early Adoption Scenario, but at a higher learning investment.

5. Future considerations

Through various policies, programs and initiatives, the Governments of Nova Scotia and Canada have laid the groundwork for early tidal industry development. Governments in other jurisdictions have provided and continue to provide similar forms of support. Technology developers find themselves at a critical juncture; they have invested heavily in RDI&D, and must continue to do so in order to reduce costs and prove commercial viability. Continued development and demonstration are important steps in the commercialization process, and to help offset risk at this stage, governments have introduced defined levels of revenue support in the form of feed-in tariffs. The latter are critical to achieving the high rate of global installations that would bring costs down.

But risk in various forms remains: the large upfront investment required; uncertainty about costs and performance of the technology; uncertain or shifting government policies; permitting delays; access to the transmission grid; availability and cost of financing; power purchase agreements; weather; market and foreign exchange fluctuations; social acceptance and environmental effects. All these factors contribute to uncertainty with respect to industry development timetables, the rate of installations (globally), and therefore establishing the confidence needed for the emergence of industry supply chains.

The Governments of Nova Scotia and Canada are able to influence some of these risk factors as they apply to tidal industry development within Canada. Government support could be channelled to reduce uncertainty in several areas, and in so doing, make a valuable contribution to realizing the tidal value proposition.

Among the key steps for consideration:

- **Continue the commitment to tidal R&D**

  Through various initiatives over the past several years, the Government of Canada and the Government of Nova Scotia have supported tidal energy R&D. Successful demonstration projects in the UK provide encouragement that the technology holds commercial potential. But considerably more investment is needed to prove the technology and bring costs down to levels where they begin to become competitive with alternative sources of renewable energy. This requires a continued commitment to R&D by governments over the next 5-10 years, plus continued support for investment in tidal capacity by industry and utilities. Both are essential to finding ways to reduce costs and enhance competitiveness, and also to reduce GHG emissions.

- **A further round of feed-in tariffs to support capacity installation beyond 23MW**

  Renewable energy standards (RES), such as those in place in Nova Scotia, are a good market-pull policy, but without targeted support, they favour the least expensive renewable energy technology, in particular, more mature technologies such as onshore wind. Feed-in tariffs are effective in supporting the development of a new technology until it can become competitive, thereby diversifying the electricity supply and stabilizing long-term prices. The current FIT and COMFIT support about 23MW of tidal capacity. A further round of FIT/COMFIT would increase the likelihood of achieving the value proposition associated with higher development scenarios.

- **Implement the regulatory elements outlined in the Marine Renewable Energy Strategy**

  A long-term view of a stable regulatory regime will provide developers a clearer line of sight to commercial development. Completion of work currently under way to formulate and implement the regulatory elements outlined in the Marine Renewable Energy Strategy is vital to defining this clear line of sight.

- **Advance industry-enabling infrastructure development to encourage supply chain interest/participation in tidal opportunities**

  The infrastructure needed to support the industry must be designed, planned, funded and built. This could occur incrementally as the industry develops. Planning should be undertaken in consultation with current and prospective industry stakeholders (FORCE berth holders, Fundy Tidal Inc., and other potential developers) to identify critical requirements.

- **Develop a strategic, collaborative tidal energy research and innovation initiative**

  Considerable amounts of data have been collected to date in studies funded by OERA, the province and the federal government. Effective, public dissemination and continued data gathering will not only assist developers by reducing upfront costs and risks, it will help Nova Scotia know its own resource and the surrounding ecosystem.

- **Create a federal-provincial innovation fund for marine renewables RDI&D, with a focus on challenging issues and where export potential is greatest**

  Several recent reports have broken down estimated learning rates by cost centre. The learning rates by cost centre, when weighted by the proportion of total costs of TEC development, show areas where proportionately greater cost reductions may be found. These indicate areas where focused R&D support could have greater impact on tidal energy. Much of the work in these particular cost centres would be sourced locally if the demand were to arise (e.g. structure, installation, operations and maintenance). This suggests fertile ground for both cost reductions in Nova Scotia/Atlantic Canada/Canada and innovations that could benefit the global tidal energy industry. For example, solutions for underwater (wet) electrical connections and substations have not yet been developed.

  Targeted research, development and innovation grants for marine electrical technology can give Canadian companies a lead in this niche of the global tidal energy supply chain. Models for specialized innovation funds include the UK's Carbon Trust and Offshore Renewable Energy Catapult.

1

Introduction

1.1 Background

The world's oceans, through tidal and wave action, contain vast amounts of hydrokinetic energy. They represent perhaps the last major untapped source of renewable energy, joining wind and solar in an expanding portfolio of clean technologies. If harnessed, this resource has the potential to greatly reduce dependence on fossil fuels to meet increasing levels of electricity demand. In so doing, it also has the potential to create an entirely new industry, resulting in substantial socio-economic benefits for those nations with resource potential and a desire to play a leading role in technology development and offering technical solutions to an emerging global industry. The challenge is to find environmentally safe and economically efficient methods of developing this potential.

Canada and Nova Scotia have signalled their intention to occupy a position at the forefront of developing a tidal energy industry. Canada has considerable tidal current potential, including the Bay of Fundy, arguably the world's leading site. Nova Scotia's interest flows from a strong commitment embedded in its renewable energy strategy to achieve 40% of its electricity from renewable sources by 2020, with tidal energy making a longer-term contribution to the energy mix post-2020. Key elements of the strategy that would realize these goals include the creation of small- and large-scale feed-in tariffs to support early stage installations; and the development of the FORCE to facilitate tidal RDI&D. FORCE is a collaborative effort of the Governments of Canada, Nova Scotia and industry. The industry has also benefitted from the many tidal energy research projects funded by the Federal Government and the OERA of Nova Scotia.

The tidal industry is at an early stage of development, and perhaps may be best characterized as an emerging technology. It relies heavily on various forms of public support for its RDI&D activities, and also on private investors. Most of the developers of large-scale tidal devices are located in the EU. Over the past decade, they have benefitted from hundreds of millions of dollars of grant funding from national and EU sources. Further support from FITs is available in the UK and France to encourage the transition to commercial scale development. Governments and industry recognize that this kind of support is needed for a period of years while costs are brought down to competitive levels with alternative renewable energy sources. Onshore and offshore wind, as well as solar energy, are offered as examples of how socializing development costs and risks can achieve both environmental and industrial objectives. European manufacturers rank among the leading global exporters of these technologies.

The nascent tidal energy industry in Canada has received substantially less support than its European counterparts. Despite this funding gap, Canada's Marine Renewable Energy Technology Roadmap (2011) still outlines a developmental path for Canada that would carve out a significant leadership role in a global industry. To date, technology innovators have capitalized on support that has been available (public and private) to advance the development of small-scale devices. An in-stream tidal device was first installed at Race Rocks on Vancouver Island in 2006. The same developer is working with Fundy Tidal Inc. to test and demonstrate a tidal turbine in Grand Passage, Nova Scotia, as part of a system aimed at balancing power production and community load.

The EU and Canada are positioning themselves as leaders in ocean energy development. Both have operational test sites for in-stream technologies, with active testing programs by several prototype developers. For both Canada and the EU (and other jurisdictions with tidal potential), the value proposition for tidal energy over the long term rests on two key factors: its cost competitiveness with other energy sources, and the benefits it generates for the local economy through supply chain development. The two are connected. In the short term, considerable support is needed to encourage industry to invest in the RDI&D needed to commercialize the technology and bring down costs to competitive levels. In the longer term, as the goal of commercialization is achieved, industry pays the economic dividend in the form of an established national supply capability to establish and operate tidal energy facilities. For the early adopter, this capability could be exportable. If so, it offers the potential to add greatly to economic impacts.

1.2 Why this study

OERA launched this study to provide government and industry with a clear understanding of the value proposition for tidal energy in Canada. Such an understanding is seen as essential to attract the level of investment in Canada for tidal technology research, development, innovation and demonstration needed to move forward and capitalize on the opportunities identified in the Marine Renewable Energy Technology Roadmap (2011). The value proposition would examine the economic benefits to Canada, Nova Scotia and the Atlantic Region, with the immediate driver being the opportunity for tidal development in Nova Scotia.

The main objectives of the study are to:

- Produce a comprehensive assessment of the value proposition for tidal energy that provides an estimate of the potential value, broader benefits and potential economic impacts of tidal power development to Nova Scotia, the Atlantic Region and Canada.
- Examine the benefits that could result from three different scenarios of how tidal development might evolve in Nova Scotia and other parts of Canada over the next 25 years and how those efforts may impact the Canadian economic opportunity in emerging world markets.

The limited experience with tidal energy beyond testing prototype devices creates a major challenge for a study that seeks to determine the value proposition that would underpin further public and private support. Accordingly, the study Terms of Reference set out a broad scope of work, requiring the consultant to cast the net widely for relevant information and lessons learned. This includes the need to:

- Consider the value propositions or business cases for marine energy developed in other jurisdictions.
- Make use of previous work that has examined supply chain requirements for tidal energy at different stages of development, taking into account the particular strengths of Canada's ocean technology sector and its competitive position vs. other jurisdictions.
- Create three plausible scenarios of tidal development in Nova Scotia and Canada that will adequately address the range of possible outcomes over the next 25 years, taking into account resource potential, tidal technologies, interactions of tidal energy with the utility system, level of tidal development and supply chain response, competitiveness with other renewable energy sources, and the policy and strategic response of federal/provincial governments. Note, the term 'Case' is used interchangeably with 'Scenario' in this report.

- Consider the opportunities and potential economic benefits flowing from the export of goods and services to support tidal development outside Canada, and the factors that are likely to affect Canadian access to export markets.
- Estimate the direct and indirect economic impact of tidal development, taking into consideration the level of spending arising from each of the scenarios, as well as the value of export opportunities.
- Provide guidance on the value of further engagement in research, development and demonstration and the early supply chain as risks and uncertainties are addressed.

1.3 Report contents

The report contains six chapters and five annexes.

Following this Introduction, Chapter 2 examines the state of tidal current development in other jurisdictions, principally in the EU, where the industry is farthest advanced. It explores tidal resource potential, the key factors affecting the pace of development, forms and levels of public support, and the value propositions put forward by industry to justify these levels of support.

Chapter 3 sets out the tidal development scenarios in Canada that form the basis for the value proposition analysis. Estimates of tidal potential in Canada and globally are reported, followed by an exploration of the rationale for tidal energy development in Nova Scotia. The various factors affecting the scale of development are examined, leading to the creation of large- and small-scale development scenarios (we also refer to the scenarios as Cases throughout the report). The competitiveness of tidal energy against other energy sources is assessed using a LCOE approach. This analysis incorporates cost reductions over time resulting from industry learning.

Chapter 4 examines supply chain opportunities arising from tidal development in Canada. It begins with a description of how the tidal industry could develop, based on the experience of the onshore and offshore wind industries. Demonstration/pre-commercial (2015-2019) and commercial development (2020-2040) phases are explored. This is followed by a description of the likely build-out activities for the large- and small-scale scenarios, leading to speculation of how a supply chain would develop over time. Supply chain opportunities are then described, with associated cost estimates for each scenario.

Chapter 5 presents the analysis that establishes the value proposition for tidal development. It begins with an overview of industry participation, identifying areas of strength and weakness. An activity-by-activity assessment of industry participation follows, working through the goods and services required during the cycle of project implementation from planning to operation. This is followed by an order of magnitude assessment of areas of Canadian participation in global tidal development. Participation levels provide the basis for the economic impact assessment of each scenario. This, coupled with an estimate of the value of reduced GHG emissions, establishes the value proposition.

Chapter 6 addresses areas of uncertainty, examining the impact of risk on the value proposition and offering options for risk mitigation. It concludes with recommendations to governments on a range of issues that would enhance the value proposition.

1.4 Considerations for interpreting the report findings

Though perhaps it would be obvious to the reader that the findings should be considered indicative, not definitive, of what could occur, a few explanatory notes would appear to be in order:

- **State of the global industry**: in-stream tidal technology and the industry developing it are emerging, having completed several years of prototype testing and hoping to deploy commercial arrays within the next few years. Seeing a path to market represents a key challenge at this stage. The major device developers and IPPs contend that unless and until there is a solid prospect for a long-term stable market, the industry will be reluctant to commit the private investment needed to continue RDI&D and move to deployment of commercial arrays. At present, the industry faces limitations on the level and duration of public support. It is only through several rounds of array deployment that costs and risks can be reduced. This may take more than a decade. During this developmental period, public funding to share cost and offset risk is considered essential to maintaining industry commitment. Such funding was critical in supporting wind and solar energy through the technology development stages on the way to commercial viability.
- **Cost uncertainty**: conducting the analysis of tidal energy competitiveness proved a challenge, not because device developers were unwilling to share cost information, but because the information they have is not a particularly reliable guide to where costs are now and at what rate they may decline. This uncertainty can be traced to the emerging technology stage of the industry, where costs are determined by one-of-a-kind requirements and not by an established supply chain. If the history with other renewable energy technologies offers any guide, these costs can be expected to decline rapidly with device standardization, purpose-built assembly facilities and logistical support, and the emergence of supply chains to both encourage and take advantage of scale economies.
- **Rate of cost reduction:** the history of technological development demonstrates clearly that costs decline as a function of the rate of production or installation. Higher rates produce more rapid industry learning, resulting in more rapidly declining costs. There is considerable uncertainty about the likely rate of global tidal installations; estimates vary widely and change frequently. This creates a challenge for the analyst since the rate of cost decline features prominently in the pace at which tidal technology may become competitive with alternative sources of renewable energy. This study relies on the most up to date projections, though these are subject to change.
- **Supply chain development**: the industry is some distance from convergence of technology and the level of standardization found in other technologies such as wind and solar. It is this level of standardization that provides the basis for supply chain development and the kind of dedicated suppliers seen in mature industries. As tidal developers begin device testing and demonstration in Nova Scotia in the next year or two, this presents prospective Canadian suppliers with a major opportunity to gain insight into industry needs and determine the kinds of goods and service they could supply to this emerging industry.
- **Wide confidence limits about results:** the LCOE and economic impact analyses are conducted using well-established methodologies. This may give the impression that the results can be interpreted with confidence. But the level of confidence can be no greater than the starting values allow, for which the confidence intervals are wide. In other words, the results should be interpreted with caution and considered indicative rather than definitive.

2

Value Proposition in Other Jurisdictions

2.1 State of the global tidal energy industry

2.1.1 Recent developments

Commercial in-stream tidal technologies for large-scale power generation are less than ten years old. 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 an earlier stage of planning elsewhere. The European Marine Energy Centre (EMEC) ocean energy test centre in Orkney is a focal point for the most intensive testing and implementation activity in the world. The seabed fixed horizontal axis turbine (HAT) is the dominant technology of interest, although one floating device is at an advanced stage of development.

The overwhelming proportion of private commercial interest in tidal energy conversion is based in the UK, although the governments of several countries have ambitious strategies in the sector. France, Canada, China, Australia, New Zealand, Ireland and the USA have all identified potential sites for development. South Korea is pursuing a large program 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. South Korea has also identified several southern island areas suited to in-stream tidal energy development.

In-stream tidal power is very much at the prototype stage. Individual devices have been shown to work and power has been delivered to the grid. Scotland has now given consent for the development of commercial arrays. Most significant is the 2013 consent to Meygen for an 86MW array in the Pentland Firth, the first phase of a 400MW project. The emerging industry is going through a period of gestation as technical, market and financial challenges are investigated and more certainty is introduced. Early estimates of the speed of commercialization have proved to be optimistic, though commercial projects are in the pipeline.

The Crown Estate has been a main promoter of marine energy development in the UK. The Crown Estate is the statutory administrator of UK seabed uses and is required to achieve the best possible revenues. Its invitation to developers to tender for wave and tidal energy leasing sites in the Pentland Firth and Orkney Waters (PFOW) in 2009 attracted bids from major European electricity utilities including Scottish and Southern Energy (SSE). SSE has since transferred most of its interests to an independent power producer, DP Energy (DPE) (an indication that tidal energy is attracting the interest of independent investors).

To date, the main focus has been on large-scale (>0.5MW device) development. There is an emerging interest in smaller devices and community-scale development. Nova Innovation has deployed a 30kW device and secured funding for a community-scale 0.5MW array of 100kW devices in Shetland, Scotland. This scale of device may be able to exploit alternative market opportunities.

In summary, the emerging tidal stream power industry has made substantial technical progress, but it remains commercially uncertain. Development and ownership is mainly in the hands of specialist development companies supported by public funds. 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.

2.1.2 Key factors affecting development

Three issues are driving public sector support for tidal energy development:

- Security of supply and price stability – reducing reliance on foreign energy sources that exhibit high price volatility;
- Economic development – industry and job creation and gross value added at national and local levels;
- Global warming – meeting commitments to reduce greenhouse gases emissions.

While these are the most obvious and direct drivers, they 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 solutions to exploit them on commercially viable terms. The European Union's maritime economy currently employs about 5.4 million people (Ecorys 2012). The expansion of the EU's 'blue economy' is central to the EU Integrated Maritime Policy (IMP) and the Europe 2020 strategy (EU 2012). Marine energy fits well with these ambitions.

At present, the primary challenges facing tidal energy development are technical – reliability and efficiency. Many of the developers closest to market are deploying devices of around 1MW capacity; 2MW units are in early prospective development. Individual prototype machines have now operated on test for over three years. Development and long term operating experience of large-scale commercial arrays is the current ambition.

Most areas with tidal stream resources are remote from population centres and have weak electricity grid capacity unsuited to the characteristics of renewable power generation. This is one of the most significant constraints on development and strengthening it is an urgent priority, especially for tidal energy development in the UK. Utilities are reluctant to commit to major investments in new transmission facilities until there is greater assurance that tidal energy will achieve commercial competitiveness.

Planning and consenting regimes are in the process of implementation in several jurisdictions. Marine spatial planning (MSP) is a key tool for the management of interactions between new marine uses (blue growth), traditional uses, and the need for ecosystem protection. An extensive framework of European and UK legislation is in place and is constantly being updated. Few detailed MSPs are yet complete, adding to the uncertainty.

Access to finance will also present a major challenge. Tidal development on a commercial scale will require access to conventional sources of financing (debt and equity), which in turn must be convinced of the reliability of the technology, the acceptability of its environmental impacts, and the strength of the markets for the energy.

2.2 Tidal development potential

2.2.1 Tidal potential and capacity growth projections

The global *theoretical* potential of ocean energy (tidal, wind and others) is estimated to be far in excess of current and foreseeable future electrical energy demand.[1] The resource potential for tidal energy alone (tidal range and in-stream) is estimated to be approximately 1,200 million MWh per year (IEA *Ocean Energy Systems).* This is enough energy to supply the annual needs of 100 million households (slightly fewer than the number of households in the U.S.).

There is a wide gap between theoretical potential and what may be regarded as practically possible in the near future. This is due not only to high technology costs (currently 3-4 times higher than alternative renewable sources), but also to infrastructure issues (lack of grid connection, port/fabrication facilities and dedicated logistical support in areas of high marine potential), administrative and regulatory issues (poorly defined authorization procedures, absence of marine spatial planning, limited knowledge of ocean energy), and limited knowledge about long-term environmental impacts.

Based on differing assumptions about the pace at which these issues may be resolved, various organizations have made estimates of the global level of installed ocean energy capacity as far out as 2050. These estimates vary widely, underscoring the inherent uncertainty. The UK's Carbon Trust estimates 190,000MW of wave energy and 55,000MW of tidal energy in their best-case scenarios (Carbon Trust 2011). By contrast, the International Energy Agency (IEA 2012) projects a range of 9,000-23,000MW (wave and tidal) by 2035, with the range depending on assumptions about the underlying policy framework, including carbon pricing. The IEA prefers not to extend projections beyond 2035 because the factors affecting development are believed to be too indeterminate. Table 2.1 provides a summary of various global and national projections. Note that many of these projections combine wave and tidal, while some are for tidal only.

Achieving such levels of ocean energy capacity presupposes the development of a major industry, which, in turn, is contingent on a 50-75% reduction in costs by 2025 (LCIGC 2012). The European industry is estimated to have invested over CA$1.1 billion in technology development since 2005 (European Commission 2014). The cumulative value of the global industry that evolves to meet the 2050 ocean energy capacity projections is estimated at CA$900-1,000 billion – an average of over CA$2.2 billion per year (Carbon Trust 2011). This represents a substantial opportunity for the broad range of goods and service suppliers that would constitute the industry. The main focus of the search for suitable sites in the world is summarised in Figure 2.1 and Table 2.2.

While this level of industry development is not out of the question by 2050, progress in meeting some of the early milestones has been slow. Rather than expecting 500-1,000MW of installed capacity by 2020, more recent estimates are that a more modest 150MW can realistically be expected (RenewableUK 2014; Bloomberg 2014).

[1] The theoretical energy potential has been estimated at 7,400 EJ/year, over 30 times current global electricity supply (54EJ or 1,800 TWh) EC (2014).

Table 2.1: Global and national marine energy capacity (tidal and wave) projections

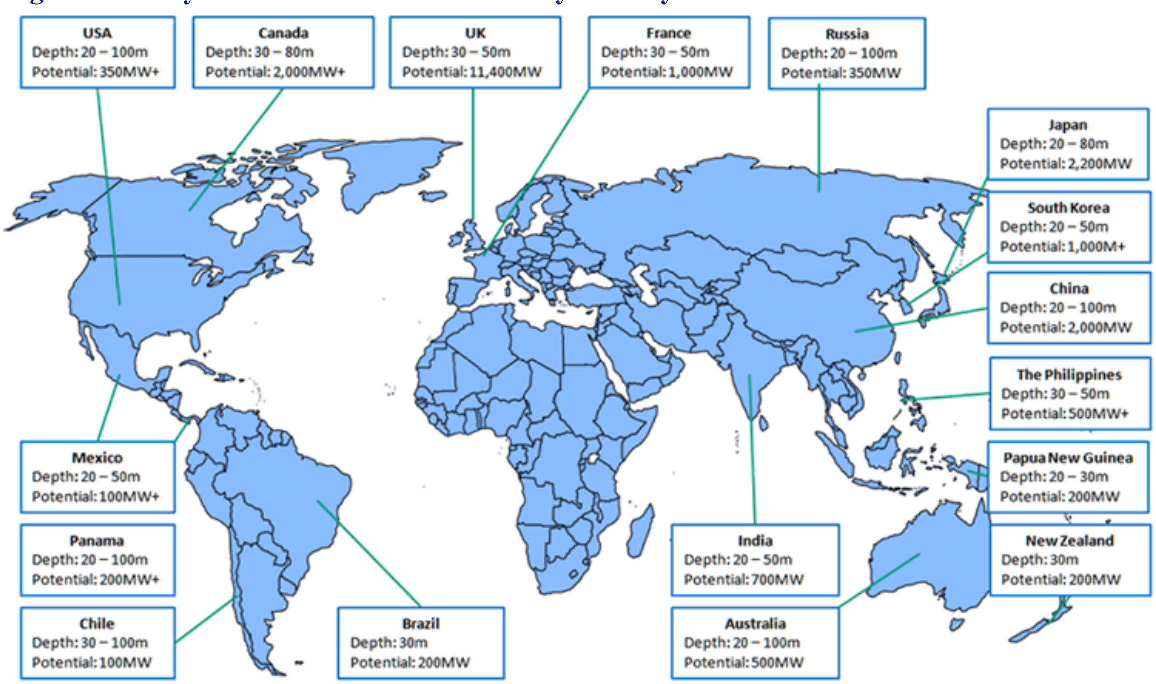
	2015	2020	2023	2024	2025	2030	2035	2040	2045	2050
Global [1]*		1 GW			>10 GW [10]**	4-9 GW	9-23 GW			13-20 GW
OECD [1]*		1 GW			2 GW	4-8 GW	8-21 GW			
EU-27 [2]*	0.6 GW	1.7 GW			2.9 GW	4-5 GW	4-11 GW	5-19 GW	5-25 GW	6-30 GW
UK		100-200 MW	328 MW [4]*			4-8 GW [5]*		8-15 GW		10-20**
France		50 MW [6]**								
Canada	5-60 MW	250 MW [11]*				300 MW				
US		10 GW [10]*				23 GW [7]*				
Ireland		500 MW [6]*								
Spain		100 MW [6]*								
South Korea	50 MW [9]**			3 GW [9]*		~2 GW [6]*				
Australia										0 GW [8]**
Portugal		250 MW [6]*								

*Ocean Renewables (excl. Wind)

**Tidal only

[1]: International Energy Agency, 2012/2013. World Energy Outlook 2012/2013.
[2]: ORECCA, 2011. European Offshore Renewable Energy roadmap.
[3]: Carbon Trust, 2012. Technology Innovation Needs Assessment (TINA): Marine Energy Summary Report.
[4]: RenewableUK, 2013. Working for a Green Britain & Northern Ireland 2013-23.
[5]: UK Energy Research Centre, Marine Energy Technology Roadmap, 2014
[6]: Strategic Initiative for Ocean Energy (SI Ocean), 2013. Ocean Energy in Europe's Atlantic Arc.
[7]: Ocean Energy Systems, 2012. Annual Report 2012: Implementing Agreement on Ocean Energy Systems.
[8]: CSIRO, 2012. Ocean Renewable Energy 2015-2050: An analysis of ocean energy in Australia.
[9]:Ernst & Young, 2013. Rising Tide: Global trends in the emerging ocean energy market.
[10]: Ernst & Young, 2014: Energies Marines: Quelles perspectives de création de valeur en France?
[11]: Marine Renewable Energy Canada, 2012. Canada's Marine Renewable Energy Technology Roadmap
[12]: Nova Scotia Department of Energy, 2012. Nova Scotia Marine Renewable Energy Strategy

Figure 2.1: Key tidal stream resource sites by country



Source: http://atlantisresourcesltd.com/marine-power/global-resources.html

Table 2.2: 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	Full scale grid-connected test/demonstration site (FORCE). Four berths awarded. Deployments expected in 2015. Several small-scale projects approved.
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.

2.2.2 Market development mechanisms

An influential 2001 review of UK tidal energy potential concluded that the best sites could produce electricity at a cost of CA$75-110/MWh and that this was "*the right order of magnitude to encourage commercial interest"* (ETSU 2001). More recently, the Low Carbon Innovation Coordination Group (LCICG 2012) suggest the LCOE from existing tidal energy technologies are CA$365-550/MWh and that a pathway to CA$185/MWh will be required for the economic viability of the sector. LCICG concluded that achieving this kind of reduction in cost could best be achieved through large-scale arrays of at least 200MW.

In the UK, large-scale renewable energy generation is incentivized by the sale of Renewable Obligation Certificates (ROCs).[2] Tidal stream energy in the UK receives 2-5 ROCs/MWh, dependent on timing, location, and size of array. These ROCs typically trade for the equivalent of CA$80-100 each. A UK tidal energy developer could expect to receive up to CA$500/MWh, subject to market conditions. The UK ROC system will be replaced in 2017 by a guaranteed price system (contract for difference – CfD – at about CA$550/MWh), which is similar to a FIT. It is worth noting this change to the CfD is placing a great deal of pressure on in-stream tidal and wave energy developers to bring their costs in line with other renewables, particularly offshore wind, by 2019. The absence of additional support for these two less mature technologies until they can become competitive in electricity auctions jeopardizes the development of a diversified portfolio of renewable energy technologies. A good reason why there may be reluctance by government to commit to further targeted support is the considerable untapped offshore wind potential of approximately 30,000 MW (Renewable UK 2014).

Many other countries offering price subsidies for renewable energy offer a guaranteed price in the form of a FIT. European examples include: France CA$300/MWh (ocean energy); Spain CA$105/MWh; Portugal CA$285-390/MWh; Denmark CA$120/MWh; and Ireland CA$393.[3] While these FITs may seem low by UK and Nova Scotia standards, other forms of support are also provided.

[2] Utilities are required by law to demonstrate the proportion of electricity sold to customers from renewable sources. They do this by purchasing Renewable Obligation Certificates (ROCs). ROCs are issued to generators by the industry regulator, Ofgem.
[3] €1=CA$1.51

2.2.3 Risk and mitigation strategies

Government support through market-pull mechanisms can increase private sector interest by improving profitability, reducing investor (financial) risk or otherwise increasing commercial confidence. Most significant are supports and price guarantees for electricity from marine sources (e.g., the Renewable Obligation Certificates in the UK.

Technology-push mechanisms designed to stimulate technology development include capital grants for commercial demonstration projects, as well as targeted research funding. These have come from a range of organizations. In the UK, research and development (R&D) grants have included Supergen 2 (£5.5m), EPSRC Marine Challenge call (£6m); Technology Strategy Board (now Innovate UK) Marine Energy Programme (over £20m awarded); and funding for key research facilities, e.g. FLoWaveTT wave and a current test facility (£9.5m). Various capital grant schemes in the UK have committed over £100m for marine energy demonstration projects. Other countries are also investing, for example, Ireland has a €10m prototype development fund.

Enabling actions, designed to remove impediments, overcome barriers or speed up development, include test facilities, infrastructure development and permitting schemes, data collection and dissemination. The UK government has focused on enabling activities to help achieve commercialization, primarily through 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.

2.3 Value propositions

2.3.1 Value propositions or justifications for public support

The renewable energy sector in many jurisdictions has received substantial direct and indirect public funding to conduct research and development, encourage the commercialization of technology, and support the growth of the supply and service industries. This section summarizes published value propositions that have been used to inform government policy and private sector investment decisions.

The private sector investment is focused on the cost of energy, revenues, financial risk, and return on investment. A review of the European literature indicates a wider set of public sector interests (see Renewable UK 2013), including economic growth, energy security and price stability, and net environmental benefit, particularly, reduction of greenhouse gas emissions (Table 2.3).

Table 2.3: Public sector interests in renewable energy

Criteria	Value Proposition Motivators	Potential Measures
Economic growth	Supply chain development	National share of development expenditures
	Employment & income	GDP, employment and income created
	Regional disparities	Industry locating in rural areas of tidal potential
	First mover advantage & export potential	Inward investment & export capability
	Industrial location	Cost of electricity (relative)
Energy Security	Reducing fossil fuel dependence	Stable electricity price
	Depletion of conventional resources	TWh displaced/cost vs alternatives
	Age of existing generating capacity	Timescale for delivery
	Geopolitics	Uncertain supply/risk
	Increasing energy demand	Secure domestic source
Climate Change	Climate change commitments	% contribution to renewable energy supply (TWh)
	Renewable energy source	Tonnes CO_2e avoided
		Cost of carbon avoided (compared to alternative clean tech.)

Public sector interest in marine energy is nuanced by multiple layers of government with differing priorities. The priorities of the various levels of government serve as an example and are shown in Table 2.4.

2.3.2 Economic growth

A key driver and benefit of developing tidal energy is the potential for economic development. Since the fast-moving waters that constitute tidal resources are often located near rural coastal communities, the opportunities for jobs, business expansions and start-ups, rural industrial diversification, synergy with other local marine industry businesses and infrastructure, and other economic benefits are compelling. Some of these benefits are hard to quantify. Studies done to project the economic benefit tend to focus on employment numbers, with some including estimates of income and gross value added (GVA).

Many studies estimate a ratio of jobs/MW based on expert judgement or comparison with other sectors (e.g. onshore wind). Multipliers may be further applied to account for indirect employment. Other studies apply more sophisticated econometric modelling techniques (e.g. Grant et al 2014). All approaches must make assumptions about the scale of the resource and future installed capacity.

Employment predictions for the UK and Scottish marine energy sectors show significant variation due to starting assumptions, in particular, projected installed capacity. The least and most optimistic estimates suggest between 1,000 and 20,000 jobs over 10 years (by 2023), with the medium scenarios in most studies falling between 5,000 and 10,000 jobs.

While most published work has focussed on the UK, a recent all-Ireland study estimated employment associated with wave and tidal energy as between 92 and 17,000 jobs (SQL 2010) depending on assumptions about capturing a share of the global market. The least optimistic prediction of market capture assumes all manufacture would take place overseas and employment would be limited to operations and maintenance. The most optimistic scenario assumes Ireland becomes a major exporter of tidal energy technology.

Table 2.4: Policy drivers and actions: EU, UK & Scotland

	European Union	UK Government	Scottish Government	Local Government
Key Policy Drivers	CO2 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 CO2 reduction targets; and a nuclear free energy policy	
Example Actions	Overarching policy infrastructure (binding CO2 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)		

Considering wave and tidal energy together, in 2013, Renewables UK estimated the direct and indirect employment by 2023 for three development scenarios. These and the all-Ireland estimates, noted above, are shown in Table 2.5.

Table 2.5: Estimates of direct and indirect jobs for low, medium and high installation scenarios

	Low	Medium	High
UK, Wave and Tidal by 2023 (Renewable UK 2013b)	56 MW Direct: 649 Indirect: 1,447	328 MW Direct: 5,631 Indirect: 6,476	676 MW Direct: 9,148 Indirect: 13,873
Ireland, Direct and Indirect, Wave and Tidal by 2030 (SQL 2010)	577 MW High market capture: 852 Medium market capture: 368 Low market capture: 92	800 MW High market capture: 8,465 Medium market capture: 3,642 Low market capture: 887	800 MW High market capture: 17,259 Medium market capture: 7,679 Low market capture: 1,986

France has not yet reported an estimated economic impact of marine energy. At the wider level, the European Ocean Energy Association predicts that by 2020, the EU ocean energy sector will generate over 40,000 direct and indirect jobs and predict, by 2050, this will increase to 471,320 (EU-OEA 2010).

Very few studies have projected other economic indicators, such as GDP. However, Highlands and Islands Enterprise commissioned an economic impact assessment in 2012 of the Orkneys (Westbrook 2012). It analyzed the local and countrywide impacts of the EMEC test centre from 2003 to 2011 (Table 2.6).

Table 2.6: Cumulative economic impact of EMEC for 2003-2011

	Employment	Income	GVA
Orkney	1,075 job years	£31.9m	£57.2m
Highlands and Islands	1,286 job years	£38.3m	£69.5m
Scotland	1,931 job years	£62.7m	£116.8m
UK	2,361 job years	£78.7m	£150m

Projected numbers for 2012 to 2020 were then extrapolated from these data. The forecast was based on an assumed 700 MW of installed wave and tidal capacity by 2020. The results are shown in Table 2.7. Westbrook further forecasts an installed capacity of 1.6 GW for the 2020-2030 period, with 2x the effects of the 2012-2020 period. The figures in Table 2.7 are based on the premise that 53% of the capital expenditure of the supply chain will be sourced in Scotland and 30% in the rest of the UK.

Table 2.7: Cumulative economic impact EMEC (projected) for 2012-2020

	Employment	Income	GVA
Orkney	3,925 job years	£122.7m	£265.1m
Highlands and Islands	12,468 job years	£370.8m	£882m
Scotland	22,791 job years	£679.6m	£1,609.1m
UK	35,677 job years	£1,068.7m	£2,559.4.m

2.3.3 Other factors

Energy Security

Developing domestic sources of energy not only generates economic benefits at home, it allows a country to have energy secure from geopolitical conflict that can interrupt supply or affect prices. As well, being a renewable resource, the prices are not affected by the rising cost of fossil fuels. Once developed, the supply of in-stream tidal energy will be highly predictable.

Climate Change

The amount of greenhouse gas and particulate matter avoided by developing in-stream tidal energy depends on the particular fuel being displaced. In countries that depend on fossil fuels to generate electricity and where suitable marine energy resources exist, developing these is of particular interest. Countries that have been signatories of the Kyoto Accord have engaged in an international trading scheme that established a market price for carbon. A price on carbon, paid to those who earn carbon credits through avoiding emissions, offsets the cost of generating renewable energy, making renewable energy more competitive with traditional sources of energy. An alternative approach, a carbon tax, increases the cost of fossil fuels. In July 2014, the International Monetary Fund recommended governments apply a carbon tax to fossil fuels and provided guidelines on the particular amounts that should be levied on various fuels. For instance, the IMF proposes a carbon tax on coal of CA$4.90 per gigajoule (about $50/MWh), and on natural gas, CA$2.20 per gigajoule (about $20/MWh) (IMF, Getting Energy Prices Right: From Principle to Practice 2014).

2.4 Summary

Estimates of the world's tidal energy resources indicate the potential for a large global industry. Generally, jurisdictions exploring the development of their marine resources estimate the cost of energy generated from the tides will eventually be competitive with other renewable sources and rising costs of fossil fuel-generated energy. However, if there is a desire to develop it, it will need to be supported until it can be competitive. A diversified portfolio of energy sources, both non-renewable and renewable, is important for any country. Tidal energy is located near rural, coastal communities that have some of skills and services needed for a tidal energy industry. Domestic sources of energy and new jobs in many such communities are coveted. Estimates of employment potential vary widely, depending not only on the anticipated scale of development but the ability of a country or region to develop its own supply chain and take advantage of export opportunities.

3

Tidal Development Scenarios

3.1 Introduction

The tidal energy conversion industry in Nova Scotia, the Atlantic Region and the rest of Canada will be created primarily on the basis of in-stream tidal energy capacity on the Nova Scotia side of the Bay of Fundy. Other sites in Canada also offer potential for tidal development (noted in Section 3.4.2). The amount of installed nameplate capacity likely to be achieved within the 25-year study period and the trajectory of installation are impossible to predict with confidence, given the uncertainty surrounding the range of factors influencing tidal development.

In light of this uncertainty, a scenario approach is used to examine the tidal energy value proposition. The first step is to establish tidal potential from a resource perspective for Canada and the rest of the world. This baseline opportunity relies on existing studies and sets the outer bound of opportunity for this study.

Tidal opportunity in Canada is divided into two segments, reflecting the nature and scale of the demand and supply sides of the potential markets: Large Scale (arrays involving devices exceeding 0.5 MW, generally transmission grid-connected), and Small Scale (involving devices of less than 0.5 MW capacity, connected to the distribution grid).

Three Large Scale scenarios of capacity growth to 2040 are explored:

- Demonstration Scenario – installed capacity reaches 64 MW (FORCE capacity);
- Early Adoption Scenario – installed capacity reaches the provincial MRE Strategy goal of 300MW by 2028, with a further 200MW by 2040;
- Late Adoption Scenario – 300 MW by 2040.

Two Small Scale scenarios of capacity growth to 2040 are explored:

- Low Scenario – installed capacity reaches 3 MW;
- High Scenario – installed capacity reaches 10 MW.

To simplify the discussion, the industrial opportunity created by global tidal potential is assessed separately for each scenario. In other words, global potential is treated as independent of what is happening in Canada and consequently is not integrated explicitly into each scenario; global potential adds to the industrial opportunity indicated by tidal development in Canada.[4]

Understanding the factors underpinning each scenario is crucial to quantifying and qualifying the value proposition. These factors include resource potential (including site characteristics), the rationale (driver) for tidal energy development, conditions for developing and accessing the electrical energy (domestic and export), and practical considerations for achieving capacity levels.

[4] It should be noted that the pace of tidal development in Canada is not independent of what is happening globally. This is because the pace of capacity installation has a direct bearing on the rate at which capital and operating costs decline, and hence, the competiveness of tidal technology with other forms of renewable energy. Included in the development scenarios created for this study is an explicit assumption about the pace of global tidal energy development.

3.2 Tidal energy potential

Canada

For Canada, the theoretical ocean energy potential (wave and tidal) is estimated at about 230,000MW, with the caveat that only a fraction could be extracted and converted into useful power using today's technology (NRC 2006). The most attractive sites are located in the Bay of Fundy (tidal), west coast of Vancouver Island (wave and tidal) and in the St. Lawrence River (river current). The amount of extractable power (all sources) is estimated to be 35,800MW.

Of the total ocean energy potential, in-stream tidal (theoretical) is estimated to be 42,000MW at some 190 sites on the Atlantic, Pacific and Arctic coasts. The estimates of extractable power vary, but a recent study indicates that using arrays of tidal devices, 2,500MW could be extracted from the most attractive site – Minas Passage in the Bay of Fundy – with a 5% impact on the tides (Karsten, McMillan, Lickley & Haynes 2008). Other sites elsewhere in Canada also offer potential, but under current government policies (including the non-availability of a feed-in tariff), the opportunity is likely to be for small-scale tidal technology to serve remote, off-grid communities now relying on expensive diesel generators.

On the assumption that tidal development would occur first at those sites where the value proposition would appear to be strongest, we focus the large-scale analysis on the potential in Nova Scotia and specifically, the Bay of Fundy. This area meets three key value criteria: excellent resource potential, relatively low cost for grid access, and a need to develop renewable sources of energy to meet legislated carbon emissions levels.

3.3 Nova Scotia tidal development considerations

Provincial marine renewable energy strategy

Realizing Nova Scotia's tidal development potential requires investment in infrastructure, tidal arrays and support services. Such investment would provide the basis for a new industry potentially valued in the billions of dollars. The extent to which this potential might actually be realized hinges on several factors including the demand for electrical energy, the regulatory environment covering tidal energy, and the price competitiveness of the energy produced including any public support.

Recognizing these factors, the Nova Scotia Marine Renewable Energy Strategy (NS MRE Strategy) is driven by 'opportunity and need' (Nova Scotia 2012). Introduced in 2012, the Strategy forms an integral part of the Province's clean energy framework, setting out policy, economic and legal conditions for renewable energy projects in anticipation of commercial development and the establishment of a new industry. The strategic objectives include delivering cost-competitive renewable energy to meet the need for more diversified and stable energy sources, and developing an industry to provide opportunities to apply local knowledge and skills to serve global export markets.

The Strategy sets out the elements for a 'phased and progressive' approach to achieving a long-term goal of producing 300MW of power from in-stream tidal projects. The main strategic thrusts are:

- **Research**: key initiatives such as FORCE and Strategic Environmental Assessments of the Bay of Fundy and the Cape Breton Coastal Region;
- **Development**: assisting with the creation of tidal device test sites, support for small-scale tidal devices and integration into community distribution systems, market development through support for enhanced transmission infrastructure (Atlantic Energy Gateway) and market support through the introduction of FIT and COMFIT for tidal energy, and supplier development through various initiatives including funding for needs assessments, tidal conferences, and studies to identify supply chain opportunities.
- **Regulatory**: several initiatives are planned or in progress including the creation of an integrated regulatory and licensing system (covering technology development and demonstration in early stages and power development for up to a 300MW commercial installation), an MRE fee and royalty system, an independent regulator, and a stakeholder engagement plan.

The need for renewable energy

The electricity sector in Nova Scotia has been dominated by coal-based generation following provincial and federal government policy of the 1970s to the 1990s that emphasized energy self-sufficiency and reducing the province's reliance on imported fuel oil. The result is a legacy of capital-intensive coal-fired generating stations providing most of the capacity and energy for the province.

In the 2000s, the policies of the governments shifted to align with reduced emissions from electricity generation. Nova Scotia introduced regulations that not only define what will be done to reduce emissions of GHGs and air pollutants (AP) from the electricity sector, but also how it will be done using a renewable energy standard (RES), based on percentage of energy sales. There is also a strong focus on energy efficiency and conservation.

In addition to existing regulations, there is an executed equivalency agreement between the federal and provincial governments that extends the expected GHG reduction requirement for the electricity sector in Nova Scotia to the year 2030. The federal government's framework for reducing GHG emissions from the electricity sector is founded on the capital stock turnover of coal-fired power plants on a specific anniversary. The direction is to eventually phase out conventional coal-fired generation.

GHG and AP reduction, combined with the renewable energy standard, are important drivers for tidal energy development in Nova Scotia.[5] In light of this policy and regulatory framework, it is reasonable to assume renewable energy sources or natural gas would displace coal generation whenever the opportunity presents itself during the study period. With more certainty on the GHG emission reduction than the air pollutant path, GHGs become a planning tool. It is possible that future AP requirements will place a greater restriction on conventional coal-fired generation than GHG reductions.

Table 3.1 provides the existing and simple projection of the greenhouse gas emission upper limits of the electricity sector as well as the existing RES.

[5] The main GHGs are Carbon Dioxide (CO_2 and Nitrous Oxide (N_2O). Other emissions include Sulfur Dioxide (SO_2), a major contributor to acidification of rivers, lakes and the ocean. Air pollutants refer specifically to particulate matter.

The regulations allow some flexibility in meeting the GHG emission levels between 2010 and 2020 and 2020 to 2030, but generally it is a constant incremental reduction year over year. These are not goals or targets; this is the law or expected to be the law. The electricity sector in Nova Scotia plans to comply and this forms the driver for a long-term transformation of the electricity sector away from the dominance of coal to a much more balanced portfolio of lower emitting fossil fuels and renewable energy sources.

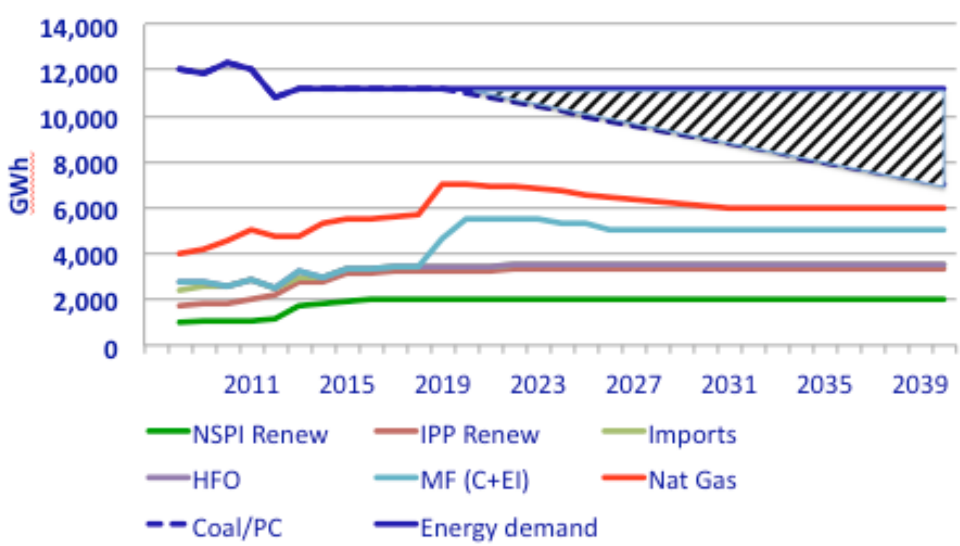
Table 3.1: Nova Scotia electricity sector transformation drive

Year	GHG Limit (Mtonnes)	RES (% of Sales)
2010	10	
2011		5% from post 2001
2013		10% from post 2001
2015		25% all sources
2020	7.5	40% all sources
2030	4.5 Equivalency	
2040	3.4 Projection	

Source: Nova Scotia Environment, *Amendments to Greenhouse Gas & Air Quality Emissions Regulations*, 2013

Figure 3.1 presents a possible generated energy plan to meet the reduced GHG emission requirements (existing to 2030, then projected), based on the electricity sector sales plus losses (net system requirement) not changing beyond 2013. This is a key assumption that has a direct bearing on the amount of new non-emitting energy to replace the GHG-restricted fossil fuel based generation. If, over time, sales decline due to continued successful new energy efficiency and conservation programs, self-generation or recession, then there would be less need for new non-emitting sources. The reverse is also true; growth in overall demand increases the opportunity. The renewable energy opportunity is within the hatched wedge from 2020 onward.

Figure 3.1: Renewable electrical energy opportunity in Nova Scotia



The electricity sector has many of the elements in place or in advanced planning to meet the 2020 requirement of reduced GHG emissions and the 40% renewable energy standard. The interconnection of the Muskrat Falls hydro development to Nova Scotia, through the Maritime Link, with the associated energy purchase agreement and opportunity for economic purchases, is key to meeting 2020 requirements.

The reduction of GHG emissions from 7.5 Mt in 2020 to 4.5 Mt in 2030 requires the replacement of about 2.8 million MWh of primarily coal/petcoke generated energy per year (by 2030). At a 40% capacity factor, it would take approximately 800 MW of installed tidal nameplate capacity to generate this quantity of energy. This capacity factor is what might be expected from a multi-array in-stream tidal power plant in the Minas Passage or advanced new wind farms by 2030. The energy could also be supplied from imported power or a technology breakthrough or some combination of tidal, wind (onshore and offshore), imports, and something new.

As a basic assumptions underpinning the system analysis in its 2014 Integrated Resource Plan, Nova Scotia Power Inc. (NSPI) adopts a GHG decline to 3.4 Mt by 2040. NSPI states that this puts emissions on a downward path consistent with the long-range goals of the federal government for 2050 (NSPI 2014). This results in a GHG reduction of 1.1 Mt beyond the 2030 level, requiring the replacement by non-emitting sources of an additional 1.2 million MWh of fossil generation. At a 40% capacity factor, the opportunity by 2040 within the Nova Scotia energy market grows to 1,050 MW of installed nameplate capacity. This is less than half the estimated extractable power from the Minas Passage (about 2,500 MW), but achieving that potential would require access to markets beyond Nova Scotia. It would also require tidal energy to be cost-competitive with alternative renewable and low-carbon energy sources (e.g., onshore wind, solar and combined cycle natural gas). We explore these and other considerations in the following section because they bear directly on the formulation of the tidal development scenarios.

Factors affecting the scale of tidal development

The ability to realize the tidal potential offered by the Minas Passage and the Bay of Fundy depends on several factors including resource considerations and turbine array configuration, grid interconnection and system integration, tidal costs and electricity rate economics, and risk and financing. The absence of acceptable levels of certainty about all of these factors creates a need for assumptions in order to formulate development scenarios. Understanding the assumptions is key to understanding the relative plausibility of the scenarios. The scenarios should not be considered as predictions of tidal development paths, but simply as hypothetical (yet plausible) constructs on which to base assessment of the tidal energy value proposition.

- **Tidal energy potential:** Research indicates the Minas Passage could yield 2,500 MW of extractable power without causing significant impact on the tidal flow. An explanation of the basis for this estimate, including assumptions about device capacity and configuration, is contained in Annex 3. This estimate and others like it for resource potential in the UK, Ireland, France, and elsewhere are based on computer simulations of how arrays of turbines are expected to operate in tidal flows. Experience with turbine performance in actual tidal conditions is limited to a few demonstration projects aimed at demonstrating the technical feasibility of single devices and optimizing their design. This work is continuing, with much research to be done to determine: the effects on performance of high turbulence in tidal flow, wake interactions and optimal device configuration, seabed conditions and limitations on device deployment, cable connections, and environmental effects.
- **Assembly and deployment logistics:** In-stream tidal units come in various designs and nameplate capacity. This is evident from the range of devices being deployed for testing at the two main test sites, FORCE in the Minas Passage and EMEC on the coast of Scotland (these are illustrated in Annex 2). These devices, floating and fixed designs with fixed or variable pitch blades, and turbine diameters of 4 to 16 m, range up to 2.5MW nameplate capacity and can weigh several hundred tonnes. Larger diameter machines with greater nameplate capacities may develop in the future for deeper water applications.

To facilitate deployment and minimize costs, assembly, staging and pre-deployment infrastructure must be built as close to the site as is practical (ideally, within a 1-2 hour shipping distance). There is a compelling business case for the same infrastructure to be utilized for the maintenance and regular refit of the turbine/generators, much the same as shipyards are used for both the building and overhaul of ships. And further, there is a compelling case for the development of a multi-user facility, again to keep costs to a minimum.

The nature and scale of such a facility, and how it would evolve, are unclear, given the uncertainty about how the industry could develop with respect to number of companies, device design and rate of capacity development (these factors would influence logistical requirements for device deployment and maintenance).

- **System Interconnection/Integration:** Tidal energy production is intermittent but completely predictable. Given the size of the Nova Scotia electrical system, the load-balancing challenges associated with adding hundreds of MW of tidal capacity into a system with substantial wind capacity (500MW by 2015) are high if the energy were to be directly absorbed by Nova Scotia demand. A 2012 Atlantic Energy Gateway study concluded that if modest additional investment were made during expansion of the bulk power system in Nova Scotia and New Brunswick to incorporate the Maritime Link, then it would be feasible to integrate at least 300MW of in-stream tidal capacity into the regional transmission grid.[6]

  Discussions with tidal developers, conducted as part of this study, make it clear there is considerable interest in developing the Bay of Fundy tidal potential beyond the 300MW goal set out in the Nova Scotia Marine Renewable Energy Strategy. The aim would be to supply the export market in the U.S. northeast. Developers contend that access to this market would allow a level of tidal development that would justify investment in infrastructure and facilities that would improve economies of scale, helping to bring down electricity rates to competitive levels. But exporting substantial levels of tidal energy to the U.S. would require strengthened transmission capacity through New Brunswick and Maine. Such an increase in capacity could form part of an Atlantic Energy Gateway strategy, though the cost and how the cost would be apportioned to each of the energy sources contributing to supply are unclear.

- **Economics:** Tidal energy technology is still in the developmental stage. Consequently, while some early capital and operating cost estimates are available, they are high and vary widely because of the "one-of-a-kind" nature of most of the input requirements and procurement decisions. As designs and production processes are industrialized and refined, costs become more predictable and also decline. This is the typical pattern with technology development, as exemplified by other sources of renewable energy, including onshore and offshore wind and solar (more on this in Chapter 4).

  Various sources place the current cost of tidal energy in the CA$450-650/MWh range (Synapse 2013; Carbon Trust 2012). By comparison, onshore and offshore wind costs are in the range of $80-100 and $250/MWh, respectively. The challenge for tidal energy is to become competitive with such alternative renewable sources as rapidly as possible. To encourage the research, development and innovation that would make this possible, several governments – including Nova Scotia – provide various incentives, including grants and electrical energy price support in the form of FITs.

[6] In its 2014 Integrated Resource Plan (IRP), Nova Scotia Power included tidal energy in its list of supply side options, but its low technology readiness score (10-15 year lead time) and relatively high installed cost ($10,000/kW) precluded tidal from active consideration in the analysis.

The Nova Scotia FIT has test and developmental declining block rates (Table 3.2) for large devices (>0.5MW), set at levels comparable to those in the UK, and with a Community FIT (COMFIT) of $652/MWh for small-scale (<0.5MW) devices. Nova Scotia government policy limits the electricity rate impact of the FIT to less than 2%. This effectively places a limit on installed nameplate capacity at about 20 MW under the FIT program.

Table 3.2: Nova Scotia tidal energy FIT (large-scale devices)

Developmental		Phase I Test		Phase II Test	
≤16,560 MWh	>16,560 MWh	≤3,330 MWh	>3,330 MWh	≤16,560 MWh	>16,560 MWh
$530	$420	$575	$455	$495	$375

Source: http://www.canlii.org/en/ns/nsuarb/doc/2013/2013nsuarb214/2013nsuarb214.pdf

It is unlikely that tidal costs will have dropped to be competitive with low-carbon alternatives by the time the program ends or the 20 MW limit is reached. Development beyond 20 MW is likely to require further public support, either in the form of grant programs or a reformulated FIT.

- **Financing:** Financing represents one of the major challenges for tidal development. The early years of development would be characterized as a period of high risk – technical, economic, market, and environmental. The expected return aligned with this high-risk profile puts pressure on the levelized cost of electricity given the capital-intensive nature of the technology. Ways of mitigating the risk are described in Section 6.4.

3.4 Tidal development scenarios

The 2012 Nova Scotia Marine Renewable Energy Strategy (NS MRE Strategy) envisions a phased and progressive development of Marine Renewable Energy, with a longer-term goal of producing 300MW of power from in-stream tidal energy projects. It anticipates the balance of new capacity requirements during the period would be taken up by other renewable and low carbon sources, including imports. Beyond 2028, additional tidal capacity could be installed based on market demand, competing resource options, and other factors but the NS MRE Strategy assumes no further tidal capacity additions. Implicit in the NS MRE Strategy is that the installation of 300MW of tidal capacity over the next 10-15 years would lead to competitive opportunities for Nova Scotian and Canadian companies in the international supply chain, but with higher costs associated with early development.

In this section, tidal development scenarios are presented and explained. To begin, the large scale, transmission grid-connected scenarios are described. This is followed by a discussion of small scale, distribution system-connected scenarios.

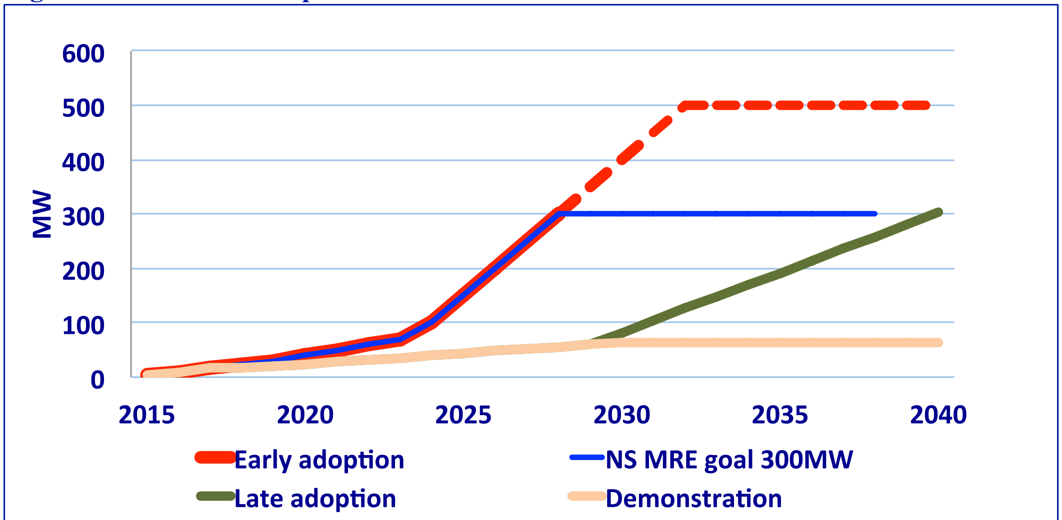
3.4.1 Large scale

Against the backdrop of the considerations described in the previous sections, we present three large-scale tidal development scenarios, all covering the period 2015-2040. These alternative paths are intended to provide contrasting conditions against which to assess potential supply chain development. The likelihood that actual development may follow one of these paths depends on the extent to which the underlying conditions are met. Consequently, it is crucial that these conditions are understood clearly.

Common to the three Large Scale scenarios is the deployment of devices at the FORCE site by the developers in the next 1-3 years. Installed capacity in each scenario is assumed to grow to 16 MW by 2017, and then increase at scenario-specific rates thereafter (Figure 3.2). Note: the developers listed below are the present berth holders; these are subject to change.

- Open Hydro/Emera installs two 2.0MW turbines in 2015 and tests these for two years with plans for further deployments.
- Atlantis/Lockheed Martin/Irving installs one 1.5MW turbine.
- Black Rock Tidal Power installs a 2.5MW semi-submersible 36-turbine device, with plans to install a second.
- Minas Energy/Marine Current Turbines installs a floating 2.0MW twin-turbine, with plans to install a second.

Figure 3.2: Tidal development scenarios



Demonstration Scenario – 64MW by 2040

The Demonstration Scenario contemplates developers taking full advantage of the installed infrastructure at FORCE under various government or research initiatives, with deployment limited to 64 MW by 2030 (67 MW if including the small-scale Low Scenario). Under this scenario, the tidal industry will have not managed to achieve sufficient cost reduction to reach grid parity in Nova Scotia and public support to make up the difference has not been forthcoming.

The limited tidal development under the Demonstration Scenario occurs under the following conditions:

- The costs of tidal energy remain high, with limited prospect of becoming competitive with alternative renewable energy sources in the Nova Scotia market until after 2040.
- Government support in the form of the FIT and other measures continues to support new installations until 2030, but industry inability to achieve cost reductions results in no further capacity installed beyond 64 MW (67 MW, including small-scale tidal).

- The industry continues to use Halifax as the base for device assembly and fabrication, with devices barged to the FORCE site for deployment. A small maintenance facility is developed in the Bay of Fundy.

Early Adoption Scenario – 500MW by 2040

Following three years of testing and the installation of several pre-commercial turbines, the first commercial tidal array is installed in 2019, bringing total capacity to 30MW. This grows by annual increments of 10MW to 2023, ramping up to 50MW annual increments. In 2028, this phase will have met the 2012 NS MRE Strategy's goal of 300MW (Figure 3.2).

Subsequent annual additions of 50MW will occur until 2032, when the upper limit of regional market potential (500MW) is reached. The 500MW estimate is consistent with the hatched area of energy opportunity in Figure 3.1, less what might be taken up by other renewable sources by that time. Implicit in this scenario is that Nova Scotia and Canada accelerate the installation of tidal capacity, resulting in greater competitive opportunities for Canadian companies in the international supply chain, but with the higher costs associated with early development.

Meeting the rate and scale of tidal development defining the Early Adoption Scenario depends on the following:

- The costs of tidal energy come down rapidly, becoming competitive with alternative renewable energy sources in the Nova Scotia market after 2040.
- With indications that tidal energy costs are declining rapidly, the industry continues to receive support from governments until tidal energy is competitive with alternative renewable sources.
- The investments needed to integrate several hundred MW of tidal energy are made during the expansion of the bulk power system in Nova Scotia and New Brunswick to incorporate the Maritime Link.
- A multi-user facility is developed in the Bay of Fundy for the manufacture, assembly, staging and deployment of tidal devices. This facility is gradually transformed to provide maintenance support for the operating units.

Late Adoption Scenario – 300MW by 2040

Capacity installations occur further into the future, when costs of tidal technology are lower. It reaches the installed capacity of 300 MW by 2040. The driver continues to be the need for a reduction in GHG emissions, but with limited support to defray the high cost of the technology, capacity growth is delayed until costs have come down to more competitive levels with alternative renewable sources. The ramp-up to 300MW occurs between 2030 and 2040. Cost competitiveness is driven by the growth of tidal capacity internationally, but late entry into the marketplace reduces the competitive advantage for Nova Scotian and Canadian suppliers in accessing international supply chain opportunities.

Meeting the rate and scale of tidal development defining the Late Adoption Scenario depends on the following conditions:

- The investments needed to integrate several hundreds of MW of tidal energy are made during the expansion of the bulk power system in Nova Scotia and New Brunswick to incorporate the Maritime Link.

- Tidal device developers receive no support from governments beyond that needed to develop FORCE to its maximum capacity.

- The costs of tidal energy come down rapidly in the 2020s, becoming competitive with alternative renewable energy sources in the Nova Scotia market soon after 2040. This provides the basis for capacity growth that may continue after 2040.
- A multi-user facility for the manufacture, assembly, staging and deployment of tidal devices is developed in the Bay of Fundy by 2030. This facility is gradually transformed to provide maintenance support for the operating units.

A hypothetical export case

One criterion for developing the scenarios specified in the terms of reference for this study is that the scenarios should be plausible. Applying this criterion effectively rules out a scenario that would see development of the full potential of Minas Passage (2,500MW) within the study timeframe. We refer to this as the "Export Case", because this level of development would be contingent on access to the export market. As desirable as such a development path would be from an industrial perspective, analysis of the conditions necessary to support this rate of development indicates that it is unlikely they would be met within the 2015-2040 study period (see text box below).

Conditions necessary to support 2,500MW by 2040 – a hypothetical Export Case

Development path

Following three years of testing and the installation of several pre-commercial turbines, the first commercial tidal arrays would be installed in 2018, bringing total capacity to 40MW. This would grow by 30MW in 2019, 50MW in 2020, and 80MW in 2021, with annual increments of 100 MW thereafter. By 2025, installed capacity reaches 500MW, the upper limit of Nova Scotia market potential. Demand for renewable energy in export markets supports continued growth after 2025. By 2040, total installed capacity stands at 2,500 MW.

Meeting the rate and scale of tidal development defining the Export Case depends on the following conditions:

- Continued Nova Scotia and federal government financial support for tidal energy. This could take the form of a renewed FIT, and/or other forms of grant support and tax/investment credits until tidal energy costs come down to a level of competitiveness with alternative sources of renewable energy.
- Tidal device developers continue to receive sufficient support from governments and investors globally to maintain their interest in developing the technology to the point of competitiveness with alternative energy sources. The rate at which costs drop is a function of the level of global capacity installation.
- With continued support, the costs of tidal energy come down rapidly, becoming competitive with alternative renewable energy sources in domestic and export markets by 2021. Continued government and investor support is contingent on significant cost reductions in the next 5-7 years.
- A multi-user facility is developed in the Bay of Fundy for the manufacture, assembly, staging and deployment of tidal devices. This facility is gradually transformed to provide maintenance support for the operating units.
- The necessary grid interconnections are in place by 2025 to support the export of tidal and other renewable electrical energy to the U.S. market. Proponents of the interconnection give early commitment to construct the transmission facilities to provide the tidal industry with sufficient certainty to commit to investing in the fabrication facilities and infrastructure needed to meet annual capacity increases of 100 MW out to 2040.
- The delivered cost of tidal energy in the U.S. northeast is competitive with alternative renewable energy sources by 2025.

3.4.2 Small scale

Low Scenario – Installed capacity reaches 3MW

The Community Feed-in Tariff program is available for small-scale tidal energy development in Nova Scotia, for devices with rated capacity of less than 0.5MW that feed into the distribution grid and where capacity exists. Project developer, Fundy Tidal Inc. of Westport, NS, has been awarded COMFIT agreements for 5 sites in Nova Scotia: Digby Gut (1.95 MW), Petit Passage (500 kW) and Grand Passage (500 kW) in Digby Neck, and Great Bras d'Or Channel (500 kW) and Barra Straight (100 kW) in Cape Breton Island. The terms require the developer to begin delivering electricity to the grid within 5 years of being awarded the COMFIT. This implies the devices will be commissioned by 2017. In the scenarios calculating LCOE, 3 MW of small-scale tidal energy devices are assumed to be installed between 2015 and 2017 in the Digby Neck region.

Fundy Tidal Inc. is presently assessing the characteristics of the water and seabed, presence of marine life, fishing zones, and navigational uses and seeking public input on potential locations for turbines in Grand Passage and Digby Gut. Fundy Tidal is planning a 1-year demonstration of a 65 kW Clean Current turbine in 2015 in Grand Passage. It has formed a strategic partnership with Tribute Resources and Tocardo International to install a 1.95 MW array of Tocardo tidal turbines in the Digby Gut of the Bay of Fundy. Fundy Tidal Inc. will be the project developer, operator and retain a majority interest in the projects (fundytidal.com).

The two Cape Breton COMFIT sites, where the water depth and speeds are not as great as along Digby Neck, are more challenging sites to develop economically with current technology.

Meeting the rate and scale of tidal development defining the Small Scale - Low Scenario depends on the following conditions:

- Continued progress in resource, site and environmental assessments, and community consultations;
- Sufficient capacity of the connection to the distribution system (unless access to the transmission system is permitted);
- Success obtaining permits and licenses and a power purchase agreement; and
- Financing and/or strategic partnerships to complete the COMFIT projects.

High Scenario – Installed capacity reaches 10MW

In Nova Scotia, Community Feed-in Tariff agreements have been awarded for the delivery 3.55 MW of small-scale tidal energy to the electrical grid. The sites along the Digby Neck (Digby Gut, Petit Passage, Grand Passage) have sufficient tidal resources for 66 MW of tidal energy, but their development is constrained by the capacity of the local distribution grid. There are also several small passages in Yarmouth County that could support small-scale tidal energy devices.

To reach 10MW economically, development may need to occur further afield. In New Brunswick, the Grand Manan Channel and Western Passage have resources suitable for small-scale tidal. There are other suitable tidal resources in British Columbia and Québec. In British Columbia, Haida Gwaii, Seymour Narrows, Campbell River, Discovery Pass, Boundary Passage have sites with large potential but there are numerous barriers to developing them on a large scale. British Columbia also has numerous small channels suitable for small-scale tidal energy development

(CHC 2006). Northern development policies in Québec and needs for remote or off-grid development in British Columbia will determine these opportunities.

Locations in Ungava Bay and the Hudson Strait, in Québec, are rich with tidal energy but the unique challenges of developing it in these northern waters are considerable. However, where nearby communities depend on diesel-generated electricity, small-scale tidal energy could be cost competitive.

Meeting the rate and scale of tidal energy development defining the Small Scale - High Scenario depends on the following conditions:

- Lessons learned from Digby Neck and Cape Breton can be transferred to other locations;
- Storage and smart grid implementation is successful;
- Local supply chain - items such as installation, operation and maintenance work that cannot be easily be brought in, can be sourced locally;
- Equipment and procedures can be adapted to very cold waters;
- Once environmental, transportation, navigation and other regulatory requirements are met and First Nations consultations and strategic environmental assessments are conducted, permits and licenses are granted by the respective provincial/territorial and federal governments; and,
- In the absence of a feed-in tariff in these jurisdictions, tidal energy can be developed at a competitive cost.

3.5 Levelized cost of energy

The LCOE is widely used to compare the costs of different generating technologies. The LCOE methodology uses 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 cost 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 includes 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. If done in Canada, the competitiveness of tidal energy conversion improves vis-à-vis non-renewable energy alternatives.

3.5.1 Cost estimates of tidal energy

In Nova Scotia, the most recent and complete estimate of tidal energy costs is the 2013 submission to the Nova Scotia Utilities and Review Board by Synapse Energy Economics for the development of the large-scale developmental feed-in tariff. Synapse consulted with potential project developers and staff at Nova Scotia Power, Inc., Emera, the Nova Scotia Department of Energy, Marine Renewables Canada, Fundy Tidal Inc., the Fundy Ocean Research Centre for Energy, and the Consumer Advocate. For a 10MW array, Synapse estimated the capital costs to be CA$71.3 million, annual operating and maintenance costs of $5.3 million per year and a decommissioning cost, net of salvage, of $5.2 million. The Synapse estimates, in present values, are presented in Table 3.3 (assumptions: 15 year economic life, 2% inflation, 10% after-tax discount rate).

Table 3.3: Present value of costs of 10 MW tidal generating facility, 2013

UARB/Synapse 2013 FIT	Starting costs (FIT)		
Cost Centre	**$**	**%**	**$/MW**
Design, engineering, permitting	6,500,000	5.8%	650,000
Structure	23,000,000	20.6%	2,300,000
Power/Electrical	21,500,000	19.3%	2,150,000
Subsea connection	6,000,000	5.4%	600,000
Grid Connection			
Monitoring and Control	1,600,000	1.4%	160,000
Installation	12,700,000	11.4%	1,270,000
Total capital costs	71,300,000	64.0%	7,130,000
O&M (PV annual costs)	38,694,069	34.7%	3,869,407
Decommissioning-SV (PV)	1,477,629	1.3%	147,763
	111,471,698	100.0%	11,147,170

3.5.2 Cost estimates, disaggregated by main activity

Very few breakdowns of CAPEX or OPEX estimates are publically available. Cost centres include: design, engineering, permitting; structure and prime mover; power take-off; station keeping; grid connection; installation; and operation and maintenance. Of those provided, they are broken down differently, making comparisons difficult. Though there are some similarities, the percentages vary across studies. Three such studies are summarized in Table 3.4 below. Carbon Trust conducted an analysis of potential costs (Carbon Trust 2011), the Low Carbon Innovation Coordination Group conducted a technology innovation needs assessment (TINA) (LCICG 2012b), and SI Ocean conducted a study of costs and cost reduction opportunities (SI Ocean 2013). Some of the differences in percentages are due to the particular device design being used in the analysis and whether it is held in place by a gravity base or pile.

The most recent and regionally relevant cost breakdown was provided by Synapse Energy Economics, as noted above. We vetted these numbers with device and project developers and they generally agreed with the breakdown, noting it is highly dependent upon the turbine design and system used for station-keeping. This study uses the Synapse 2013 costs, cost centres and weightings as the base case for the analysis.

Table 3.4: Tidal device cost breakdown by major cost centre

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.

3.5.3 Cost Reductions

The historical costs of wind energy serve as an example of cost reductions that are possible over time. From the 1980s to 2004, 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. Furthermore, advances in the technology improved the viability of low wind speed sites such that the land area in the US 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).

Learning rates are typically used to estimate the potential for cost reductions in new technologies arising from the industry learning that develops with experience. The application of a learning rate to estimate cost of energy reductions 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 learning rates for tidal energy conversion ranging from 7-15%. They use 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 of tidal current technologies.

Learning rates, though commonly used, are more multifaceted and prone to bias than they appear. Learning rates are drawn from studies of past technologies: their cost decreases with the global installations over time. However, a number of 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 various variables are difficult to discern and even more difficult to predict. Thus, the suitability of a learning rate from another time, location and technology, such as past onshore or offshore wind power in the UK, is less than perfect. Accordingly, learning rates and the resulting cost reductions should be interpreted with caution. The sensitivity of the tidal energy conversion LCOE to the learning rate assumption will be discussed in Section 3.5.5.

Several recent reports have broken down estimated learning rates by cost centre (Carbon Trust 2011; RenewableUK 2013; LCICG 2012b). The learning rates by cost centre, when weighted by the proportion of total costs of tidal energy conversion (TEC) development noted in Table 3.5 below, show some areas where proportionately greater cost reductions can be found. These indicate areas where focused R&D support could have greater impact on the costs of energy from tidal energy conversion. Much of the work in these particular cost centres would be sourced locally if it is available (e.g. structure, installation, operations and maintenance). This suggests fertile ground for both cost reductions in Nova Scotia/Atlantic Canada/Canada and innovations that could benefit the global tidal energy industry. Table 3.5 shows the cost centre weightings and the learning rates in those cost centres, as estimated by the Carbon Trust (2011).

Table 3.5: Cost centre weightings and learning rates

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%**	

3.5.4 The LCOE for each Nova Scotia tidal energy development scenario

For this study, the SI Oceans (2013) and Carbon Trust (2011b) overall learning rate of 12% is used as the base case. We assume a 25-year economic life and an 8.8% discount rate (before-tax real rate + risk premium, as implied by the Synapse 10% after-tax nominal discount rate). Costs are in 2013 Canadian dollars (1 USD=1.10 CAD).

The utilization rate is assumed to be 95% and capacity factors range from 37% to 45% depending on the particular site characteristics where turbines can be placed. Annex 3, *Estimating the Plausible Installed Capacity for Nova Scotia's Tidal Energy Industry*, describes the various locations where turbines would likely be installed in the Minas Passage. These are described in Table 3.6. The very best sites are Category 1 sites. They are within 2,500 m of FORCE and have a water depth of between 30-50 m. The mean capacity factor for 1MW devices installed in Category 1 sites is estimated to be 45%. Based on what is presently known about interactions between devices in an array, it is estimated there is space for 82 MW of installed capacity in Category 1 sites (assuming 2MW devices). The next best sites are Category 2 sites, where the mean capacity factor is estimated to be 41%. There is space for approximately 224 MW of installed capacity in the Category 2 sites. It is assumed the best sites will be used first. There is approximately space for 630 MW of installed capacity in Category 3 sites, where the estimated mean capacity factor is 37%.

Table 3.6: Capacity factors by installed MW in the Minas Passage

Category	1	2	3
Installed Capacity MW	82	224	630
Mean Capacity Factor	45%	41%	37%
Minimum Capacity Factor	40%	35%	30%
Utilization Rate	95%	95%	95%
Depth Range	30-50 m	30-60 m	30-75 m
Distance from FORCE	2500 m	3000 m	4000 m
Number of 2MW turbines	41	112	315
Mean Power Generated	37 MW	96 MW	247 MW

Combining the Large Scale and Small Scale scenarios described above, the assumed installations in 5-year increments are shown in Table 3.7 along with the estimated CAPEX and OPEX.

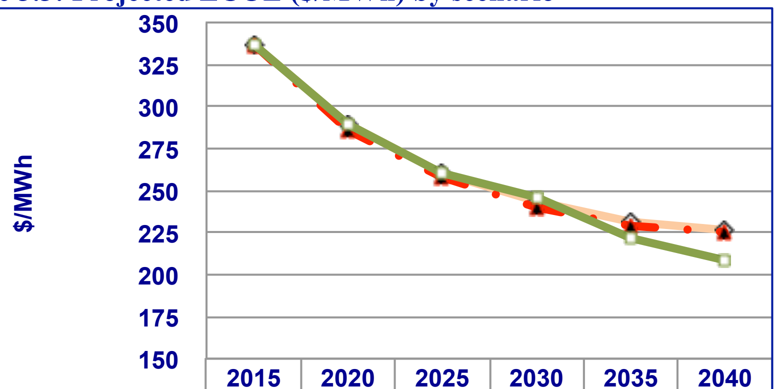
Table 3.7: Projected MW installed capacity and costs by Scenario

	Demonstration Scenario			Early Adoption Scenario			Late Adoption Scenario			Global
Scenario	MW	CAPEX	OPEX	MW	CAPEX	OPEX	MW	CAPEX	OPEX	MW
2015	4	29	2	4	29	2	4	29	2	20
2020	27	176	41	40	257	57	27	176	41	150
2025	47	281	116	150	850	251	47	281	116	325
2030	67	376	220	400	1,979	736	82	470	236	500
2035	67	376	327	500	2,382	1,413	192	942	461	1,125
2040	67	376	423	500	2,382	2,101	300	1,356	821	1,625

Global tidal MW: IEA 2013

Figure 3.3 summarizes the downward trend of the LCOE in each of the three scenarios over time. Each of these is discussed below.

Figure 3.3: Projected LCOE ($/MWh) by scenario



	2015	2020	2025	2030	2035	2040
Demonstration	336.46	289.30	260.73	243.28	231.39	226.32
Early adoption	336.46	285.96	258.24	239.84	229.09	224.95
Late adoption	336.46	289.30	260.73	245.89	222.26	208.73

Demonstration Scenario: Like all scenarios, there will be cost reductions as a result of global industry learning in the Demonstration Scenario. In Nova Scotia, all the large-scale devices will be sited in the best sites (Category 1) so the best capacity factors will be achievable. The net effect is estimated to be an LCOE in 2040 of $226.32 per MWh (in 2013 dollars).

Early Adoption Scenario: This Scenario sees the most rapid installation of in-stream tidal energy conversion devices in Nova Scotia. The global industry will not be as far along the learning curve before a large number of units is installed under the Early Adoption Scenario. All the Category 1 and 2 sites will be used (306 MW of installed capacity) and the remaining units (194 MW) will be in the lowest capacity factor Category 3 sites. The net effect of the learning and lower quality sites is that the LCOE will continue to decrease but will not be lower than the LCOE in the Late Adoption Scenario in 2040. The LCOE in 2040 under this scenario is forecast to be $224.95 per MWh. (This does not include higher costs of developing Category 2 and 3 sites, just lower capacity factors.)

Late Adoption Scenario: With the slower rollout of installations than the Early Adoption Scenario, there will be counteracting influences on LCOE. Since the installed capacity in the rest of the world is expected to grow at the same pace in all scenarios, learning rates will reduce costs in any case. With the slower pace of construction of the Late Adoption Scenario, proportionately more devices will be built and installed when the industry is further along the learning curve. This scenario will see all of the Category 1 sites used, and many of the Category 2 sites. The Category 2 sites will have lower capacity factors, bringing down the mean power generated per device, thereby having an upward effect on LCOE. The net effect is estimated to be an LCOE in 2040 of $208.73 per MWh. (This does not include higher costs of developing Category 2 sites, just lower capacity factors.)

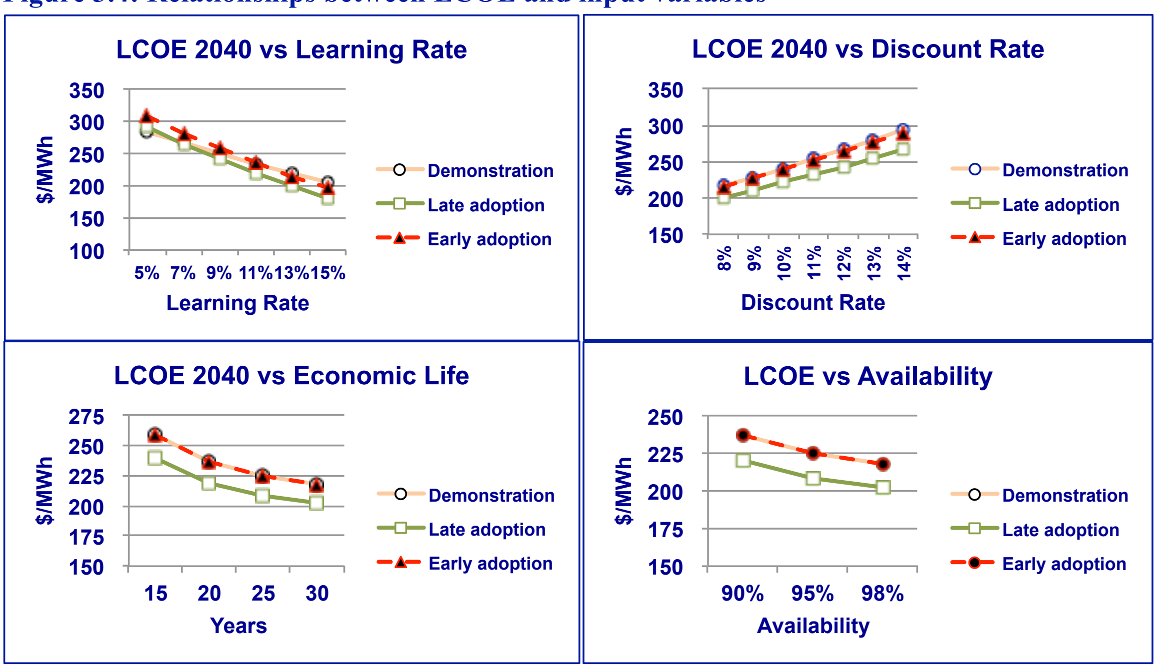
In all scenarios, by 2040, the oldest devices will be due to be replaced. Replacements will be at a much lower cost than the first-generation devices due to learning and they will be replaced first in the Category 1 sites. The rapid build out of Early Adoption Scenario will see more replacements sooner but this will occur after this study's forecast horizon of 2040.

With the faster build-out in the Early Adoption Scenario, specialized knowledge or technologies may be developed here before they are elsewhere in the world, providing for export opportunities for Canadian companies.

3.5.5 Sensitivity

The relationships between the LCOEs and four key input assumptions were tested. The four variables are: learning rate (range: 5%-15%), discount rate (8%-14%), economic life (15-30 years), and device availability (90%-98%). The results are shown in Figure 3.4. The graphs show the relationship between each input variable and LCOE, comparing the effect on the cost in the three scenarios. Taking the learning rate as an example, the relationship between LCOE and the learning rate is an inverse one; the higher the learning rate, the lower the LCOE will be by 2040. The learning rate may be seen as a proxy for the rate of capacity installation and its effect on energy cost: a higher installation rate would shift the curves to the left, resulting in lower energy costs for a given learning rate. By contrast, there is positive relationship between the discount rate and LCOE; the higher the discount rate (or cost of financing), the higher the LCOE will be.

Figure 3.4: Relationships between LCOE and input variables



Further, drawing on the Early Adoption Scenario as an example, the sensitivities of the 2040 LCOE estimate to the four variables are shown together in the Figure 3.5 below. It shows the LCOE is most sensitive to the availability of the devices (coefficient of variation c_v = standard deviation/mean =16%). In other words, downtime results in a significant loss of revenue as a result of lost productivity. In the event that downtime is a result of equipment failure, the cost of this downtime would be further increased by repair costs.

The second most influential variable of the four is the assumed learning rate (c_v=9%). The LCOE is quite sensitive to the discount rate as well (c_v =7%). For example, if the discount rate is 10% higher than the 8.82% Base Case assumption, or 9.7% (8.8% x 1.10= 9.7%), the 2040 LCOE estimate changes from $224.91 to $235.25, an increase of $10.34/MWh.

The least impactful, though still noteworthy, variable of the four tested is economic life. Since a large proportion of the costs is fixed, it is understandable that the longer the devices can generate power, the lower the cost per MWh. This study assumes the level of output from the devices will be the same through their entire economic life, though there is not yet sufficient operating data to substantiate this assumption. Degradation as the equipment ages is possible.

Figure 3.5: Sensitivity of the Early Adoption scenario LCOE to input variables

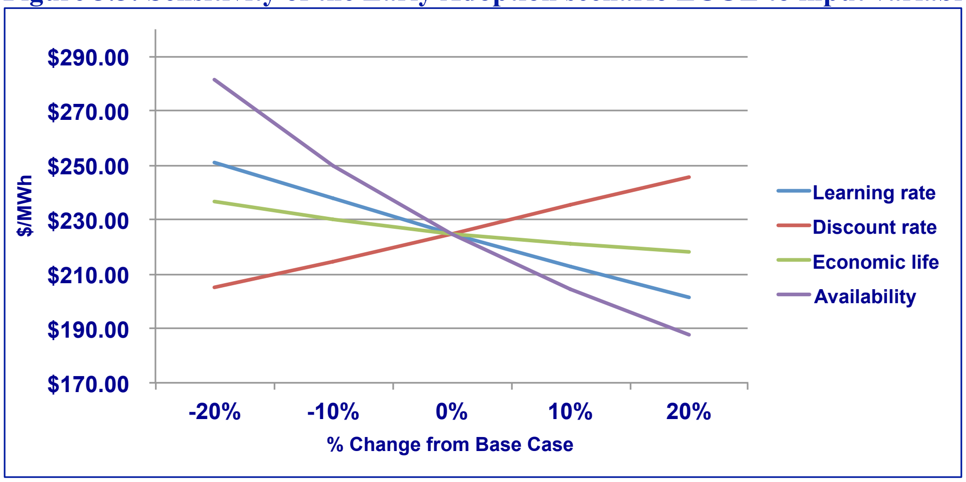


Table 3.8 provides the sensitivity of LCOE 2040 for the Early Adoption Scenario at various deviations from the starting values. The base case is the one used to calculate the LCOEs in Section 3.5.4.

Table 3.8: LCOE sensitivity – Early Adoption Scenario vs deviations from Base Case assumptions

Base case value	Learning rate 11%	Discount rate 8.8%	Economic life 25	Availibility 95%
Deviation fr. Base case		LCOE $/MWh		
-20%	$225.25	$179.06	$206.74	$245.55
-10%	210.40	187.60	200.86	218.27
0%	196.44	196.40	196.44	196.44
10%	183.33	205.45	193.07	178.58
20%	171.03	214.73	190.46	163.70
Mean	$197.29	$196.65	$197.51	$200.51
Standard Deviation	$21.44	$14.11	$6.46	$32.39
Coefficient of variation	11%	7%	3%	16%

3.6 Competitiveness with alternative low-carbon energy sources

The presence of unique tidal resources in Nova Scotia and absence of carbon emissions in tidal energy conversion gives reason to explore the development of this renewable resource. However, as with any emerging technology, initial costs are high. Until tidal energy reaches parity with the next best renewable alternative, the extra cost for energy, paid either by the taxpayer or ratepayer, is essentially an investment in learning (Brattle Group, 2013).

Tidal will be more expensive than competing non-renewable sources of energy for quite some time, at least in the absence of a price on carbon. Reaching parity with the next best source(s) of renewable or low-carbon energy in the region is foreseeable, however, taking into account the greater predictability of the tides than the wind.

Our estimates of costs of energy from various renewable sources, drawing on Black and Veatch/NREL (2012) and Dalton (2013) to estimate the costs of the alternatives, are shown in Table 3.9. They show the dramatically decreasing costs of newer renewable sources, tidal energy and photovoltaic. Onshore wind energy also shows a decrease in LCOE over the time period, though being a fairly mature technology, the rate at which it will decrease is much smaller. Low-carbon fossil fuel alternatives, such as natural gas and coal with carbon capture and storage (CCS), show increasing LCOEs. This is because the decreases from developing the newer technologies for CCS begin to be offset by projected increases in the cost of the fuel.

Table 3.9: Levelized costs of energy forecasts – Nova Scotia ($/MWh)

	Natural Gas					Photovoltaic		Tidal
	Simple Cycle	Combined-cycle	With CCS	Onshore Wind	Pulverized Coal with CSS	Residential	Commercial	Early Adoption
2015	116.74	74.11	n/a	109.44	n/a	388.30	348.20	336.46
2020	131.83	84.27	151.03	109.44	180.87	338.47	305.58	285.96
2025	147.83	95.05	166.55	106.55	180.83	313.53	283.85	258.54
2030	166.68	107.75	184.85	103.82	194.00	298.22	271.75	239.84
2035	193.31	125.70	210.68	103.82	208.55	288.52	262.05	229.09
2040	232.97	152.41	249.16	103.82	225.18	278.83	253.16	224.95

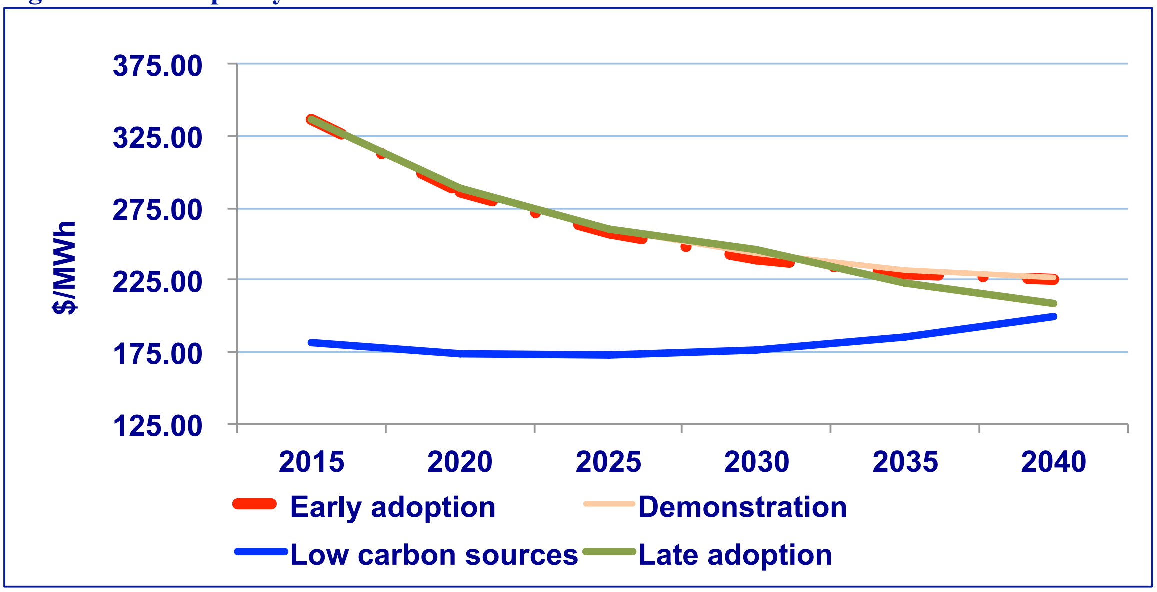
Offshore wind also represents a potential alternative renewable energy source, though with the abundant onshore wind resource in Nova Scotia (which is not yet fully exploited), offshore potential remains to be defined and has not yet attracted any development proposals. It may do so in the future, though it is not clear the wind regime in Nova Scotia waters shares the favourable characteristics found elsewhere (greater consistency at higher speeds than onshore, resulting in generally higher capacity factors). Nonetheless, if the U.K. experience offers guidance (see below), then we could expect the offshore wind LCOE to be above onshore wind (throughout the study period), but eventually at or below the other low-carbon alternatives listed in Table 3.9.

In the U.K., the world leader in offshore wind potential and installed capacity, offshore wind is the current (and likely future) alternative against which tidal energy would compete. By mid-2014, offshore wind capacity had reached 3,650MW, with 4,600MW under construction or with approval to proceed. In addition, projects with a total capacity of 32,500MW are at various stages of planning and development (RenewableUK 2013). Estimates vary for the LCOE for offshore wind projects installed prior to 2012, ranging from a low of CA$150-220/MWh (IRENA 2012) to a high of CA$270-350/MWh (Deutsche Bank 2011). A detailed study of the prospects for offshore wind energy and supply chain development in the U.S. estimates an LCOE of about US$197/MWh in 2015, dropping to US$167/MWh by 2030 (Navigant 2013).

3.6.1 Public support needed for tidal energy to become competitive

To be competitive with other low-carbon sources of energy in Nova Scotia, the cost of energy from tidal conversion would likely need to reach parity with electricity generated from a combination of combined-cycle natural gas, distributed photovoltaic energy and imported hydroelectric power. Using a weighted cost of these, and assuming 1/3 of the electricity comes from each source, the projected costs of tidal energy generated electricity would reach parity with these sources sometime after 2040. This is shown in the Figure 3.6. The wedge formed by the converging lines (tidal energy under each scenario with the combined low-carbon alternatives) indicates the learning investment: the cost premium that would need to be supported by taxpayers or ratepayers to develop this new source of renewable energy.

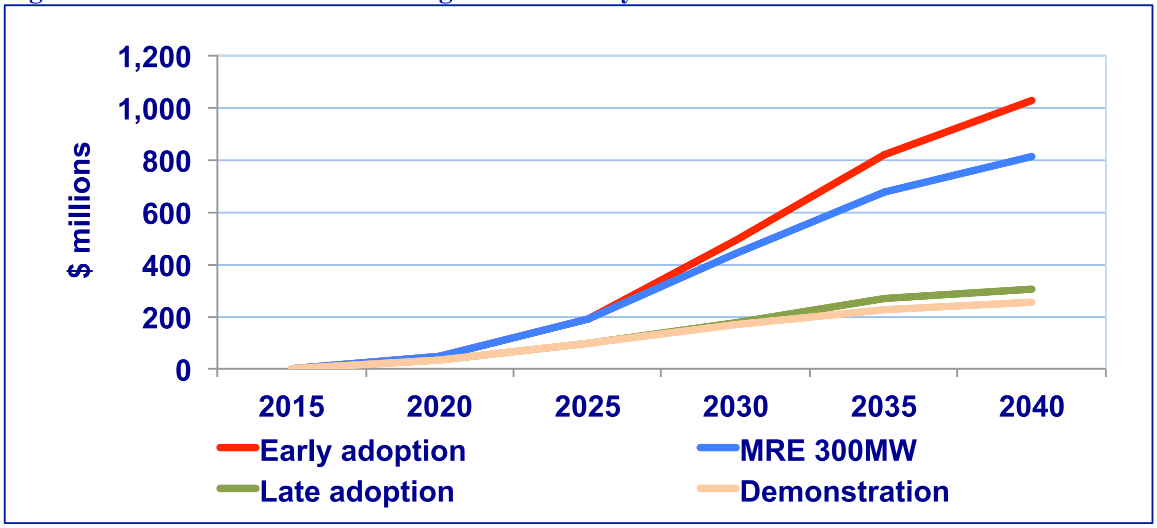
Figure 3.6: Cost parity with low-carbon alternatives



The learning investment is illustrated in Figure 3.7. It is the difference between the cost of tidal energy (LCOE x 5-year MWh) over a blend of photovoltaic, imported hydro and combined cycle natural gas for the 25 years of the forecast period. The investment will peak for each scenario by 2035. After some time, tidal energy will be less expensive than the three combined alternative sources, at which time savings will occur. The three scenarios will begin to pay back after the end of the 25-year forecast period. The net learning investment over the 25-year period, in present value terms would be $256 million for the Demonstration Scenario, $305 million for the Late Adoption Scenario, and $1,028 million for the Early Adoption Scenario. The learning investment would be $813 million if installation were limited to the NS MRE Strategy 300MW.The Late Adoption Scenario pays back the most by 2040 but the rate at which the scenarios pay back after 2040 will be the greatest in the Early Adoption Scenario.[7]

[7] Forecasts of global installed capacity have been decreasing dramatically in the last two years (e.g. RenewableUK 2014). Policy changes in the UK, difficulty raising capital, and other factors have made forecasts post-2020 highly uncertain. Should there be a positive change in UK support for tidal energy development, global installations after 2020 could be much higher. As an example of how such a development would affect the Nova Scotia situation, if global installations after 2020 were 50% higher than forecasted in this report, the learning investments would be: Demonstration - $216 million, Late Adoption - $206 million, and Early Adoption - $810 million. Grid parity would be reached by 2040 in the Late Adoption Scenario, and somewhat later in the Demonstration and Early Adoption Scenarios.

Figure 3.7: The cumulative learning investment by scenario



3.7 Summary

The three scenarios indicate the cost of energy drawn from the tides will likely be competitive with the most plausible low-carbon alternatives soon after the end of the forecast period. The taxpayers' or ratepayers' investment to support the development of in-stream tidal energy conversion will likely begin to pay back in that time as well. The benefits of the Early Adoption and Late Adoption Scenarios should be given due consideration and weighed against one another. The Late Adoption Scenario will provide 300MW of electricity from in-stream tidal energy at the lower cost, thanks largely to global learning in that time. In contrast, the earlier and greater investment in tidal energy development in the Bay of Fundy will encourage early learning and innovation that can result in exportable expertise and technologies, and greater economies of scale to attract developers and supply chain participants.

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4

Tidal Industry Supply Chain Opportunities

4.1 Developing a global tidal energy industry

4.1.1 Lessons the wind industry has to teach

A tidal industry is developing, led by several tidal device developers and IPPs. Some of the world's largest industrial equipment manufacturers have acquired the technology companies that developed the original prototypes. RDI&D have progressed to the point where several devices have been installed in EU waters for testing and optimization. The challenge over the next several years is to fully industrialize the process – prove the reliability; design facilities with minimal environmental impacts; reduce costs by increasing the rate of installations, spurring innovation and creating supply chains – resulting in the capacity to produce electricity at competitive prices with alternative renewable sources.

When and how a tidal energy industry may develop remains uncertain. Other renewable energy technologies such as onshore and offshore wind may offer some guidance. From modest annual increments in the early 1980s, cumulative global installed wind capacity now approaches 300GW (of which about 7GW is offshore), producing about 2.5% of global electrical energy. Annual investment in new capacity at the end of 2012 approached US$80 billion (IEA 2013).

- Though windmills have been used in various ways for centuries, serious R&D on adapting the technology to produce electricity only began in the late 1970s, following the sharp rise in oil prices. Since the early 1980s, advances in design, supported by public funding in Denmark, the U.S., Germany, and Spain, led to greater unit capacity, reduced cost and increased use. Wind turbine unit capacity has increased from 75kW to 5MW, with rotor diameter growing from 17m to over 120m. Capacity cost has dropped from US$3,500/kW to less than US$1,500/kW, while LCOE has declined from US$250 to as low as US$50-100/MWh in some countries (IEA 2013).

  IPPs implement most wind projects, typically in response to requests for bids by electrical utilities. The IPP may be technology neutral, selecting the turbine make/model that best meets the selection criteria for location, wind conditions, performance and price. The major turbine manufacturers (Vestas, Siemens, Enercon, Gamesa, GE, Goldwing) specialize in design and development, as well as assembly of the nacelles (the unit at the top of the tower housing the drivetrain, generator and controls). Extensive supply chains of companies manufacture the various components and sub-components: towers, blades, mechanical and electrical equipment, generators and control systems. This decentralized and specialized industry structure contributes greatly to achieving economies of scale.

- The development of offshore wind farms began in the early 2000s, attracted by generally stronger and steadier wind speeds in offshore areas. Most of the turbines used in offshore projects are adapted from onshore designs, with rated capacities in the 3-4MW range. The early shallow-water projects tended to be in the under-200MW range, but with greater operating experience and confidence in the technology, more recent projects are in the 400-600MW range. These projects are using turbines designed specifically for offshore conditions, with larger rotors and rated capacities exceeding 5MW (the focus now is on developing 6-8MW machines).

These larger units (nacelles) require assembly at tidewater locations (rather than existing plants), necessitating investment in new manufacturing facilities. There is also a move to deeper water (>30-35m), necessitating the development of more robust foundation designs (including a shift from conventional steel monopiles to steel jackets, integrated "float-out-and-sink" concrete designs, and even floating systems). Moving into near-shore waters has expanded the supply chain to include foundation design and manufacture, as well as the marine capabilities needed for cabling, deployment, installation and maintenance. Moving farther offshore also creates a need for development and installation of marine high-voltage direct current (HVDC) systems to carry power over longer distances to reduce cable costs and electrical losses.

4.1.2 Tidal energy – demonstration and pre-commercial phase: 2015-2019

The development of a tidal energy industry can be expected to follow a pattern similar to that experienced by wind energy. RDI&D is well underway, with the prospects for a tidal industry gaining momentum in recent years as several major manufacturing companies have begun to apply their technical, industrial and financial strength to advance the technology. Governments have provided hundreds of millions of dollars in direct and indirect financial support. Tariff support for grid-connected devices is being made available. Several tidal devices are being tested at EMEC, the European Marine Energy Centre, and at other locations in the EU. All four berths at the FORCE demonstration and development site in the Bay of Fundy have been allocated to device developers, with Open Hydro planning to install two 2MW devices for testing in 2015. Installation specifics for the other three developers have not yet been disclosed, but installation is expected in the 2016-2017 period.

From the perspective of market pull and push, the industry path would appear to be set for the next 4-5 years. Locations where the resource is most promising have mechanisms in place to support prototype and early commercial grid-connected installations. Nova Scotia offers a FIT (available up to a maximum of about 20 MW to keep the impact on electricity rates to no more than 2%). The UK has subsidized renewable energy development with a system of ROCs[8] for over a decade, but is phasing out this approach (by 2017) in favour of a FIT (introduced in 2014). The FIT is available for projects up to 30 MW provided they are installed by 2019 (Renewable UK 2013). The Nova Scotia and UK FITs provide tidal producers with a comparable level of support ($450-500/MWh). France also offers a FIT, though at a lower rate (because further subsidies have been provided to help establish the industry).

The next major phase for the industry is likely to be the installation of pre-commercial arrays (±10MW based on ±2MW devices) at the test sites, once testing confirms the reliability of the individual devices. Industry observers suggest that a minimum of two years continuous performance would be needed to meet the reliability and operability criteria established by Independent Power Producers (IPPs), insurers, lenders, investors and utilities. This suggests 2018-2019 at the earliest for the first pre-commercial arrays. The FITs in the various jurisdictions are essential to industry development to this stage.

[8] Renewable energy producers in the UK are given Renewable Obligation Certificates (ROCs) for each MWh of electricity generated, with the number of ROCs varying by source of energy (tidal producers receive 2-5 ROCs/MWh, while wind producers receive 2 ROCs/MWh, a reflection of the relatively greater incentives tidal companies need to spur development). ROCs trade on the open market (monthly auctions) and are bought by electric utilities in order to meet renewable targets. Values in early 2014 were in the $70/WMh range, providing tidal energy producers with $350/MWh (compared with a FIT of about $450).

There is considerable uncertainty about the industry development path after 2019, because policy is unclear about future levels of public support for technology development. The basis for the uncertainty lies in tidal energy costs that will still be too high in 2020 to be competitive with alternative renewable sources. This threshold may not be reached until 2030 at the earliest, in large part because it has taken the device developers much longer than anticipated to conduct the RDI&D.[9] In the meantime, device developers are urging governments to continue the support they say is essential to maintaining industry interest – support to encourage the deployment of the additional arrays that are essential to achieving the industry scale, supply chain specialization and efficiencies that will bring costs down. (RenewableUK 2013; SI Ocean 2014)

The nascent tidal industry, then, finds itself at a critical juncture. Costs must come down to be competitive, but costs can only come down if the rate of capacity installation increases. And while industry looks to government for support, government is looking to industry to do more to resolve some of the outstanding challenges. Among the key challenges identified by the analysts at SI Ocean, an EU collaborative project aimed at building a pan-European ocean energy sector: (SI Ocean 2013; 2014)

- **Technology fragmentation and design consensus**: in contrast with the wind sector where industry has converged on minor variations of the standard three-blade turbine and tower-mounted nacelle, there is little design consensus among developers beyond a horizontal axis. This greatly inhibits supply chain development.
- **Enabling technology**: a substantial share of tidal costs is embedded in the technology needed for deployment and retrieval to conduct maintenance operations. Reducing this source of cost is a matter of improved device design as well as more cost-effective marine logistics.
- **Risk management**: technology developers bear much of the risk (offset by government support) of device deployment, thereby limiting the scale of projects. Utility scale projects (±100MW) are too risky for developers and investors. Increased collaboration and risk sharing are needed to spur deployment and development.
- **Grid access, connectivity and infrastructure**: these are expensive given the remote location of many promising tidal sites (FORCE is an exception, given its proximity to the Nova Scotia grid). Utilities want assurance that tidal costs will be competitive before committing resources; conversely, failure to provide grid access limits deployments, in turn, limiting the opportunities for supply chain development and cost reduction.

Assuming the combination of factors needed to break the logjam emerges over the next few years, the tidal industry will enter a commercial phase of development by about 2020. *Implicit in this assumption is the global installation of some 150MW of tidal capacity in small arrays between 2015 and 2020.* This rate of installations is essential to force a reduction of tidal costs to about $290/MWh by 2020 (Figure 3-3). During this period, device developers will continue to bear much of the risk as technology is refined and reliability established. Unless and until there are clear signs that costs are likely to reach competitive levels and an expectation of demand for utility-scale arrays is likely to emerge, developers would be expected to continue to rely on existing plants to produce device components, transporting these to tidewater facilities located as close as possible to tidal sites for final assembly and deployment. In light of the uncertainty and relatively slow growth, limited supply chain development is likely to occur during this period.

[9] For example, the *UK National Renewable Energy Action Plan* released in 2009 had projected 1,300MW of deployed capacity for marine energy (tidal and wave) by 2020. In a 2013 report, RenewableUK revised this projection to 130MW. (RenewableUK, *Wave and Tidal Energy in the UK, Conquering Challenges, Generating Growth*, 2013.)

4.1.3 Commercial development phase: 2020-2040

Assuming delivered tidal energy can enter electrical grids at a cost competitive with alternative renewables, the global industry would be characterized by a rapid build-out of capacity in locations worldwide. This could exceed 500 MW by 2030. This expansion could only occur as a result of important changes in the structure and operation of key aspects of the tidal industry as we know it today.

- IPPs would emerge to take responsibility for project design, implementation and operation, much as they do in the mature wind energy industry.
- The technology developers – the companies currently providing the industry push and bearing much of the risk – would transition to their more typical role as technology suppliers.
- IPPs would have access to conventional sources of finance and insurance based on devices meeting accepted reliability criteria and the availability of manufacturer warranties.
- A convergence of technologies would be expected, given the need to achieve production and installation efficiencies.
- The projected pace of development coupled with the size of the devices would require investment in facilities in close proximity to tidal sites to assemble components, fabricate structures and foundations, and load out for installation.
- The investment in new facilities would be difficult to justify unless there were some assurance of long production runs (several years) at plant capacities of 50-100 units per year.
- The assembly facilities would also serve a maintenance/overhaul function during build-out, with a greater share of space and resources as installed capacity increased.
- Device deployment and retrieval for maintenance would be carried out by purpose built vessels, greatly enhancing efficiency and reducing cost.
- With greater standardization and increased demand, there would be a transition from made to order inputs to an industry supply chain offering off the shelf goods and services typical of mature technologies (such as wind energy).

4.2 Tidal development in Canada

4.2.1 Large-scale development in the Bay of Fundy – scenario build-out activities

Activity common to each scenario

The in-stream tidal energy industry in Canada is embryonic, consisting essentially of the FORCE development and demonstration site, suppliers involved in developing the site, and in the assembly/fabrication and deployment/retrieval of the Open Hydro device in 2009/10. Also, Fundy Tidal Inc., (an IPP) is playing a leading role in small-scale tidal development. In addition, several firms and researchers offer a range of technical and scientific expertise applicable to tidal energy development. European-based large-scale device manufacturers have begun to establish a presence in Nova Scotia as they prepare for installation and testing of devices at FORCE. The first installation (two 2MW units) is planned for 2015, with the three other berth-holders following in 2016 or 2017.

Before a supply chain can develop in Canada, there must be a consistent source of demand for the goods and services it would supply. The tidal development scenarios in Chapter 3 set out alternative views of how demand could evolve, providing the basis for the analysis of how a supply chain could develop.

Common to each Scenario is a test phase, 2015-2017, when the berth holders at FORCE deploy their devices. The Province establishes a licensing regime for commercial development. This is followed by a small array deployment when one or more of the developers (or Fundy Tidal, Inc.) deploy additional devices, bringing total capacity to 20MW by 2018.

To this point, with deployments spread across four (or possibly more) developers and some uncertainty about a future commitment to tidal energy within the Province, it is likely that assembly of the 10 or so devices (assuming average capacity of 2MW) and any structural fabrication would take place in existing facilities in Halifax, with devices towed to the Bay of Fundy for deployment. In other words, before 2018 there is still likely to be insufficient clarity around tidal competitiveness (including reliability and financing) and the prospect of a rapid build-out to warrant investment in assembly/fabrication facilities.

The nature and extent of supply chain development would depend greatly on what happens after 2018. This is when the scenarios begin to diverge. The nature of the activities in each Scenario is broadly similar (though may differ in detail), consisting of three phases and five main elements: Planning (project planning and design); Implementation (device construction, deployment, marine cabling/integration); and Operation (operations and maintenance).

Demonstration Scenario

Implicit in the Demonstration Scenario is the assumption that the market pull for tidal capacity beyond the level of FORCE capacity does not arise. Tidal benefits from a reduced FIT available during the 2020s, but does not reach the level of competitiveness needed to expand beyond 64MW. The conditions and assumptions that underpin this Scenario are set out in Chapter 3.

The Demonstration Scenario activities would differ markedly from those described for the Early Adoption and Late Adoption Scenarios. Specifically:

- **Device assembly/fabrication**: The Demonstration Scenario assumptions would not provide justification for investment in device production and load out facilities in the Bay of Fundy. This work would continue to be staged from Halifax. By 2029, build out under this Scenario ends.
- **Logistical requirements**: With no expectation of anything more than slow incremental growth in tidal capacity, the justification for investing in purpose-built support vessels does not arise. Logistical support is leased on an as-required basis.
- **Marine cabling/integration**: marine cabling beyond that required to complete the FORCE development would be limited to integrating the gradual build-out to 64MW.
- **Operation and Maintenance**: A small base in the Bay of Fundy would provide O&M support, with marine logistics leased on an as-required basis.

Early Adoption Scenario

Implicit in the Early Adoption Scenario is the assumption that by the end of 2018 there is sufficient market pull for up to 500MW of tidal capacity. All conditions and assumptions that underpin this Scenario are set out in Chapter 3. NSPI would signal its intent to issue RFPs for specified blocks of power, with a first phase of 300MW. A level of certainty of this kind would be needed to provide the basis for the market entry of IPPs, as well as for investment in facilities for device production (assembly/fabrication) needed for an efficient build out.

- **Device assembly/fabrication**: The facilities would be located in the Bay of Fundy as close as possible to the main deployment area (assumed to be Minas Passage) and would likely be phased in according to the scale required to meet the terms of successive RFPs (50MW/year is assumed in the Early Adoption Scenario). Scale is important because it helps to bring down the unit costs. But scale also carries investment risk, since the greater the scale the longer the production run needed to justify the investment in the facility.

  There is no clear guidance on the number of different device designs that may be deployed over the next 25 years, but it is more likely to be fewer than more. In part this is because IPPs and utilities would prefer to limit risk by settling on one or two proven devices. It is also because of the need to minimize device costs by avoiding duplication of investment in device production facilities in the Bay of Fundy. A single, multi-user production facility is possible, but radical differences in device design and load out requirements, suggest this may be unlikely. Moreover, there may be technical reasons related to subsea electrical requirements and system integration that limit the range of devices that would be deployed. These and other factors set up a competitive environment to be the first to meet utility and IPP service criteria. Since there is uncertainty about how all this will evolve, for purposes of this analysis, we assume a single production facility (though not ruling out different users over time).

- **Logistical requirements**: Design differences also create different logistical requirements for deployment and retrieval, as well as installation (fixing or tethering the devices to the seabed). Various gravity base and floating solutions are being proposed, each designed with the objective of minimizing capital and operating costs. Some of these solutions require purpose-built vessels, while others would rely on conventional workboats or crane barges. Some require piled or pinned substructures (with buoyant or removable turbine units), while for others, the turbine and gravity base form an integrated structure. Differences in the approach trigger different goods and services from the supply chain.

- **Marine cabling/integration**: When fully outfitted, FORCE will provide grid connection for 64MW of tidal capacity. Innovative design and development work (technology and installation) needs to be done on the marine electrical system – the cabling and integration (including the need for subsea transformers and substations) of multiple tidal devices and multiple arrays. Some of this developmental work would presumably occur during the demonstration and pre-commercial phase (2015-2019), providing valuable RDI&D opportunities for local industry.

- **Operation and Maintenance**: Given the complexities and costs of conducting work in the marine environment, the tidal devices are designed for years of uninterrupted service. Device developers indicate that scheduled maintenance is likely to be required every five or so years, requiring devices to be retrieved or floated and brought back to the shore base for overhaul. With 200-300 devices in the water, routine maintenance would be an on-going activity requiring the retrieval and re-deployment of 1-2 devices per week (allowing for winter and weather down-time).

Late Adoption Scenario

Implicit in the Late Adoption Scenario is the assumption that the market pull for tidal capacity beyond the level of FORCE capacity does not arise until 2030, with build-out reaching 300MW by 2040. The market pull is based mainly on cost competitiveness, including a reduced FIT. The conditions and assumptions that underpin this Scenario are set out in Chapter 3.

The activities described for the Early Adoption Scenario also apply to the Late Adoption Scenario, albeit occurring further in the future and at a smaller scale. Specifically:

- **Device assembly/fabrication**: The Late Adoption Scenario assumptions would also provide justification for investment in device production and load out facilities in the Bay of Fundy, though the facility would not be built until the late 2020s and would have a smaller scale consistent with a lower annual installation rate. By 2030, when the build out under this Scenario begins, the industry is likely to have converged on one or two designs that it is capable of producing more efficiently and at much lower cost than a decade earlier.
- **Logistical requirements**: The same logistical considerations would apply to the Late Adoption Scenario, though by 2030, logistical equipment and methods would have been refined in line with any changes in device characteristics, contributing to greater efficiency and lower costs. Also, with lower annual installation rate (and lower retrieval/re-deployment rate during operations), less equipment (vessels/barges) would be required.
- **Marine cabling/integration**: The technological issues and methods for cabling and integration presumably would have been worked out in other areas by 2030, facilitating completion of this work and reducing its cost.
- **Operation and Maintenance**: Fewer devices should simplify O&M logistical requirements, as well as the space required for maintenance work. Presumably, advances in design and manufacture also would reduce the level of maintenance required for each device, including extending the maintenance interval.

4.2.2 Small-scale development – scenario build-out activities

The small-scale development build-out activities for the High and Low Scenarios are conceptually similar to those described above (for large-scale development), differing mainly as a result of the device size and how projects are implemented (specifically, the scale of each project). Since the technology is designed for distributed energy applications in high cost markets (rather than a concentration of large multi-MW grid-connected arrays), only a limited number of units would be installed in any one location. The difference between the High and Low Scenarios, then, lies in the number of projects, not the scale of any one project.

- **Device assembly/fabrication**: Fully manufactured devices (weighing 2-4 t and less than 5m in the largest dimension) could be transported (surface or sea) to assembly sites. Foundation structures would vary in size and weight according to device characteristics, but would require limited space and basic facilities for fabrication.
- **Logistical requirements**: Designed for remote locations, devices would be easily deployed using locally available crane, barge and support vessels. Purpose-built vessels would not be necessary.
- **Marine cabling/integration**: Elaborate marine cabling would not be necessary; devices are designed for integration with diesel generation, other renewable energy sources, or existing distribution networks.
- **Operation and Maintenance**: Devices are designed for shallow water operation (<25m), making retrieval for maintenance relatively straightforward. The IPP would contract for retrieval, with maintenance services provided by the manufacturer.

4.3 Supply chain development and requirements

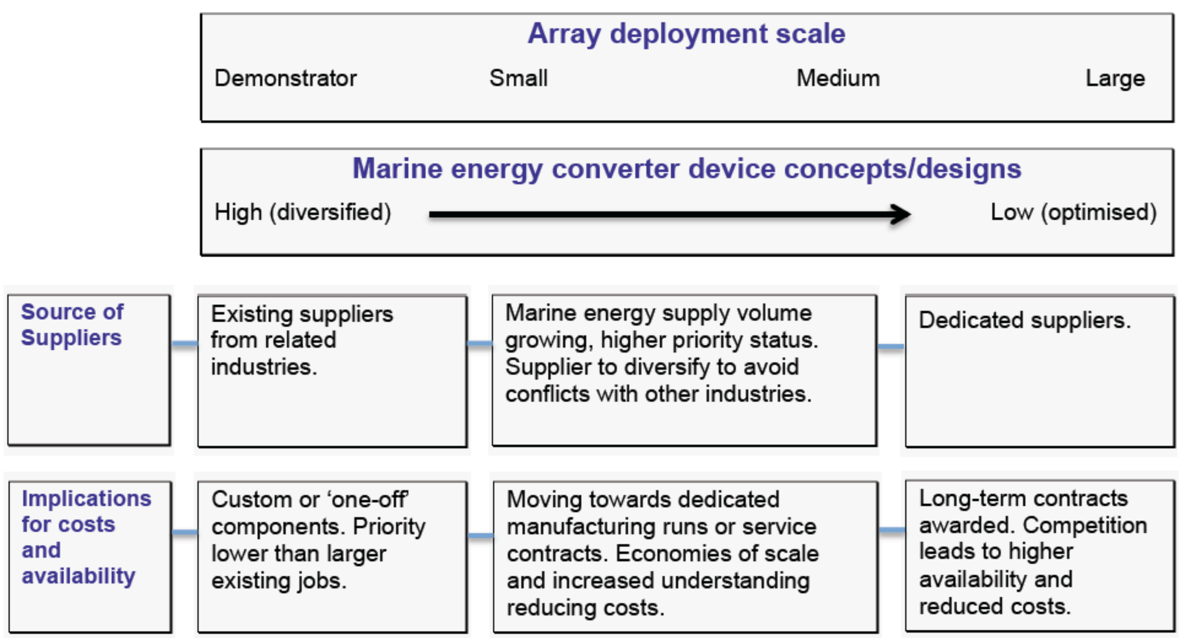
4.3.1 How a supply chain would develop over time

At this early stage of tidal industry development, there is no dedicated supply chain. In its 2011 report, EquiMar (a research project of the European Commission) provided an excellent perspective on the current state of the tidal industry and the conditions under which a supply chain would develop:

> Present experience of the marine energy supply chain is that some major components such as gearboxes, blades, hydraulic generators, etc., that would eventually be mass-produced are currently being manufactured as custom (one-off) units. Costs are therefore high with full design, development and custom tooling/fabrication often required. This increases costs and lead times for prototypes, both of which are likely to be reduced for arrays. An approach most device developers are trying to use for as many of their components as possible is to use existing (off-the-shelf) components either in a similar application or modified in some way (e.g., existing gear box modified sealing and material to resist corrosion). Whilst an approach might not provide the optimal solution for a component it provides a cost-effective method to accumulate operational experience of a device as a whole before moving to precisely-specified components once the technology is clarified and the market sector looks more secure.

Figure 4.1 illustrates how the marine energy supply chain could develop over time. The key to this evolution lies in there being sufficient market pull and industry push to scale-up production from single prototypes to commercial arrays.

Figure 4.1: Development of the tidal energy supply chain



EquiMar 2011.

4.3.2 Supply chain opportunities in Nova Scotia/Canada

Though the tidal industry is still at the prototype stage, considerable work to identify supply chain requirements at a general level has been carried out. Among the more comprehensive initiatives is *The Community & Business Toolkit for Tidal Energy Development*, produced by the Acadia Tidal Energy Institute at Acadia University (ATEI 2013). Based on this work, Table 4.1 provides a summary of the main activities and requirements within each of the main stages of a tidal project. Greater detail on the technical requirements and supply opportunities is contained in Annex 4. Note, the NS MRE 300MW phase of the Early Adoption Scenario is identified separately.

Table 4.1 represents a pivotal aspect of the value proposition assessment because the requirements it sets out become opportunities for suppliers, with related expenditure estimates providing the quantum of that opportunity over the projection period. Accordingly, several points arising from Table 4.1 merit explanation:

- The activities and requirements are common to all tidal developments, regardless of scale and location.
- The ‘Supplier’ column uses generic titles to indicate the types of companies that would provide goods and services for tidal development. OEMs are the short form for ‘original equipment manufacturers’, referring to large industrial companies such as Voith, GE, Andritz and DCNS (Open Hydro).
- Cost estimates represent total expenditures needed to complete each scenario. O&M costs represent the present value (PV) of annual expenditures. They are incurred as soon as the first devices are installed and increase annually with the capacity of each scenario.
- Costs, both in the aggregate and by major activity, are based on the estimates that underpin the Nova Scotia FIT (Synapse 2013). These estimates were derived with input from device developers. The device developers interviewed as part of this study (some of whom also provided information to Synapse) accept the cost estimate as reasonable in the aggregate, but some suggest the distribution of costs against activities differs from their experience. This is borne out by industry figures in Table 3.4 (Chapter 3) that give greater weight to installation and less to manufactured components. Where Synapse does not provide a cost breakdown within categories (e.g., Pre-project planning), this is estimated by the consultants.
- Differences in cost breakdown become important when trying to determine the value of tidal development to a local or regional economy. The figures in Table 4.1 would suggest that a minimum of 60% of capital expenditures would be made locally based on the nature of project activities (project components marked with an asterisk are ones with little or no current Canadian/Nova Scotian capability). This does not necessarily mean local contractors would carry them out, but they clearly represent attractive opportunities. The cost breakdown for the activities contained in Table 3.4 suggests minimum local expenditures would fall in the 70% range. Given the uncertainty surrounding cost estimates, a 60-70% range is used in this report. No attempt is made to ‘fine-tune’ changes in percentage cost breakdown over time or across scenarios, given the wide confidence limits surrounding the estimates.
- Average cost per MW declines over time as a result of ‘industry learning’. The highest reduction occurs in the Late Adoption Scenario because the build-out occurs farthest out in time, benefitting from industry cost reductions gained elsewhere. The Early Adoption Scenario is not far behind, while the Demonstration Scenario benefits least from cost reductions because the installed capacity is front-end loaded.

Table 4.1: Nova Scotia tidal project requirements and costs by scenario ($000 2013)

Cost centre (1)	Supplier	Total Expenditures: 2015-2040				% of total
			Early Adoption			
		Demonstration	NS MRE	Maximum	Late Adoption	
MW		67	300	500	300	
1. Pre-project planning						
Site screening						
Resource assessment	Consultant	320	1,305	2,025	1,153	0.1%
Constraints analysis	Consultant	128	522	810	461	0.0%
Health & safety analysis	Consultant	256	1,044	1,620	922	0.1%
Grid connection assessment	Consultant	192	783	1,215	692	0.1%
Logistical analysis	Consultant	320	1,305	2,025	1,153	0.1%
Technology assessment	Consultant	256	1,044	1,620	922	0.1%
Preliminary feasibility analysis	Consultant	128	522	810	461	0.0%
Environmental & technical assessment						
Environmental scoping	Consultant	639	2,610	4,049	2,305	0.2%
Physical surveying	Consultant	1,278	5,219	8,099	4,610	0.3%
Meteorological & resource assessment	Consultant	959	3,914	6,074	3,458	0.3%
Grid infrastructure assessment	Consultant	639	2,610	4,049	2,305	0.2%
Marine infrastructure assessment	Consultant	1,278	5,219	8,099	4,610	0.3%
Sub-total		6,392	26,095	40,494	23,052	1.7%
2. Project implementation						
Planning						
Public consultation	Consultant	1,203	4,912	7,622	4,339	0.3%
Mi'kmaq ecological knowledge	MEKS services	1,203	4,912	7,622	4,339	0.3%
Environmental assessment	Consultant	3,610	14,736	22,867	13,018	1.0%
Permitting and regulatory approval	Legal	6,016	24,560	38,112	21,696	1.6%
Sub-total		12,032	49,120	76,224	43,392	3.2%
Design						
Front-end engineering design	IPP/Engineer*	4,512	18,420	28,584	16,272	1.2%
Procurement	IPP*	1,504	6,140	9,528	5,424	0.4%
Detailed design	IPP/Engineer*	9,024	36,840	57,168	32,544	2.4%
Sub-total		15,040	61,400	95,280	54,240	4.0%
Procurement & assembly						
Construct operations facilities	IPP/Contractor	1,000	1,500	2,000	1,500	
Develop site for device assembly/maint.	IPP/Contractor		75,000	100,000	75,000	
Mechanical (turbine & power take-off)	OEM*	38,822	158,489	245,942	140,007	10.3%
Electrical (generator & transformer)	OEM*	66,552	271,695	421,614	240,012	17.7%
Subsea cabling	OEM*	30,832	125,870	195,324	111,192	8.2%
Control system	OEM*	8,648	35,305	54,786	31,188	2.3%
Grid connector	IPP/Contractor	7,896	32,235	50,022	28,476	2.1%
Device framing & foundation	IPP/Contractor	89,112	363,795	564,534	321,372	23.7%
Final assembly	IPP/Contractor	29,704	121,265	188,178	107,124	7.9%
Transportation services	IPP/Contractor	5,546	22,641	35,135	20,001	1.5%
Sub-total		277,112	1,131,295	1,755,534	999,372	73.7%
Installation & commissioning						
Mobilize logistical equipment	IPP/Contractor	6,542	26,709	41,447	23,594	1.7%
Install foundation/moorings	IPP/Contractor	26,170	106,836	165,787	94,378	7.0%
Load-out and install devices	IPP/Contractor	9,814	40,064	62,170	35,392	2.6%
Install marine electrical systems	IPP/Contractor	16,356	66,773	103,617	58,986	4.4%
Commission facilities	IPP/Contractor	6,542	26,709	41,447	23,594	1.7%
Sub-total		65,424	267,090	414,468	235,944	17.4%
Total		376,000	1,535,000	2,382,000	1,356,000	100.0%
Average cost per MW		5,432	5,117	4,612	4,375	
3. Operation & maintenance (2)						
Management	IPP	125,341	450,879	621,807	243,080	29.6%
Maintenance	IPP/Facility	293,027	1,054,082	1,453,684	568,281	69.2%
Decommissioning	IPP/Contractor	5,081	18,279	25,208	9,855	1.2%
Total		423,450	1,523,240	2,100,700	821,215	100.0%

1. Cost breakdown based on Synapse 2013. Cost for operations facilities and device assembly/maintenance estimated by consultant. All costs in 2013 dollars.
2. O&M and decomissioning costs expressed as percentage of total annual costs (2015-2040).
* Indicates requirements that need not be produced or conducted locally

4.4 Summary

Tidal energy offers great opportunities for industry in Europe and Canada, as supply chains develop to meet goods and services requirements. The challenge facing the global industry over the next few years is to demonstrate the reliability of tidal devices and show that the industry is on a path to produce electricity at competitive prices with alternative renewable sources. Assuming this is achieved, the tidal industry would likely enter a commercial phase of development after 2020, characterized by a transition from made-to-order inputs to an industry supply chain offering off-the-shelf goods and services typical of mature technologies such as wind energy.

Supply chain opportunities cover a wide range of goods and services, and can be grouped under five main headings: device component manufacture; device assembly, fabrication of support structures and device integration; marine logistical requirements for device installation and retrieval; marine cabling and integration of facilities into electrical systems; and on-going operation and maintenance. Each of these occurs to a greater or lesser degree under each of the large-scale and small-scale development scenarios, representing supply opportunities ranging in overall value up to the hundreds of millions of dollars. With the exception of the manufacture of components for the devices, the other activities must take place at the tidal energy development site. For Nova Scotian, regional and Canadian companies, this greatly enhances the supply chain opportunities. This experience would provide a basis for Canadian companies to participate in tidal development elsewhere, particularly if commercial development were to commence here first.

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5

Estimating the tidal value proposition

5.1 Scope and considerations

This chapter integrates the various elements of the value proposition – a weighing up of benefits and costs. For this analysis, the benefits consist of the direct supply opportunities created for industry and labour force; the broader economic impacts of tidal development and on-going operations; the export opportunities created through supply chain development; the value of avoided emissions through the displacement of fossil fuel generated electricity; and, greater energy security through diversification into renewable energy. The costs consist of private investment, as well as what we refer to as the public investment in industry learning – the gap between tidal energy costs and the cost of alternative sources of electrical energy.

The three large-scale tidal development scenarios examined produce widely differing results across the benefit and cost indicators. This should not be surprising, because the scenarios themselves present widely different approaches to the timing and scale of development – two of the main factors determining the results. This is not accidental; to a certain extent the scenarios are intended to present technically plausible yet different development paths from which contrasting benefits and costs results would emerge.

The benefits and costs are not directly comparable in the sense that they simply can be added to produce a neatly conclusive net result. This stems in part from the nature of the indicators themselves and in part from the varying quality of the results in terms of levels of uncertainty surrounding key assumptions. For example, future tidal capital and operating costs are speculative, as are the potential for and value of export opportunities; also, varying estimates are available for the values placed on avoided emissions.

5.2 Industry participation

5.2.1 Overview

Though in-stream tidal energy represents a relatively new technology – indeed, a new industry – in Canada, many of the activities comprising a tidal project would be familiar to those companies with experience planning and building for, and operating in, the marine environment. This marine sector encompasses several industries including offshore oil & gas, shipping, naval installations, shipbuilding and fishing. It also includes the supply of goods and services, including scientific and applied R&D, to each of these industries and others operating in the marine environment generally.

A recent report on Nova Scotia's ocean technology industries highlights the strengths and weaknesses of the sector (Duke 2012). Among the strengths identified are strong universities and research centres, skilled workforce, excellent transportation infrastructure and location, and the stability provided by the federal shipbuilding contract.[10] Limited product manufacturing, a heavy reliance on federal budgets and a lack of coordinated marketing and promotion were seen as

[10] Irving Shipbuilding was awarded a 25-year contract to build Arctic patrol vessels and navy warships at the Halifax Shipyard. The contract, with an overall value in the range of $30 billion, covers the design and construction of some 20 ships. This means steady work for the yard and for the hundreds of suppliers of goods and services in the province and elsewhere in Canada. Work on a $300 million yard refit began in 2012. Vessel construction is expected to begin in 2015.

weaknesses. The report also identified important market and technology trends, including the demand for more versatile products and products suitable for use in rugged environments. Also emphasized were opportunities using remote sensors and instrumentation for gathering oceanographic data and routine performance monitoring.

An emerging global tidal energy industry fits key aspects of the demand profile identified by Duke, and accordingly represents an important potential market opportunity for Nova Scotia's ocean technology sector, and for suppliers in the rest of the Atlantic Provinces and elsewhere in Canada. For some suppliers, meeting the domestic tidal energy goods and services requirements would be fairly straightforward because they currently have the direct capability and capacity. For others, it would be a matter of adapting their offering and expanding their capacity in anticipation of, or in response to, demand. Interviews conducted with prospective suppliers indicate that many would be taking a 'wait and see' approach, holding off decisions on investing in adaptation or expansion until it becomes clear a strong and consistent demand exists or can be safely anticipated.

An important aspect of this assessment of industry participation concerns the scope for capitalizing on export opportunities arising from tidal development outside Canada. While the nature of such opportunities would be similar to those in the domestic market, a key question concerns the ability to compete in export markets. *Competitiveness would be enhanced if tidal development in the Bay of Fundy were to commence in advance of development in other jurisdictions. Local companies could then claim direct experience, which would be particularly important in aspects of development requiring innovative solutions (e.g., marine cabling and array integration, remote sensing and instrumentation).*

The discussion of industry participation and value proposition in the following sections covers both large- and small-scale development, with exceptions noted where relevant.

5.2.2 Industry participation in domestic tidal development

With at least 60-70% of the value of tidal development tied to activities occurring at or near the development site, the direct opportunities for local and regional participation are considerable in the case of both small-scale and large-scale development. This percentage range is based on the project expenditure data appearing in Table 4.1, and pertains to the early stages of development under each of the scenarios. As confidence in the continued prospects for tidal development grows, domestic industry could adapt and compete effectively in the supply of some of the goods and services that initially are likely to be imported (e.g., certain device components, turbine blades). With established small-scale device manufacturers in Canada, the extent of any imports would be based on the choice of technology made by IPPs.

Reducing cost and containing risk are identified in policy documents as the key objectives that are (or should be) driving the development strategies of device manufacturers and IPPs (IEA 2014; SI Ocean 2014; UKERC 2014). While this highlights the need to be competitive, it also introduces an important element of conservatism in procurement strategies. To the fullest extent possible, manufacturers will rely on their existing facilities, allowing them to refine operations and extend production runs to minimize costs. Also, by relying on trusted suppliers, manufacturers limit their risk (a major consideration at this early stage of industry development). Both considerations are likely to limit the extent to which OEMs and small-scale device developers establish new manufacturing facilities (as distinct from device assembly facilities near the tidal sites, described in Chapter 4), and the extent to which domestic industry succeeds in displacing existing component suppliers.

Nova Scotian, regional and other Canadian suppliers have the capability and experience to supply a substantial share of the goods and services required for large-scale development, with capability approaching 100% for small-scale projects where domestically manufactured devices are used. Capability by input requirement is illustrated in Table 5.1 and discussed below (detail on each of the activities may be found in Annex 4).

Pre-project planning

- **Site screening**: this activity is aimed at identifying tidal energy site potential from the perspective of each of the items listed in Table 5.1. This suite of activities would ordinarily be carried out by a large integrated environmental/engineering consultancy, of which there are at least three based in Nova Scotia, with offices elsewhere in the Atlantic Provinces and Canada. Local content for this activity would be 100%.
- **Environmental and technical assessment**: once a potential site is identified, environmental scoping studies and various surveys are conducted to inform design and development planning, and to determine permitting and licensing requirements. Again, these assessments would be carried out by large integrated environmental/engineering consultancies, with the involvement of outside specialists, if necessary. Local content for this activity would be 100%.

Project implementation

- **Planning**: assuming the pre-project planning results in internal approvals to proceed, the proponent would progress to the project design and development stage, completing the various consultations and detailed environmental assessments needed to secure regulatory authorizations. This work would be contracted to consultants with specialized expertise, and to law firms specializing in regulatory matters. Local content for this activity would be 100%.
- **Project design**: the project proponent (presumably an IPP) contracts for marine architectural and engineering services to assess front-end design options, including potential devices and array configuration, and to prepare cost estimates. A procurement strategy covering bidding process, contract management and risk is developed. With this input and once all approvals are received, the project moves to detailed design covering tidal devices, electrical equipment, cabling, control systems, grid connection, marine logistics, health and safety, and cost estimates. Design would be conducted by an engineering consultancy, offering specialized services in marine and electrical installations. The IPP could opt to retain project management responsibilities, but is more likely to contract the services of an Engineering, Procurement and Construction (EPC) contractor. Local content for this activity is likely to be in the range of 80%.
- **Fabrication and assembly**: large-scale development in the Bay of Fundy would require construction of a device assembly and fabrication site. The various components comprising the device (mechanical, electrical and control) are shipped to the assembly site for integration with the locally fabricated support structure/system. The OEM supplies the components, while local contractors carry out site construction and subsequent structural fabrication, assembly and integration of devices (with some OEM input). The highly specialized subsea cabling would be imported. Given the value of imported components and materials, local content would be in the range of 50%.
- **Installation and commissioning**: depending on design, the tidal device would be deployed as a single unit (integrated gravity base design) or in sections (foundation/mooring system and subsequent installation of device). This would require purpose-built vessels or locally available workboats/barges. Vessels, possibly with assistance of remotely operated vehicles (ROVs), would install marine cable to connect devices and to connect arrays to offshore substations, and also to install cable to connect the substation to the grid. Design and installation of marine electrical systems of this kind requires innovation, providing local suppliers with an excellent opportunity to develop and export the expertise. Local content is estimated at about 70%.

Table 5.1: Tidal energy project development requirements and supply capability

Activity/input	Supplier	Supplier location: Nova Scotia	Atlantic Region	Other Canada	Import
1. Pre-project planning					
Site screening					
Resource assessment	Consultant				
Constraints analysis	Consultant				
Health & safety analysis	Consultant				
Grid connection assessment	Consultant				
Logistical analysis	Consultant				
Technology assessment	Consultant				
Preliminary feasibility analysis	Consultant				
Environmental & technical assessment					
Environmental scoping	Consultant				
Physical surveying	Consultant				
Meteorological & resource assessment	Consultant				
Grid infrastructure assessment	Consultant				
Marine infrastructure assessment	Consultant				
2. Project implementation					
Planning					
Public consultation	Consultant				
Mi'kmaq ecological knowledge	MEKS services				
Environmental assessment	Consultant				
Permitting and regulatory approval	Legal				
Design					
Front-end engineering design	IPP/Engineer*				
Procurement	IPP				
Detailed design	IPP/Engineer*				
Procurement & assembly					
Site development for device assembly/maintenance	IPP/Contractor				
Mechanical components (turbine & power take-off)	OEM*				
Electrical components (generator & transformer)	OEM*				
Subsea cabling	OEM*				
Control system	OEM*				
Grid connector	IPP/Contractor				
Device framing & foundation	IPP/Contractor				
Final assembly	IPP/Contractor				
Transportation services	IPP/Contractor				
Installation & commissioning					
Mobilize logistical equipment	IPP/Contractor				
Install foundation/moorings	IPP/Contractor				
Load-out and install devices	IPP/Contractor				
Install marine electrical systems	IPP/Contractor				
Commission facilities	IPP/Contractor				
3. Operation & maintenance (2)					
Management	IPP				
Maintenance	IPP/Facility				
Decommissioning	IPP/Contractor				

Legend

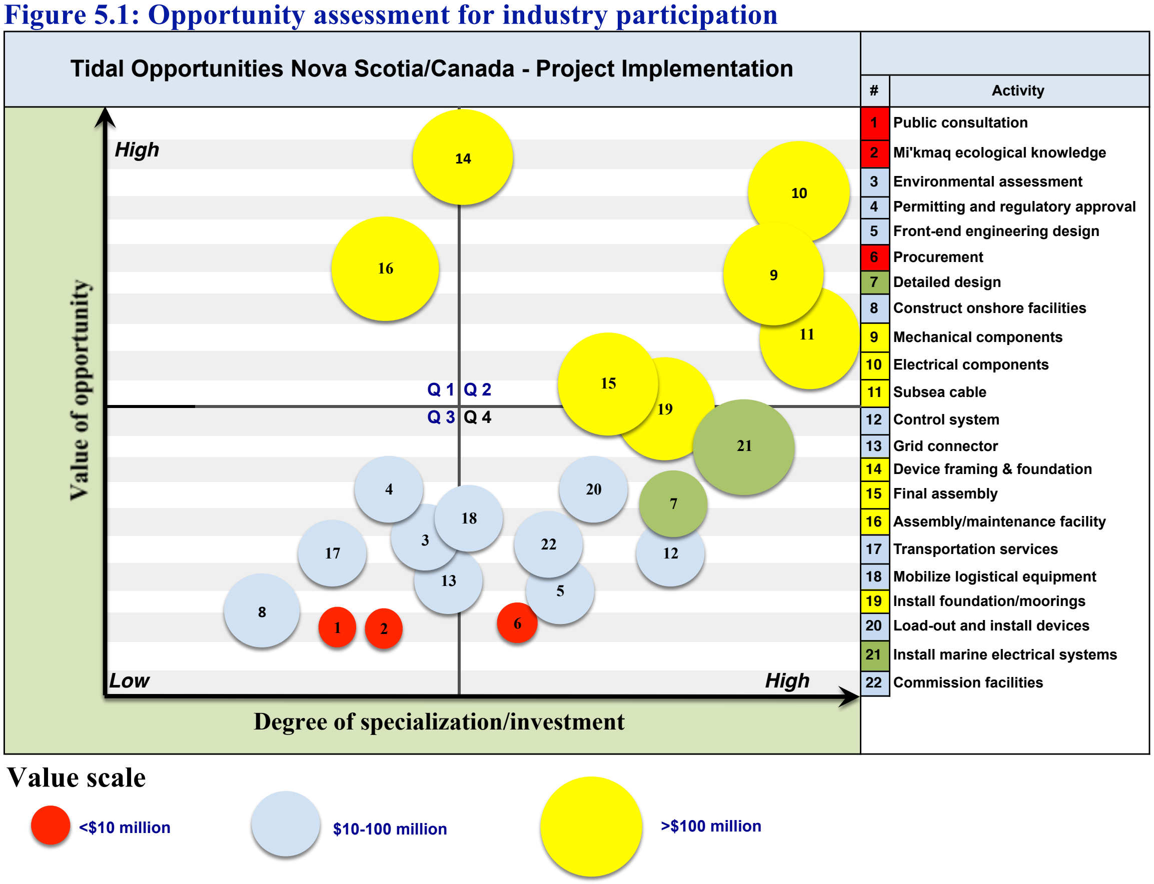
- Local activity/good local or regional capability (assumes purpose built device assembly facility and installation vessels)
- Local activity/some local or regional capability (assumes purpose built device assembly facility and installation vessels)
- National capability for small-scale tidal development
- Specialized equipment (tidal device components) likely to have high import content throughout development
- Specialized services likely to have high import content in early years of development

Operation and maintenance

- **Management**: the IPP manages the project, conducting a range of services including performance monitoring, inspection, environmental monitoring, maintenance scheduling and administration with respect to customer, regulatory and related requirements. IPP employees would carry out some of these activities, while others would be supplied through contract services. Allowing for a non-resident IPP, local content would be 90%.
- **Maintenance**: scheduled maintenance involves retrieving the devices (either by lifting or floating, depending on design), taking them to the facility for overhaul and refurbishment, and redeploying them. Under the Early and Late Adoption Scenarios, maintenance would provide a steady stream of activity for a technical team of 50-100 highly skilled workers at the facility (assuming 1-2 devices in for maintenance at all times). Allowing for imported replacement components, local content would be 75%.
- **Decommissioning**: removal of devices, cabling and associated equipment once the device or system has reached the end of its useful life. Local content would be 100%.

The activity assessment map in Figure 5.1 provides a visual guide to identifying opportunities for industry participation in tidal development. It arrays relative value of opportunity against degree of specialization/size of investment for each of the main project inputs in project implementation.

Figure 5.1: Opportunity assessment for industry participation



- Inputs in Q2 (#9, 10, 11) are attractive because of their high value, but are doubtful prospects because high barriers to entry characterize the market for these products (the manufacture of mechanical and electrical components and subsea cable).

- Inputs bordering Q2 (#14, 15, 19) also represent high value, but are not as specialized. Though the particulars of the services in each scenario may be different from those typically required in the Atlantic Provinces, with some adaptation and investment, high participation by local contractors and skilled workers would be expected. Local contractors would also be expected to construct the assembly/maintenance facility (#16).
- Inputs in Q4 tend to be ones requiring careful assessment because specialization is relatively high, while value is relatively low. Two inputs of particular interest (highlighted in green) would be installation of marine electrical systems (#21) and detailed design (#7). This is because the market for these services is potentially large and the services themselves require development. They present an attractive opportunity given the potential global demand. Other inputs would require adaptation of existing capabilities, but would not necessarily offer the same export potential.
- Inputs in Q3 fall well within the bounds of existing capabilities of regional contractors and individuals.

5.2.3 Industry participation in global tidal development

Participation in global tidal development projects (as suppliers or owners) represents a potentially valuable opportunity for Nova Scotia, regional and Canadian suppliers. Some projections suggest the marine energy market (tidal and wave) could grow to several hundred billion dollars over the next 35 years. The capability and capacity developed by Canadian suppliers in early tidal projects in the Bay of Fundy would provide an excellent foundation for participating in this global market.

Quantifying the possible export value poses a challenge, but suffice it to say, even a very small share of this potentially very large market would provide a major boost for domestic industry. The most challenging aspect of measuring this potential rests with identifying specific opportunity areas. This is because the same logic that drives the relatively high potential local content reflected in Table 5.1 also applies to other jurisdictions, especially the EU with its industrial strength and long history of offshore oil & gas development and marine capabilities. Indeed, when spending on EU manufactured devices (electrical, mechanical and control components) is included, regional content could approach 100%.

Nonetheless, areas where Nova Scotia and regional companies could participate in global markets have been identified in publications (Marine Renewables Canada 2013; NS MRE Strategy 2011) and through interviews conducted with developers and the ocean technology industry in Nova Scotia (companies are identified in Annex 5). These include areas where Canadian companies have developed or are developing expertise in relevant research methods and processes, inputs requiring adaptation of existing products and services, and inputs where innovation is required to achieve technical objectives. Several tidal development inputs would fall into these categories:

- Resource modelling and site characterization (directly applicable);
- Constructing purpose-built vessels and work boats (directly applicable);
- Fabricating support structures (directly applicable);
- Sensors, acoustics, instrumentation and monitoring (some adaptation required);
- Manufacturing composite turbine blades (innovation and adaptation required); and
- Marine cable installation, interconnection and electrical systems (innovation required).

Turning these and other supply chain opportunities into realistic export market prospects depends very much on local industry gaining direct experience in tidal projects, and building that expertise into world class capability (and capacity). It would seem there are two necessary conditions for this process of industry building to succeed in Nova Scotia: i) early commitment to commercial scale tidal development; and, ii) firm indications of sufficient market pull to result in accelerated growth of tidal capacity over a period of years. The early commitment allows firms to develop their expertise, while the prospect of scale provides justification for investment in supply chain capacity and capability. With capacity, this capability would then be exportable.

Development on this scale could also attract inward investment in capacity to manufacture device components (as distinct from assembling components manufactured elsewhere), thereby increasing the scope for supply chain development. But based on discussions with device developers, this seems unlikely given the level of investment required and risks associated with building and operating additional facilities (while existing facilities in the EU are underutilized). While conditions under which this could occur are imaginable, they seem remote possibilities (e.g., predictable demand rising to a level where it would outstrip the capacity of existing facilities; or, the cost of shipping device components for assembly rising to a level where it made more sense to manufacture locally).

As noted, the future value of the global marine energy industry is difficult to predict, though based on conservative build-out rates and using competitive capital and operating costs for marine energy devices, one estimate puts the cumulative value in the $900-1,000 billion range by 2050 (Carbon Trust 2011). Though these figures are large (averaging over $2-3 billion/year), they are relatively modest by comparison with investment in wind energy, currently running at about US$80 billion per year (IEA 2013). Accordingly, the future value could be much greater.

In short, the prospect of securing a competitive position in a global market of this size represents a substantial opportunity for Canadian companies. Based on the breakdown in Table 4.1, the inputs listed above might account for 10-15% of total expenditures ($90-100 billion). Even if Canadian companies were able to secure a market share of just 5% in the supply of these goods and services, the value would approach $5 billion. This is speculative, but does provide at least an order of magnitude estimate of the export potential.

Large-scale development

As argued above, the success Nova Scotia and other Canadian companies have in gaining access to an emerging export market is likely to depend greatly on the timing, pace and scale of tidal development here. In this respect, our tidal development scenarios would likely lead to significantly different outcomes:

- **Demonstration Scenario**: under this scenario, tidal energy deployment does not proceed beyond the device testing and demonstration stage. Local supply capability develops to the minimal level necessary to support this activity, but falls short of what is needed to compete in global markets.
- **Early Adoption Scenario:** this would provide local suppliers with the most favourable conditions for developing their capability/capacity and entering the export market. Under this scenario, commercial development takes off in 2023, and escalates rapidly to 500MW by 2032. In effect, Canada becomes an early adopter. Public financial support to bridge the gap between tidal cost and competitiveness forms a key assumption underpinning the timing and pace of development. This support can be seen as the public investment in developing this renewable energy source and the industrial capability created in the process. It should also be noted that, while the Early Adoption Scenario provides the most favourable conditions for developing export capacity, much also depends on tidal development activity elsewhere. Rapid development in the UK and France, for example, could put EU suppliers in an advantageous position in export markets (i.e., Canada); this, after all, forms an

important aspect of the value proposition put forward by the respective trade associations in those countries to justify on-going financial support (RenewableUK 2013).

- **Late Adoption Scenario:** under this scenario, commercial development does not proceed until tidal becomes cost-competitive with alternative energy sources (the 2030s). Canada becomes a late adopter, assuming that development in other areas accelerates post-2020 with continued public support. Consistent with the timing and pace of development in Canada, only minimal local supply capacity would emerge before the 2030s, a decade after a supply chain would have developed in the EU. In these circumstances, the prospect of export opportunities for Canadian suppliers is greatly diminished. On the other hand, if continued public support in other areas were not forthcoming, then the risk is that the technology would not develop at the rate needed to cause costs to come down to competitive levels. In the absence of market pull, the private sector would likely withdraw investment, effectively postponing further development of tidal technology to some future time when renewable options for reducing carbon emissions are appropriately valued (including pricing carbon).

Small-scale development

As with large-scale opportunities, the success Canadian companies have in gaining access to an emerging export market is likely to depend greatly on the timing, pace and scale of tidal development here.

- **Low Scenario**: the limited scale of activity would limit the extent to which the Low Scenario would provide a springboard for the development of export potential.
- **High Scenario**: the range of conditions under which installations occur and the rate and scale of development provide an excellent basis for device developers as well as the underlying supply chain to refine the technology and installation techniques, facilitating an expansion into export markets. This may be a niche opportunity given the technology and its applications (high cost, remote locations), but one that, because of the relatively small scale of each installation, could create a market for turnkey projects. By virtue of their experience, Canadian IPPs using Canadian technology and suppliers could compete effectively in this market. Also, these companies would be in an excellent position to pursue 'large-scale' opportunities because the distinction between 'small-' and 'large-' scale devices is likely to become increasingly blurred over time.

5.3 Economic impact

5.3.1 Value of industry participation in domestic development

Applying the expected participation levels (above) to expenditure estimates by activity provides a rough guide to the value of tidal development to industry in the region and Canada more generally. These estimates of local content or participation levels are informed by the consultants' cumulative experience, as well as the results of consultations with tidal developers, prospective suppliers and government officials (see Annex 5 for the contact list). For illustrative purposes, the percentages are applied to the Early Adoption Scenario in Table 5.2, indicating that local industry could account for at least 60% of total capital spending and 80% of O&M spending over the 2015-2040 period (as noted in Chapter 4, though we could reasonably expect local content to be higher in moving from the Demonstration to Early Adoption Scenarios, the same content percentages are applied to each Scenario). These are weighted averages derived by summing the individual content estimates and expressing the dollar amounts as percentages of the respective total capital and O&M expenditures.

Table 5.2: Value of tidal development to regional industry – 2015-2040 ($000 2013)

Cost centre (1)	Supplier	Total Expenditures: 2015-2040					% spent in Canada (2)	NS MRE Case (3)
			Early adoption					
		Demo	NS MRE	Maximum	Late adoption	% of total	%	$000 (2012)
MW		67	300	500	300			
1. Pre-project planning								
Site screening								
Resource assessment	Consultant	320	1,305	2,025	1,153	0.1%	100%	1,305
Constraints analysis	Consultant	128	522	810	461	0.0%	100%	522
Health & safety analysis	Consultant	256	1,044	1,620	922	0.1%	100%	1,044
Grid connection assessment	Consultant	192	783	1,215	692	0.1%	100%	783
Logistical analysis	Consultant	320	1,305	2,025	1,153	0.1%	100%	1,305
Technology assessment	Consultant	256	1,044	1,620	922	0.1%	100%	1,044
Preliminary feasibility analysis	Consultant	128	522	810	461	0.0%	100%	522
Environmental & technical assessment								
Environmental scoping	Consultant	639	2,610	4,049	2,305	0.2%	100%	2,610
Physical surveying	Consultant	1,278	5,219	8,099	4,610	0.3%	100%	5,219
Meteorological & resource assessment	Consultant	959	3,914	6,074	3,458	0.3%	100%	3,914
Grid infrastructure assessment	Consultant	639	2,610	4,049	2,305	0.2%	100%	2,610
Marine infrastructure assessment	Consultant	1,278	5,219	8,099	4,610	0.3%	100%	5,219
Sub-total		6,392	26,095	40,494	23,052	1.7%		26,095
2. Project implementation								
Planning								
Public consultation	Consultant	1,203	4,912	7,622	4,339	0.3%	100%	4,912
Mi'kmaq ecological knowledge	MEKS services	1,203	4,912	7,622	4,339	0.3%	100%	4,912
Environmental assessment	Consultant	3,610	14,736	22,867	13,018	1.0%	100%	14,736
Permitting and regulatory approval	Legal	6,016	24,560	38,112	21,696	1.6%	100%	24,560
Sub-total		12,032	49,120	76,224	43,392	3.2%		49,120
Design								
Front-end engineering design	IPP/Engineer*	4,512	18,420	28,584	16,272	1.2%	75%	13,815
Procurement	IPP*	1,504	6,140	9,528	5,424	0.4%	75%	4,605
Detailed design	IPP/Engineer*	9,024	36,840	57,168	32,544	2.4%	90%	33,156
Sub-total		15,040	61,400	95,280	54,240	4.0%		51,576
Procurement & assembly								
Construct operations facilities	IPP/Contractor	1,000	1,500	2,000	1,500		100%	1,500
Develop site for device assembly/maint.	IPP/Contractor		75,000	100,000	75,000		100%	75,000
Mechanical (turbine & power take-off)	OEM*	38,822	158,489	245,942	140,007	10.3%	0%	0
Electrical (generator & transformer)	OEM*	66,552	271,695	421,614	240,012	17.7%	0%	0
Subsea cabling	OEM*	30,832	125,870	195,324	111,192	8.2%	0%	0
Control system	OEM*	8,648	35,305	54,786	31,188	2.3%	0%	0
Grid connector	IPP/Contractor	7,896	32,235	50,022	28,476	2.1%	100%	32,235
Device framing & foundation	IPP/Contractor	89,112	363,795	564,534	321,372	23.7%	100%	363,795
Final assembly	IPP/Contractor	29,704	121,265	188,178	107,124	7.9%	75%	90,949
Transportation services	IPP/Contractor	5,546	22,641	35,135	20,001	1.5%	100%	22,641
Sub-total		277,112	1,131,295	1,755,534	999,372	73.7%		586,120
Installation & commissioning								
Mobilize logistical equipment	IPP/Contractor	6,542	26,709	41,447	23,594	1.7%	50%	13,355
Install foundation/moorings	IPP/Contractor	26,170	106,836	165,787	94,378	7.0%	90%	96,152
Load-out and install devices	IPP/Contractor	9,814	40,064	62,170	35,392	2.6%	90%	36,057
Install marine electrical systems	IPP/Contractor	16,356	66,773	103,617	58,986	4.4%	50%	33,386
Commission facilities	IPP/Contractor	6,542	26,709	41,447	23,594	1.7%	50%	13,355
Sub-total		65,424	267,090	414,468	235,944	17.4%		192,305
Total		376,000	1,535,000	2,382,000	1,356,000	100.0%		905,216
Average cost per MW		5,432	5,117	4,612	4,375			
3. Operation & maintenance (4)								
Management	IPP	125,341	450,879	621,807	243,080	29.6%	90%	405,791
Maintenance	IPP/Facility	293,027	1,054,082	1,453,684	568,281	69.2%	75%	790,562
Decommissioning	IPP/Contractor	5,081	18,279	25,208	9,855	1.2%	100%	18,279
Total		423,450	1,523,240	2,100,700	821,215	100.0%		1,214,632

1. Cost breakdown based on Synapse 2013. Cost for operations facilities and device assembly/maintenance estimated by consultant. All costs in 2012 dollars.
2. Indicates initial share of expenditures by input assumed to be procured in Canada (mainly Nova Scotia). Share is assumed constant across scenarios and over time.
3. The percentage share of expenditures is applied to the Early Adoption Scenario (MRE 300MW) spending to illustrate the dollar content
4. O&M and decomissioning costs expressed as percentage of total annual costs (2015-2040).

* Indicates requirements that need not be produced or conducted locally

5.3.2 Methodology

In order to determine the full impacts of tidal energy development in Nova Scotia, the direct expenditures (Table 5.2) are used to drive the Statistics Canada Inter-provincial Input-Output (IO) model (2010 version). The model captures the relationship amongst industries in the province (and the extent to which spending in Nova Scotia triggers impacts elsewhere in Canada), measuring how direct expenditures on tidal goods and services create output, jobs and income in the economy:

- **Direct impact**: refers to the impact generated at the tidal development site. Direct GDP refers to the value-added by the activities related to assembly and deployment of devices, while direct employment and labour income refers to the jobs and payroll generated by these activities.
- **Indirect impact**: refers to the impacts at the supply chain level arising from purchased inputs triggered by the direct activity. For example, the assembly facility would buy materials from manufacturers, maintenance from service companies and fuel and consumables from various suppliers. These suppliers, in turn, buy their inputs from other companies, and so on. Taken together, the process of producing these goods and services creates profits, employment and income, generating indirect impacts.
- **Induced demand**: refers to the demand created in the broader economy through consumer spending of incomes earned by those employed in direct and indirect activities. It may take a year or more for these rounds of consumer spending to work their way through an economy.

To prepare the data to drive the IO model, direct expenditures from Table 5.2 are first classified by commodity using standard classification codes. The model accepts this detailed expenditure information and generates the direct, indirect and induced impacts according to the standard economic indicators:

- **Gross value of output**: Economic impact arises as industry expenditures work their way through the economy. Direct tidal development spending on inputs becomes the revenue of many another companies, which they, in turn, spend on inputs for the goods and services they produce, and so on. Gross value of output, then, is the cumulative sum of these sales and purchases of intermediate and final goods and services. These transactions occur in Nova Scotia, and also spill over to other provinces where supply and service industries are located.
- **Gross Domestic Product**: GDP captures the value of final goods and services produced in the economy, providing a measure of the value-added or income generated (wages and salaries for labour and returns to and of capital in the form of profit and depreciation).
- **Employment**: This captures the numbers employed, expressed in FTE jobs.
- **Labour Income**: this captures payments in the form of wages and salaries earned in an industry. Returns to labour in the form of wages, salaries and earnings form a key component of GDP.

5.3.3 Economic impact

Tidal development can be expected to have a substantial impact on the economy of Nova Scotia, and also the economies of the Atlantic Region and Canada. Because most of the in-stream tidal development in each of the small- and large-scale scenarios occurs in Nova Scotia waters (the

Bay of Fundy and Cape Breton), the direct impacts are concentrated in Nova Scotia, with spill-over effects in the Atlantic Region and elsewhere in Canada. Cumulative and average annual impacts by scenario are summarized in Table 5.3 (including the NS MRE Strategy 300MW phase of the Early Adoption Scenario). Note that these impacts represent cumulative totals for development and operations over the 25-year simulation period, with average annual values also presented.

Table 5.3: Tidal development economic impact (2015-2040)

	Demonstration		Early adoption				Late adoption	
	(67MW)		NS MRE (300MW)		Maximum (500MW)		(300MW)	
	Cumulative	Average/yr	Cumulative	Average/yr	Cumulative	Average/yr	Cumulative	Average/yr
Tidal expenditures ($000s)								
Total CAPEX (1)	376,500		1,535,000		2,382,000		1,356,000	
Total OPEX (1)	423,450		1,523,240		2,100,700		821,215	
NS CAPEX (60% of total) (2)	229,665		921,000		1,453,020		827,160	
NS OPEX (80% of total) (2)	338,760		1,218,592		1,680,560		659,972	
Total spending in NS	**568,425**	**22,737**	**2,139,592**	**85,584**	**3,133,580**	**125,343**	**1,484,132**	**59,365**
Economic impacts								
GDP ($000s)								
Direct	283,245	11,330	1,072,263	42,931	1,559,919	62,397	737,669	29,507
Indirect	77,602	3,104	294,045	11,762	427,376	17,095	202,102	8,084
Induced	86,649	3,466	328,327	13,133	477,202	19,088	225,664	9,027
Total	**447,495**	**17,900**	**1,694,635**	**67,826**	**2,464,497**	**98,580**	**1,165,435**	**46,617**
Jobs (FTE)								
Direct	3,948	158	14,958	598	21,740	870	10,281	411
Indirect	949	38	3,594	144	5,224	209	2,470	99
Induced	892	36	3,381	135	4,914	197	2,324	93
Total	**5,788**	**232**	**21,933**	**877**	**31,879**	**1,275**	**15,075**	**603**
Labour income ($000s)								
Direct	215,027	8,601	814,774	32,591	1,184,222	47,369	560,006	22,400
Indirect	45,981	1,839	174,228	6,969	253,230	10,129	119,750	4,790
Induced	36,325	1,453	137,641	5,506	200,052	8,002	94,603	3,784
Total	**297,333**	**11,893**	**1,126,643**	**45,066**	**1,637,504**	**65,500**	**774,359**	**30,974**

Source: Statistics Canada Inter-Provincial Input-Output Model (2010)

1. See Table 3.7 and 5.2

2. See Table 5.2

The interpretation of the values in Table 5.3 follows the NS MRE Strategy 300MW phase of the Base Scenario (use the corresponding values to interpret the Scenarios):

- **Tidal Expenditures:** Total capital expenditures (CAPEX) of $1,535.0 million plus operating expenditures (OPEX) of $1,523.2 million refer to total cumulative spending over 25 years. Nova Scotia content (where direct expenditures occur) is 60% of CAPEX ($921.0 million) and 80% of OPEX ($1,218.6 million) for a total of $2,139.6 million. All values are expressed in 2013 dollars (excluding inflation).
- **Gross Domestic Product:** The NS MRE Strategy 300MW installation generates an overall GDP impact of $1.7 billion, including a direct impact of $1.1 billion. The average annual direct GDP impact is $42.9 million.
- **Employment:** Almost 22,000 full-time equivalent (FTE) jobs would be created, 15,000 of these engaged in direct activities at the assembly facility and in marine logistics, initially in planning and device assembly, construction and deployment, and within 4-5 years in maintenance activities as well. Average direct employment per year would reach about 600 FTEs, with an average of about 880 FTEs when indirect and induced effects are included.

- **Income:** Tidal development and operations would generate about $815 million in direct labour income, with an overall impact of $1.1 billion including spinoff impacts. The average annual direct income impact would be $32.6 million.
- **Tax revenues:** though difficult to quantify, the construction and operation of the tidal energy facilities would generate millions to tens of millions of dollars annually (depending on scale) through corporate and personal income, sales and excise, and municipal property taxes.

It is important to note that these impacts would *primarily affect the rural economy bordering the Bay of Fundy*. The rural economy is characterized by relatively high unemployment rates and generally lower income levels than more urban areas. An industry offering the employment and income levels indicated in Table 5.3 would provide a much-needed economic infusion.

5.4 Value of avoided GHGs and pollutants

Reducing harmful emissions from fossil fuel use represents one of the main drivers behind initiatives to develop renewable energy sources. In Nova Scotia, the positive environmental impacts resulting from tidal development arise mainly from the avoidance of GHGs (CO_2 and N_2O) and other pollutant emissions (SO_2, a leading cause of ocean and freshwater acidification, mercury and particulate matter) from coal-fired electrical generating stations. Though quantifying the volume (in tonnes) of avoided emissions tends to be relatively straightforward, quantifying the value poses a challenge as there are alternative means for doing this leading to wide variations in unit prices.[11] A clear path for emissions pricing (through trading regimes or otherwise) in Canada has been elusive.

Despite these challenges, using conservative prices for each tonne of GHG and pollutants displaced (based on the emissions type and quantity/MWh from NSPI's coal-fired Lingan Power Station), the benefit attributable to tidal energy ranges from just under $195 million for the Demonstration Scenario to about $975 million for the Early Adoption Scenario (Table 5.4).

Table 5.4: Quantity and value of GHGs and pollutants displaced by tidal energy

	Demonstration (67MW)		Late Adoption (300MW)		Early Adoption (500MW)	
Total MWh 2015-2040	4,700,000		9,530,000		23,643,000	
GHG/pollutant	Tonnes	$000s	Tonnes	$000s	Tonnes	$000s
Carbon dioxide (CO_2)	4,723,048	118,076	9,593,018	239,825	23,797,929	594,948
Sulphur dioxide (SO_2)	63,300	63,950	128,569	129,895	318,948	322,235
Mercury (Hg)	0.09	8,300	0.18	16,860	0.45	41,830
Nitrous oxide (N_2O)	8,165	3,330	16,583	6,760	41,139	16,780
Total		193,656		393,340		975,793
Present value (5%)		90,488		157,722		405,768

Source: https://www.nspower.ca/en/home/about-us/environmental-commitment/air-emissions-reporting/default.aspx
CO_2 price: $25/t. Government of Canada, 2010, *Renewable Fuels Regulations Regulatory Impact Analysis Statement*
SO_2 price: $1,010/t. Diener Consulting Inc., 2001.
Hg price: $92.8 million/t. Diener Consulting Inc., 2001.
N_2O price:$408/t. Matthews, H.S. and Lave, L.B. 2000.
Note: The Moderate Case results would approximate the quantity and value of GHGs displaced by the NS MRE goal of 300MW

[11] Economists use two main tools to inform policy and business decisions: the Social Cost of Carbon, or SCC (the difference between the present GDP and the future GDP taking into account carbon emissions damage), and the Marginal Abatement Cost, or MAC (reflecting the marginal cost of one unit of abatement to meet a specific abatement target). See, Sustainable Prosperity, 2011. *The Value of Carbon in Decision-Making*.

5.5 Summary

In Nova Scotia, with at least 60-70% of the value of tidal development tied to activities occurring at or near a development site, the direct opportunities for local and regional participation are considerable across each scenario in the case of both small-scale and large-scale development. For some suppliers, meeting the domestic tidal energy goods and services requirements would be fairly straightforward because it is a matter of adapting existing products and services to tidal development needs. For others, an expansion of capabilities and capacity would be required. The level of interest in investing in supply chain capacity would be higher with greater strength and consistency of tidal development.

The 30-40% supply gap occurs in the manufacture of specialized technical items including device components, electrical equipment and cabling. Manufacturers are likely to rely on their existing facilities (in the EU or Asia) to source these items, allowing them to refine operations and extend production runs to minimize costs. It is not out of the question that device manufacturers would establish manufacturing plants in Canada, but the production level required to justify such an investment likely exceeds device demand even under the Early Adoption Scenario.

Tidal developments outside Canada provide export opportunities for Canadian suppliers. The nature of such opportunities would be similar to those in the Canadian market, though prospective Canadian suppliers could expect strong competition from local industry. The ability to compete in export markets would be greatly enhanced if tidal development in the Bay of Fundy were to commence in advance of development in other jurisdictions. This potential for this is greatest under the Early Adoption Scenario. It is least under the Demonstration and Late Adoption Scenarios.

Tidal development can be expected to have a substantial impact on the economy of Nova Scotia, and also the economies of the Atlantic Region and Canada. Because most of the in-stream tidal development in each of the small- and large-scale scenarios occurs in Nova Scotia waters (the Bay of Fundy and Cape Breton), the direct impacts are concentrated in Nova Scotia, with spill-over effects in the Atlantic Region and elsewhere in Canada.

In addition to the GDP, jobs and income impacts, tidal development would also produce benefits in the form of reduced costs arising from avoided GHG and pollutant emissions. These benefits range from about $200 million under the Demonstration Scenario to almost $1.0 billion under the Early Adoption Scenario.

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6

Concluding observations

6.1 Value proposition

In-stream tidal energy is an emerging technology with the potential to form the basis for a new industry in Canada and other jurisdictions. The three tidal development scenarios examined produce widely differing economic impacts across the selected indicators (Table 6.1). This is because the scenarios are based on different assumptions regarding the scale and timing of development – two of the main factors determining the economic impact.

Table 6.1: Nova Scotia tidal development value proposition

	Demonstration (67MW)		Early adoption				Late adoption (300MW)	
			NS MRE (300MW)		Maximum (500MW)			
	Cumulative	Average/yr	Cumulative	Average/yr	Cumulative	Average/yr	Cumulative	Average/yr
Total spending in NS ($000s) (1)	**568,425**	**22,737**	**2,139,592**	**85,584**	**3,133,580**	**125,343**	**1,484,132**	**59,365**
Economic impacts								
GDP ($000s)								
Direct	283,245	11,330	1,073,263	42,931	1,559,919	62,397	737,669	29,507
Indirect	77,602	3,104	294,045	11,762	427,376	17,095	202,102	8,084
Induced	86,649	3,466	328,327	13,133	477,202	19,088	225,664	9,027
Total	**447,495**	**17,900**	**1,695,635**	**67,825**	**2,464,497**	**98,580**	**1,165,434**	**46,617**
Jobs (FTE)								
Direct	3,948	158	14,958	598	21,740	870	10,281	411
Indirect	949	38	3,594	144	5,224	209	2,470	99
Induced	892	36	3,381	135	4,914	197	2,324	93
Total	**5,788**	**232**	**21,933**	**877**	**31,879**	**1,275**	**15,075**	**603**
Labour income ($000s)								
Direct	215,027	8,601	814,774	32,591	1,184,222	47,369	560,006	22,400
Indirect	45,981	1,839	174,228	6,969	253,230	10,129	119,750	4,790
Induced	36,325	1,453	137,641	5,506	200,052	8,002	94,603	3,784
Total	**297,333**	**11,893**	**1,126,643**	**45,066**	**1,637,504**	**65,500**	**774,358**	**30,974**
Emissions avoided								
Tonnes: 000s	4,795.5	191.8	9,738.2	389.5	24,158.0	966.3	9,738.2	389.5
$millions	198.4	7.9	402.9	16.1	999.6	40.0	402.9	16.1
Present value: $millions	92.7	3.7	161.6	6.5	415.7	16.6	161.6	6.5
Learning investment								
Energy price gap: PV$000s	255,500		813,000		1,030,000		305,250	

Source: Statistics Canada Inter-Provincial Input-Output Model (2010)

1. See Tables 3.7 and 5.2

The economic impacts summarized in Table 6.1 present cumulative (2015-2040) and average annual values for each Scenario. Using the NS MRE Strategy 300MW phase of the Early Adoption Scenario to interpret the Scenarios:

- **Employment:** Almost 22,000 full-time equivalent (FTE) jobs would be created, 15,000 of these engaged in direct activities at the assembly facility and in marine logistics, initially in planning and device assembly, construction and deployment, and within 4-5 years in maintenance activities as well. Average direct employment per year would reach about 600 FTEs, with an average of about 880 FTEs when indirect and induced effects are included.

- **Gross Domestic Product:** The NS MRE Strategy 300MW installation generates an overall GDP impact of $1.7 billion, including a direct impact of $1.1 billion. The average annual direct GDP impact is $42.9 million.
- **Income:** Tidal development and operations would generate about $815 million in direct labour income, with an overall impact of $1.1 billion including spinoff impacts. The average annual direct income impact would be $32.6 million.
- **Tax revenues:** though difficult to quantify, the construction and operation of the tidal energy facilities would generate millions to tens of millions of dollars annually (depending on scale) through corporate and personal income, sales and excise, and municipal property taxes.

It is important to note that these impacts would *primarily affect the rural economy bordering the Bay of Fundy*. The rural economy is characterized by relatively high unemployment rates and generally lower income levels than more urban areas. An industry offering the employment and income levels indicated in Table 6.1 would provide a much-needed economic infusion.

Export potential adds to the value proposition. Even a market share of 5% in the supply of inputs accounting for just 10% of the estimated CA$1,000 billion global market would amount to an export value in the CA$5 billion range. The latter exceeds cumulative tidal development spending in Canada, even under the Early Adoption Scenario. As noted, because of timing and scale, export potential for Canadian suppliers would be greatest under the Early Adoption Scenario. Under the high market share assumptions, the economic impacts flowing from this level of participation could exceed the cumulative economic impacts arising from domestic tidal development by a factor of two to three (based on the not unreasonable assumption that impacts would be roughly proportional to levels of spending shown under the Early Adoption Scenario in Table 6.1).

In addition to the GDP, jobs and income impacts, tidal development would also produce benefits in the form of reduced costs arising from avoided GHG and pollutant emissions. These benefits range from about CA$200 million under the Demonstration Scenario to almost CA$1.0 billion under the Early Adoption Scenario.

Set against these benefits is the cost of generating them. The analysis indicates that the tidal LCOE is not expected to achieve parity with low carbon alternatives in Nova Scotia until after 2040. The gap in each Scenario, referred to in Table 6.1 as the ‘learning investment’, is covered through some form of public support. The net level of support (total public support less positive revenues generated after 2040 as the cost of alternative sources of energy exceed tidal) varies widely by Scenario. It is lowest under the Late Adoption Scenario (about CA$305 million) because most of the capacity is installed after 2030, allowing the system to benefit from greatly reduced tidal capital and operating costs. The investment is greatest under the Early Adoption Scenario (about CA$1.0 billion) because most of the capacity is installed before 2030, resulting in limited benefit from cost reductions due to industry learning. The learning investment would be $813 million if installation were limited to the NS MRE Strategy 300MW.

It is worth repeating that implicit in these scenarios is the trade-off between energy costs and industrial opportunity: the lower costs associated with the Late Adoption Scenario come at the expense of lost first mover advantages and related supply opportunities both domestically and in export markets. These advantages and supply opportunities are greater under the Early Adoption Scenario, but at a higher learning cost.

6.2 Areas of uncertainty and risk

In order to garner the benefits from tidal energy development summarized above, a number of risks need to be mitigated so the industry can become established. In Canada, as in the UK, Europe and elsewhere, the risk in tidal energy development arises from the large upfront investment required, and uncertainty about costs and performance of the technology, government policies, permitting, access to the transmission grid, power purchase agreements, supply chain development, weather, market and foreign exchange fluctuations, social acceptance and environmental effects. These, in turn, affect the availability and cost of financing.
Prevalent risks at this stage of development are technology, policy and supply chain risks. Stemming from these is uncertainty about costs and revenue. Each of these risks and how to mitigate them are discussed below.

Regulatory environment and policy risk

In Nova Scotia, provincial and federal technology-push mechanisms such as R&D grants, enabling mechanisms such as the development of FORCE and the Fundy Advanced Sensor Technology (FAST) project, and market-pull mechanisms such as Nova Scotia's Renewable Electricity Plan are in place. The feed-in tariffs (COMFIT and FIT) reduce an important component of the risk – the price for electricity delivered – though power purchase agreements are as yet undetermined. As well, the FIT is available for uptake by the four berth holders at FORCE and represents a price commitment for 15 to 18 years, depending on the test path taken. Development through the FIT program may not result in more than a 2% increase in electricity rates, thereby limiting it to about 20 MW. FORCE was built as a test centre and has permits to develop up to 5 MW. It is in the process of upgrading facilities and gaining permits required for 20 MW. The cables it will install will have the capacity for 64 MW, unless additional power cables are deployed in future.

There is also uncertainty surrounding permitting requirements and the time needed to go through the regulatory process (this is not confined to Nova Scotia, but is an acknowledged uncertainty in all jurisdictions with tidal potential), which yields uncertainty about costs, timing and outcomes. The costs, time required and uncertainty related to environmental assessments and site characterization form part of this risk.

Always at risk is the social acceptance of tidal energy development: cost, impact on the marine environment, the use of the waters and coastal areas, and the visual impact of structures and industrial activity on and offshore (RenewableUK 2012, p. 26). Social licence can be lost if care to consult communities and protect the environment is not taken.

Longer-term government policies and financial support to mitigate risk to sustain the development of the tidal energy conversion industry need to be signalled. Developers will also need to know there will be long-term support for the development of tidal energy industry beyond 2017 - that a market will exist for the electricity generated, and there will be price support until costs can be competitive with other renewable and low-carbon alternatives in the province.
As noted by Leete, Xu and Wheeler, "Clarity, consistency and predictability of the regulatory support environment are all critical factors for investors" (2013, p. 870). Until then, the uncertainty will delay the next steps of developers and allow other jurisdictions to move ahead in creating more supportive policy regimes.

These policies will need to be signalled soon. The commitment of financial and human resources to invest beyond array-testing at the FORCE site and the COMFIT developments and in the latter part of this decade may be contingent upon the indications there will be an industry here – beyond the planned small- and large-scale deployments of 23.55MW, beyond the planned 64MW FORCE capacity, and beyond the current FIT agreement. Appropriate supports are discussed in Section 6.4 and suggested actions in Section 6.5.

Technology Risk

Part of the technology risk relates to costs (equipment, installation, maintenance) and performance (operating reliability, capacity factors, and utilization). RenewableUK (2013) summarizes the prevalent uncertainties related to technology development:

- Cost reduction - progression slower than competing technologies;
- Survivability of devices - operating data for a year or more are limited;
- Capacity factors being lower than expected - to date, operating data are limited;
- Delays and costly installation and maintenance due to challenges of working in fast-moving water, brief periods of slack tide, a nascent supply chain, and limited availability of vessels and installation equipment;
- Premature convergence on what could be a suboptimal design for the sake of expediency to prove maturity for investors (p. 23).

The investment is large and upfront and the investment horizon is quite long so design choice is important. The four FORCE berth holders and two of the COMFIT sites have identified their turbine designs for the test phase. Exact timelines, costs and performance remain to be established, but installing these devices will allow for operating data to be collected, thereby reducing the uncertainty for later projects. Governments support mechanisms such as demonstration grants, to be discussed in Section 6.5, can facilitate this.

Supply Chain Risk

During the early stages of development, the skills in the supply chain for tidal energy conversion are undeveloped or being supplied to other industries. Having few suppliers can result in backlogs and other delays, and uncompetitive pricing. Until suppliers have gained experience with tidal energy projects, they are unlikely to provide performance guarantees. Forging strategic partnerships with others in the supply chain, as has been done by the various consortia holding FORCE berths, and is sought by Fundy Tidal Inc., can be effective in sharing the risk among multiple parties and developing new knowledge. Government policies and support provided for the development of the in-stream tidal energy industry generally, as well as targeted funding for innovation by supply chain companies, can help build a robust and globally competitive supply chain.

6.3 Impact of uncertainty and risk on the scenarios and the value proposition

Investors interested in in-stream tidal energy projects are scarce at this stage. The projects are not within the bailiwick of venture capitalists due to the size and investment horizon. Bank debt will be difficult to access until the technology reaches maturity and has a well-established track record and others to share the risk. Bank debt provides important financial leverage that enhances returns to equity holders. The returns are not yet proportionate to the risk, making it difficult to attract equity capital.

Besides government funding, balance sheet financing has been the predominant source of investment. Merger and acquisition activity in the industry – device developers being absorbed by large industrials – has increased the capacity for balance sheet financing for research and development and pre-commercialization activities.[12] However, a much larger capital investment is now needed to deploy sufficiently large commercial arrays (approximately $7 million per MW).

In Nova Scotia, the early development strategy has dealt with providing research funding, establishing a test site and introducing price support through FIT and COMFIT. Nonetheless, the value proposition leveraged by these supports may be impacted by various factors, including the difficulty of securing financing to develop tidal energy. Given the intent of the Nova Scotia Marine Renewable Energy Strategy, we can expect that many of these factors will be addressed, but beyond these factors, there remain risks from:

- Uncertainty regarding spatial licensing - developers' sole rights to develop a certain acreage, installed capacity, or number of devices beyond pre-approved 'berths' within the FORCE Crown Lease area;
- The domestic limit of a 2% increase to electricity rates from tidal energy conversion;
- Environmental assessment at FORCE only for 5MW;
- Uncertainty about a future Feed-in Tariff (rate and duration) for energy developed beyond 23.55MW;
- Uncertainty about expansion of COMFIT sites due to grid capacity and subsequent COMFITs being made available;
- Availability of space in the electrical system in Nova Scotia for variable power that will not already be taken up by wind;
- The insufficient intertie to the New Brunswick transmission system to deliver electricity to the north eastern US, effectively limiting exports (though this will be increased with the construction of the Maritime Link);
- The port facilities in and near the Bay of Fundy and the readiness and willingness of local companies to start-up, re-tool or expand to supply a new tidal energy industry, given the inherent uncertainty.

The present regulatory environment in Nova Scotia effectively limits the development of in-stream tidal energy to 23.55 MW (20MW at FORCE plus 3.55 MW from COMFIT sites). This is below the size of development needed for economies of scale and a positive return on investment and so will effectively limit the work being done here to array-testing and a relatively small amount of tidal energy being delivered to the grid.

To maintain, or regain, the momentum and to transition from pre-commercialization to commercialization of in-stream tidal energy conversion, it will be up to governments to support the industry through this phase, and then while it develops into a reliable, cost-effective source of renewable energy. The three Scenarios explored in this study will require different levels of support from the provincial and federal governments but will have commensurate benefits. For instance, the Early Adoption Scenario will require the greatest support but will yield the greatest benefit to Nova Scotia, the region and Canada in terms of jobs and GDP, rural industrial diversification, energy security, GHG emission reductions, and export opportunities. For there to be sufficient tidal energy development to give rise to a significant local supply chain, government support should be multifaceted, sizable, long-term and predictable.

[12] Siemens AG recently announced (November 2014) it is selling its tidal power business, Marine Current Turbines.

6.4 Risk mitigation through government supports

In Nova Scotia, a number of support mechanisms and enabling activities have been put in place or are underway, which have been successful in attracting international investment and world-leading technology developers. They have come from various federal and provincial sources: Natural Resources Canada (NRCAN), Sustainable Development Technology Canada (STDC), the OERA (formerly OEER/OETR) of Nova Scotia, the Natural Sciences and Engineering Research Council (NSERC), and the Atlantic Canada Opportunities Agency (ACOA), along with various municipal and corporate partners. Marine renewable energy projects are also eligible under such programs as IRAP and SR&ED.

These supports have been as follows:

- Renewable energy standard/requirement;
- Feed-in tariff and community feed-in tariff;
- Updated SEA for the Bay of Fundy and Cape Breton regions;
- FORCE;
- Subsea cable and grid connection with a capacity of 64MW at FORCE (in progress);
- The FAST platform development;
- Research on fish and marine mammal tracking, sediment dynamics and coastline integrity;
- Mi'kmaq Ecological Knowledge Studies;
- Research conducted on potential environmental interactions of tidal energy devices;
- Pathways of effects model;
- Statement of best practices;
- Site characterization, resource measurement and modelling research;
- Study and recommendations for marine renewable energy legislation (Fournier 2013);
- Community and Business Toolkit for Tidal Energy Development;
- Community Engagement Handbook;
- Collaborative work on standards for tidal energy as part of Technical Committee114 of the International Electrotechnical Commission; and
- Establishment of Marine Renewables Canada (MRC) Atlantic Office.

With new technology development, a gap in government support typically occurs between R&D grants and market-pull mechanisms. This gap can cause development of the industry to stall. The in-stream tidal energy industry is at that point now. This is a time when support mechanisms that will mobilize financing such as demonstration grants are needed to help the industry develop the track record needed to reduce the uncertainty that presently deters insurers and investors.

The funding pool needs to be increased and mechanisms to leverage funds established. An example is the Green Investment Bank, a UK government-owned corporation that invests government funds by taking equity positions in green infrastructure projects and raising additional capital from domestic and international private co-investors. The government equity investment helps to de-risk and lower the cost of capital of projects in renewable energy.

A model for demonstration grants is the Crown Estate's £20million grant for the construction of wave and in-stream tidal arrays (RenewableUK, 2013). Other examples can be found in Germany and Denmark, where offshore wind energy was successfully developed through timely and effective government support.

Research and development funding based on a collaborative, strategic innovation model can also be effectively targeted toward:

- Cost reduction through optimization of CAPEX, OPEX, energy yield, and longevity of equipment;
- On-going design refinements to optimize installation and maintenance procedures;
- Further understanding and modelling of the resource and interactions between devices in arrays;
- Availability of vessels and installation equipment given the demands of other marine industries in the region;
- Development of standards and best practices.

Also at this stage, continued government funding for resource measurement, site characterization and environmental assessments – and making results publically available – will further reduce both uncertainty and the upfront cost for developers. These activities will also allow Nova Scotia, the region and Canada, to better understand its own tidal energy resource and the ecosystem surrounding the tidal energy sites.

Continuing the collaborative approach to permitting procedures and conducting environmental assessments and site characterization work in anticipation of commercialization will reduce the upfront costs and uncertainty of potential delays or full-out barriers to development.

In 2014, the OERA updated the Bay of Fundy and the Cape Breton Region Strategic Environmental Assessments (SEA). Such consultation with the public is integral to earning and preserving the necessary social licence. Development of a marine spatial plan for the Bay of Fundy would be a natural extension of this work. Developed through research and consultations with stakeholders, a marine spatial plan would guide public and private uses of the waters. It is developed through research and consultations with stakeholders. The Rhode Island Ocean Special Area Management Plan is an example of such a plan.

6.5 Future considerations

Through various policies, programs and initiatives, the Governments of Nova Scotia and Canada have laid the groundwork for early tidal industry development. Governments in other jurisdictions have provided and continue to provide similar forms of support. Technology developers find themselves at a critical juncture; they have invested heavily in RDI&D, and must continue to do so in order to reduce costs and prove commercial viability. Continued development and demonstration are important steps in the commercialization process, and to help offset risk at this stage governments have introduced defined levels of revenue support in the form of feed-in-tariffs. The latter are critical to achieving the high rate of global installations that would bring costs down.

But risk in various forms remains: the large upfront investment required; uncertainty about costs and performance of the technology; uncertain or shifting government policies; permitting delays; access to the transmission grid; availability and cost of financing; power purchase agreements; weather; market and foreign exchange fluctuations; social acceptance and environmental effects. All these factors contribute to uncertainty with respect to industry development timetables, the rate of installations (globally), and therefore establishing the confidence needed for the emergence of industry supply chains.

The Governments of Nova Scotia and Canada are able to influence some of these risk factors as they apply to tidal industry development within Canada. Government support could be channelled to reduce uncertainty in several areas, and in so doing, make a valuable contribution to realizing the tidal value proposition. Among the key steps for consideration are ones that:

Continue the commitment to tidal R&D

Through various initiatives over the past several years, the Government of Canada and the Government of Nova Scotia have supported tidal energy R&D. Successful demonstration projects in the UK provide encouragement that the technology holds commercial potential. But considerably more investment is needed to prove the technology and bring costs down to levels where they begin to become competitive with alternative sources of renewable energy. This requires a continued commitment to R&D by governments over the next 5-10 years, plus continued support for investment in tidal capacity by industry and utilities. Both are essential to finding ways to reduce costs and enhance competitiveness, and also to reduce GHG emissions.

Implement a further round of feed-in tariffs to support capacity installation

To build a regional marine energy industry, developing new technologies and practices for export, and developing 300 or 500MW of electricity from the tides, continued government and investor financial support would be needed. The LCOE of tidal energy conversion is unlikely to be competitive with other renewables and low-carbon sources until after 2040, leaving tidal energy power producers at a cost disadvantage in a competitive bidding process for power supply contracts until then. The value proposition can be enhanced if federal and provincial support is adequate, stable and predictable so as to provide sufficient certainty for the industry and supply chain to engage in commercial-scale development.

Renewable energy standards, such as those in place in Nova Scotia, are a good market-pull policy, but without price support, they favour the least expensive renewable energy technology, in particular, more mature technologies such as onshore wind. Feed-in tariffs are effective in supporting the development of a new technology until it can become competitive, thereby diversifying the electricity supply and stabilizing long-term prices. The current FIT and COMFIT support about 23MW of tidal capacity. A further round of FIT/COMFIT would increase the likelihood of achieving the value proposition associated with Early or Late Adoption scenarios.

The differential between a feed-in tariff and the costs of alternative low-carbon or renewable resources would be a part of the “learning investment” described in Section 3.6.1. According to the estimates in this study, this part of the investment will begin to pay back with lower costs after 2040.

Implement the regulatory elements outlined in the Marine Renewable Energy Strategy

A long-term view of a stable regulatory regime will provide developers a clearer line of sight to commercial development. Completion of work currently under way to formulate and implement the regulatory elements outlined in the Marine Renewable Energy Strategy is vital to defining this clear line of sight.

- Design and communicate the marine renewable energy regulations, the licensing system, lease and development rights, permitting and approval requirements for work in the Bay of Fundy and Bras d'Or Lakes.
- A coordinated permitting and approval activities between federal and provincial departments.
- A Statement of Best Practices.
- A marine spatial plan for the Bay of Fundy to guide public and private uses of lands and waters.

Advance industry-enabling infrastructure development to encourage supply chain interest/participation in tidal opportunities

The infrastructure needed to support the industry must be designed, planned, funded and built. This could occur incrementally as the industry develops. Planning should be undertaken in consultation with current and prospective industry stakeholders (FORCE berth holders, Fundy Tidal Inc., and other potential developers) to identify critical requirements.

For essential information on the other end of the value chain, a transmission screening study should be commissioned on the interconnection of tidal energy at Onslow to the Salisbury line.

Develop a strategic, collaborative tidal energy research and innovation initiative

Considerable amounts of data have been collected to date in studies funded by OERA, the province and the federal government. Effective, public dissemination and continued data gathering will not only assist developers by reducing upfront costs and risks, it will help Nova Scotia know its own resource and the surrounding ecosystem.

- Compile a database of findings, ideally geo-referenced, open-source and publically accessible, to which data from completed and subsequent studies can be added or linked.
- Research should be continued to gather and publish baseline data on: resource measurement, site characteristics, bathymetry, sediment dynamics, marine mammal and fish behaviour in and around the tidal energy conversion sites, ice and debris, and near and far field effects of energy extraction.
- The next phase of the FAST program should be funded.
- An environmental assessment of an expanded FORCE site for development beyond 20 MW should be undertaken.

Create a federal-provincial innovation fund for marine renewables RDI&D, with a focus on challenging issues and where export potential is greatest

Provide research, development and innovation funding for marine electrical technologies. There are still a number of technical innovations needed to see tidal energy delivered to the grid. For example, solutions for underwater (wet) electrical connections and substations have not been found yet. Targeted research, development and innovation grants for marine electrical technology can give Canadian companies a lead in this niche of the global tidal energy supply chain. The Roadmap describes some of the necessary innovations. Funding priorities can be identified as part of an updated strategic industry plan to provide guidance to funders at the provincial and federal level. Models for specialized innovation funds include the UK's Carbon Trust and Offshore Renewable Energy Catapult.

Through Innovacorp or a federal-provincial specialized marine innovation fund, provide venture capital to develop and commercialize sensor technologies for use in harsh ocean environments. The Nova Scotia ocean technology companies have the intellectual property and expertise to adapt technologies for use in the global tidal energy industry.

Through the provincial and federal governments, provide funding for research on installation, operation and maintenance of arrays and demonstration grants, such as those provided by the Crown Estate in the UK. Such research can reduce the uncertainty for developers, insurers and investors and reduce the cost of energy.

As well, establishment of a public/private investment fund, such as the Green Investment Bank in the UK, should be investigated as a way to leverage government funds, de-risk projects, lower costs of capital, and attract equity investors.

References

Agence de l'Environnement et de la Maîtrise de l'Energie. (2013). *Note stratégique sur les énergies marines renouvelables.*

Allan G, Bryden I, McGregor P, Stallard T, Swales J, Turner K, Wallace R (2018) Concurrent and legacy economic and environmental impacts from establishing a marine energy sector in Scotland. Energy Policy 36 (7) 2734-2753.

Allan G, Lecca, P,. McGregor P, Swales J. (2014). The economic impacts of marine energy developments: A case study from Scotland *Marine Policy*, *Volume 43*, *122-131*

Bain & Company. (2008). *A closer look at the development of wind, wave & tidal energy in the UK: Employment opportunities and challenges in the context of rapid industry growth.* http://www.bain.com/publications/articles/employment-opportunities-and-challenges-in-the-context-of-rapid-industry-growth.aspx

Black & Veatch/NREL. (2012) Cost and Performance Data for Power Generation Technologies. Prepared for the National Renewable Energy Laboratory. Retrieved from: http://bv.com/docs/reports-studies/nrel-cost-report.pdf

Bloomberg (2014) http://www.bloomberg.com/news/articles/2014-11-25/siemens-exits-tidal-power-industry-blaming-slow-development

Brattle Group. (2013). A Learning Investment-based Analysis of the Economic Potential for Offshore Wind: The case of the United States. Retrieved from: http://www.cleanenergystates.org/resource-library/resource/report-a-learning-investment-based-analysis-of-the-economic-potential-for-offshore-wind-the-case-of-the-united-states#.UxoEksuPI1I

Burer, M., Wustenhagen, R. (2009). Which Renewable Energy Policy is Adventure Capitalist's Best Friend? Empirical Evidence from a Survey of International Clean tech Investors, Energy Policy, 37, 4997-5006.

CannmetEnergy & Natural Resources Canada. (2011). *The Marine Renewable Energy Sector: Early-Stage Supply Chain.* http://canmetenergy.nrcan.gc.ca/sites/canmetenergy.nrcan.gc.ca/files/files/pubs/MarineRenewableEnergySupplyChain_EN.pdf

Carbon Trust, 2004. UK, Europe and Global Tidal Stream Energy Resource Assessment. Report by Black and Veatch.

Carbon Trust, 2005. Tidal Stream - Phase II UK Tidal Stream Energy Resource Assessment. Report by Black and Veatch.

Carbon Trust. (2006). Future Marine Energy: Results of the Marine Energy Challenge: Cost Competitiveness and growth of wave and tidal stream energy. www.carnontrust.com

Carbon Trust. (2011). Accelerating Marine Energy: The potential for cost reduction – insights from the Carbon Trust Marine Energy Accelerator. Retrieved from: https://www.carbontrust.com/media/5675/ctc797.pdf

Carbon Trust. (2011a). Accelerating Marine Energy. www.carbontrust.com/media/5675/ctc797.pdf

Carbon Trust. (2011b). UK Tidal Stream Current Resource and Economics. Report by Black and Veatch. Available at: www.carbontrust.com/media/77264/ctc799_uk_tidal_current_resource_and_economics.pdf

Carbon Trust. (2012). Technology Innovation Needs Assessment (TINA): Marine energy Summary Report. Available at: www.carbontrust.com/media/168547/tina-marine-energy-summary-report.pdf

Centre for Sustainable Energy & Hassan, G. (2005). *Community Benefits from Wind Power: A study of UK practice & comparison with leading European countries.* http://www.carbontrust.com/media/168547/tina-marine-energy-summary-report.pdf

Collective Wisdon Solutions, exp. Services Inc., & Maritime Tidal Energy Corp. (2011). *Marine Renewable Energy Infrastructure Assessment.* http://www.novascotia.ca/energy/resources/EM/renewable/Marine-Renewable-Energy-Infrastructure-Assessment.pdf

Crown Estate. (2011). Wave and tidal energy in the Pentland Firth and Orkney Water: How they could be built. Report prepared by BVG Associates. http://m.thecrownestate.co.uk/media/71431/pentland-firth-how-the-projects-could-be-built.pdf

Crown Estate. (2013). Wave and tidal energy in the Pentland Firth and Orkney Waters: Delivering the first phases of projects. Crown Estate, Edinburgh.

CGEDD. (2013). Ministère de l'écologie, du développement durable et de l'énergie, Ministère de l'économie et des finances, Ministère du redressement productif. *Rapport de la mission d'étude sur les énergies marines renouvelables.* http://www.ladocumentationfrancaise.fr/var/storage/rapports-publics/134000275/0000.pdf

DB Climate Change Advisors. (2011). UK Offshore Wind: Opportunity, Costs & Financing.

DCENR. (2008). All Island Grid Study Workstream 1 Renewable Energy Resource Assessment. Department of Communications, Energy and Natural Resources. Report prepared by ESBI Engineering and Facility Management, Dublin.

DECC. (2011). Review of the generation costs and deployment potential of renewable electricity technologies in the UK. Department of Energy and Climate Change. Available at www.gov.uk/government/uploads/system/uploads/attachment_data/file/147863/3237-cons-ro-banding-arup-report.pdf

DTI. (1993). Tidal Stream Energy Review, Report No ETSU T/05/00155/REP, Department of Trade and Industry.

Dalton, John. (2013). Direct testimony on behalf of the Nova Scotia Department of Energy; in the matter of: An application by NSP Maritime Link Incorporated for approval of the Maritime Link Project. Retrieved from: http://nsuarb.novascotia.ca/sites/default/files/documents/muskratfalls/m-43_-_dalton_direct_evidence_and_exhibits.pdf

Del Rio, Pablo & Mercedes Burguillo. (2009). *An empirical analysis of the impact of renewable energy deployment on local sustainability.* Renewable and Sustainable Energy Reviews. Vol. 13 pp. 1314-1325

Department of Energy & Climate Change. (2013). *New Energy Infrastructure Investment to Fuel Recovery*. http://www.gov.uk/government/organisations/department-of-energy-climate-change)

Draper S, Adcock TAA, Borthwick AGL, Houlsby GT. 2014 Estimate of the extractable Pentland Firth tidal stream power resource. Renewable Energy. 63 650-7

ETSU (2001)

Ecorys (2012) Blue Growth Scenarios and Drivers for Sustainable Growth from the Oceans Seas and Coasts.http://ec.europa.eu/maritimeaffairs/documentation/studies/documents/blue_growth_third_interim_report_en.pdf

EU. (2012). Communication from the Commission to the European Parliament - Blue growth opportunities for marine and maritime sustainable growth; COM (2012) 494 final

EU-OEA. (2010). Oceans of Energy Roadmap 2010-2050. European Ocean Energy Association. www.erec.org

EU. (2012). Communication from the Commission No 494: Blue Growth opportunities

Ernst and Young. (2010). Cost and financial support for wave and tidal stream and tidal range generation in the UK: a report for Department of Energy and Climate Change and the Scottish Government. Available at htpp://webarchive.nationalarchives.gov.uk/20121205174605/http:/decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/renewable%20energy/explained/wave_tidal/798-cost-of-and-finacial-support-for-wave-tidal-strea.pdf

Ernst and Young. (2010). Cost and financial support for wave and tidal stream and tidal range generation in the UK: a report for Department of Energy and Climate Change and the Scottish Government. Available at htpp://webarchive.nationalarchives.gov.uk/20121205174605/http:/decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/renewable%20energy/explained/wave_tidal/798-cost-of-and-finacial-support-for-wave-tidal-strea.pdf

European Commission 2014 Ocean Energy: Impact Assessment, accompanying the document, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Action Needed to Deliver on the Potential of Ocean Energy by 2020 and Beyond. Retrieved from: http://ec.europa.eu/maritimeaffairs/policy/ocean_energy/documents/swd_2014_12_en.pdf

European Wind Energy Association (EWEA). (2009). *Wind Energy – the Facts – Volume 2, Costs & Prices*.

European Wind Energy Association (EWEA). (2011). *Wind in our Sails. The Coming of Europe's Offshore Wind Energy Industry.*

FREDS/MEG. (2004). Harnessing Scotland's Marine Energy Potential. Marine Energy Group, Scottish Executive

Fournier, R. (2013). Marine Renewable Energy Legislation: A Consultative Approach. Retrieved from: http://www.oera.ca/wp-content/uploads/2013/04/Fournier-Final-Report.pdf

Gill, A.B., 2005, Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Journal of Applied Ecology, 42, 605-615.

ICES, 2010a. Report of the Working Group on Ecosystem Effects of Fishing Activities (WGECO). ICES CM 2010/ACOM:23.

ICES, 2010b. Report of the Working Group on Integrated Coastal Zone Management (WGICZM). ICES CM 2010/SSGHIE:05.

ICF International. (2014). *Emerging Electricity Technologies in Nova Scotia.*

IEA. (2010). Projected costs of Generating Electricity, International Energy Agency, Paris. Available at: www.iea.org/publications/freepublications/publication/projectedcosts.pdf

IEA. (2012). World Energy Outlook 2012, International Energy agency, Paris. Available at: www.iea.org/publications/freepublications/publication/English.pdf

INFOREM, Observatoire Emploi-Formation. (2010). *Impact emploi-formation des project d'énergies marines renouvelables.*

Inger, R., Attrill, M.J., Bearhop, S., Broderick, A.C., Grecian, W.J., Hodgson, D.J., Mills, C., Sheehan, E., Votier, S.C., Witt, M.J. & Godley, B.J., 2009. Marine renewable energy: potential benefits to biodiversity? An urgent call for research. Journal of Applied Ecology, 46, 1145-1153

International Energy Agency. (2012). *Renewable Energy Medium-Term Market Report 2012*.

International Energy Agency. (2013). *Technology Roadmap – Wind Energy.*

International Renewable Energy Agency, IRENA. (2012). Renewable Energy Technologies: *Cost Analysis Series.* Volume 1: Power Sector, Issue 5/5.

Johnson K, Kerr S, and Side J (2013). Marine Renewables and Coastal Communities - experiences from the offshore oil industry in the 1970s and their relevance to marine renewables in the 2010s, *Marine Policy* 38 491-99.

Jamasb T and Kohler J. (2007). Learning curves for Energy Technology: a critical assessment. Available at www.repository.cam.ac.uk/bitstream/handle/1810/194736/0752&EPRG0723.pd?sequence=1

Junginger M Faaij A and Turkenburg WC. (2005). Global Experience curves for Wind farms. Energy Policy 33 (2) pp133-150

LCICG (2012a) Technology Innovation Needs: Offshore Wind Energy. Low Carbon Innovation Coordination Group.

LCICG. (2012b). Technology Innovation Needs: Marine Energy. Low Carbon Innovation Coordination Group.

Lantz, E., Hand, M., and Wiser, R. (2012). *The Past and Future Cost of Wind Energy*, World Renewable Energy Forum, Denver, Colorado. Retrieved from: www.nrel.gov/docs/fy12osti/54526.pdf

Leete, S., Xu, J., Wheeler, D. (2013). Investment Barriers and Incentives for Marine Renewable Energy in the UK: an Analysis of Investor Preferences, Energy Policy, 60, 866-875.

Lindman A and Soderholm P. (2012). Wind Power learning rates: A conceptual review and mate-analysis. Energy Economics 34(3) 754-761

Low Carbon Innovation Coordination Group. (2012). Technology Innovation Needs Assessment (TINA): Marine Energy Summary Report. Retrieved from: http://www.carbontrust.com/media/168547/tina-marine-energy-summary-report.pdf

MEG. (2009). Marine Energy Supply Chain Survey. Prepared for the Marine Energy Group by Sgurr energy & IPA.

MacDougall, S. (2013). Financial Evaluation and Cost of Energy, in MacDougall, S., and Colton, J. (eds.), *Community and Business Toolkit for Tidal Energy Development,* Acadia Tidal Energy Institute, Mar. 2013, pp. 131-145. Retrieved from: http://tidalenergy.acadiau.ca/tl_files/sites/tidalenergy/resources/Documents/Toolkit/Module_7Sweb.pdf

MacKay D.J.C. (2007). "Under-estimation of the UK tidal Energy resource" available at http://www.inference.phy.cam.ac.uk/sustainable/book/tex/TideEstimate.pdf

Mansini, A., Menchetti, E. (2012). The Impact of Behavioral Factors in the Renewable Energy Investment Decision Making Process: Conceptual Framework and Empirical Findings, Energy Policy, 40, 28-38.

Mansini, A., Menchetti, E. (2013). Investment Decisions in the Renewable Energy Sector: An Analysis of Non-financial Drivers, Technological Forecasting and Social Change, 80 (3) 510-524.

Marine Renewables Canada. (2013). *Marine Renewable Energy in Canada & the Global Context: State of the Sector Report.* http://www.marinerenewables.ca/wp-content/uploads/2012/11/State-of-the-Canadian-MRE-Sector-20131.pdf

Marine Renewable Energy Technology Roadmap Steering Committee. (2011). *Charting the Course – Canada's Marine Renewal Energy Technology Roadmap*.

Ministère de l'écologie, du développement durable et de l'énergie, Ministère de l'économie et des finances, Ministère du redressement productif. (2013). *Rapport de la mission d'étude sur les énergies marines renouvelables.* http://www.ladocumentationfrancaise.fr/var/storage/rapports-publics/134000275/0000.pdf

National Renewable Energy Laboratory (NREL). (2013). *Installation, Operation, and Maintenance Strategies to Reduce the Cost of Offshore Wind Energy.* http://www.nrel.gov/docs/fy13osti/57403.pdf

Natural Resources Canada and CanmetENERG. (2011). *The Marine Renewable Energy Sector Early-Stage Supply Chain*.

Navigant Consulting, Inc. (2013). U.S. *Offshore Wind Manufacturing and Supply Chain Development.*

Nova Scotia Department of Energy. (2010a). *Renewable Electricity Plan – A Path to Good Jobs, Stable Prices, and a Cleaner Environment*.

Nova Scotia Department of Energy. (2010b). *Final Report Renewable Energy Opportunities and Competitiveness Assessment Study*. SLR Consulting.

Nova Scotia Department of Energy. (2012). *Nova Scotia Marine Renewable Energy Strategy*.

Nova Scotia Utility and Review Board. (2009). *NSPI 2009 Integrated Resource Plan Update Report*.

Nova Scotia Utility and Review Board. (2013). *In the matter of the Electricity Act and the Tidal Energy Feed-in Tariff Rate for Development Tidal Arrays, evidence of Geoffrey Keith and Mirko Previsic*.

Obermann, E., and MacDougall, S. (2013). Opportunities and Strategies for Businesses, in MacDougall, S., and Colton, J. (eds.), *Community and Business Toolkit for Tidal Energy Development*, Acadia Tidal Energy Institute, Mar. 2013, pp.172-213. http://tidalenergy.acadiau.ca/tl_files/sites/tidalenergy/resources/Documents/Toolkit/Module_9Jweb.pdf

Ocean Renewable Energy Group (OREG). (2012). *Business Opportunities from Marine Renewable Energy Development and Project Life Cycle Needs*.

Redpoint Energy Limited. (2009). *The Benefits of Marine Technologies Within a Diversified Renewables Mix – A Report for the British Wind Energy Association*.

Regeneris Consulting & Welsh Economy Research Unit at Cardiff Business School. (2013). *The Economic Impact of Development of Marine Energy in Wales.* http://wales.gov.uk/docs/desh/publications/130816economic-impact-of-developing-marine-energy-en.pdf

RenewableUK. (2010a). *UK Offshore Wind: Building an Industry – Analysis and Scenarios for Industrial Development*

RenewableUK. (2010b). *Channelling the Energy – A Way Forward for the UK Wave & Tidal Industry Towards 2020*

RenewableUK. (2010c). *State of the Industry Report – Onshore and Offshore Wind: A Progress Update*

Renewable UK. (2011a). *Working for a Green Britain: Volume 1: Future Employment and Skills in the UK Wine & Marine Industries.* http://www.renewableuk.com/en/publications/index.cfm/Working-for-a-Green-Britain-Volume-1

Renewable UK. (2011b). *Working for a Green Britain: Volume 2: Future Employment and Skills in the UK Wind and Marine Energy Industries.* http://www.renewableuk.com/en/publications/reports.cfm/Working-for-a-Green-Britain-Volume-2

RenewableUK. (2011c). *Wave and Tidal Energy in the UK : State of the industry report.* http://www.renewableuk.com/en/publications/reports.cfm/Wave-and-Tidal-SOI-2011

Renewable UK (2013). Wave and Tidal Energy in the UK: Conquering Challenges, Generating Growth. Retrieved from: http://www.renewableuk.com/en/publications/index.cfm/wave-and-tidal-energy-in-the-uk-2013

RenewableUK. (2013b). *Building an Industry – Updated Scenarios for Industrial Development*.

RenewableUK. (2013c). *Working for a Green Britain & Northern Ireland 2013-23 : Employment in the UK Wine & Marine Energy Industries.* http://www.renewableuk.com/en/publications/reports.cfm/working-green-britain

RenewableUK. (2013d). *Wind Energy in the UK – State of the Industry Report 2013*.

RenewableUK. (2013e). *UK Wind & Marine Energy Business Barometer 2013*.

RenewableUK (2014). *UK Wind & Marine Energy Business Barometer 2014.*

.

SEI (2004) Tidal and Current Energy Resources in Ireland. www.seai.ie

Scottish Executive (2001) Scotland's Renewable Resource 2001- Volume 1: the analysis. Available at www.scotland.gov.uk/Resource/Doc/47176/0014634.pdf

SI Ocean (2013). Ocean Energy: Cost of Energy and Cost Reduction Opportunities. Retrieved from: http://si-ocean.eu/en/upload/docs/WP3/CoE%20report%203_2%20final.pdf

SLR Global Environment Solutions. (2013). *Marine Renewable Energy Supply Chain Development: Ocean Technology Sector. Engagement and Strategy Report.* http://gallery.mailchimp.com/615388dd826230f1ffa50b449/files/MRESupplierReportFINAL16MAY2013.pdf

SQW. (2009 Socio-economic impact assessment of Aquamarine Power's Oyster Projects: Report to Aquamarine Power. Available at www.aquamarinepower.com/sites/resources/Reports/3137/Socio-economic%20assessment%20of%20Aquamarine%20Power%20Oyster%20project.pdf

SQW Energy. (2010). *Economic Study for Ocean Energy Development in Ireland: A Report to the Sustainable Energy Authority of Ireland and Invest Northern Ireland.* http://www.seai.ie/Renewables/Ocean_Energy/Ocean_Energy_Information_Research/Ocean_Energy_Publications/SQW_Economics_Study.pdf
Synapse Energy Economics (2013) Evidence of Geoffrey Keith and Mirko Previsic, Nova Scotia Utility and Review Board in the Matter of the Electricity Act and The Tidal Energy Feed–in

Salter SH. (2009). Correcting the underestimate of the tidal stream resource of the Pentland Firth, Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden.

Scottish Executive. (2007). Additional Support for Marine Electricity Generation in Scotland. Prepared by AEA Technology & Poyry Energy Consulting.

Shields, M.A., Woolf, D.K., Grist, E.P.M., Kerr, S.A., Jackson, A.C., Harris, R.E., Bell, M.C., Beharie, R., Want, A., Osalusi, E., Gibb, S.W. & Side, J., 2011. Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment. Ocean & Coastal Management, 54, 2-9.

Sustainable Prosperity. Policy Brief November 2011. The Value of Carbon in Decision-Making: The Social Cost of Carbon and the Marginal Abatement Cost.

Tariff Rate for Development Tidal Arrays, T-2, August 16, 0203. Retrieved from: http://uarb.novascotia.ca/fmi/iwp/cgi?-db=UARBv12&-loadframes

Synapse Energy Economics (2013) Response to Undertaking U-2, Nova Scotia Utility and Review Board in the Matter of the Electricity Act and The Tidal Energy Feed–in Tariff Rate for Development Tidal Arrays, T-25, August 16, 0203. Retrieved from: http://uarb.novascotia.ca/fmi/iwp/cgi?-db=UARBv12&-loadframes

The Ocean Renewable Energy Group (OREG). (2012). *Business Opportunities from Marine Renewable Energy Development and Project Cycle Needs.* http://www.marinerenewables.ca/wp-content/uploads/2012/11/MREDevelopmentOpportunitiesMarch30.2012_FINAL.pdf
Westbrook S (2012) European Marine Energy Centre, Economic Impact Assessment. Report for Highlands and Islands Enterprise, May 2012.

Zhao R. Hynes S, He G et al (2014) Defining and quantifying China's ocean economy, Marine Policy 43 164-17