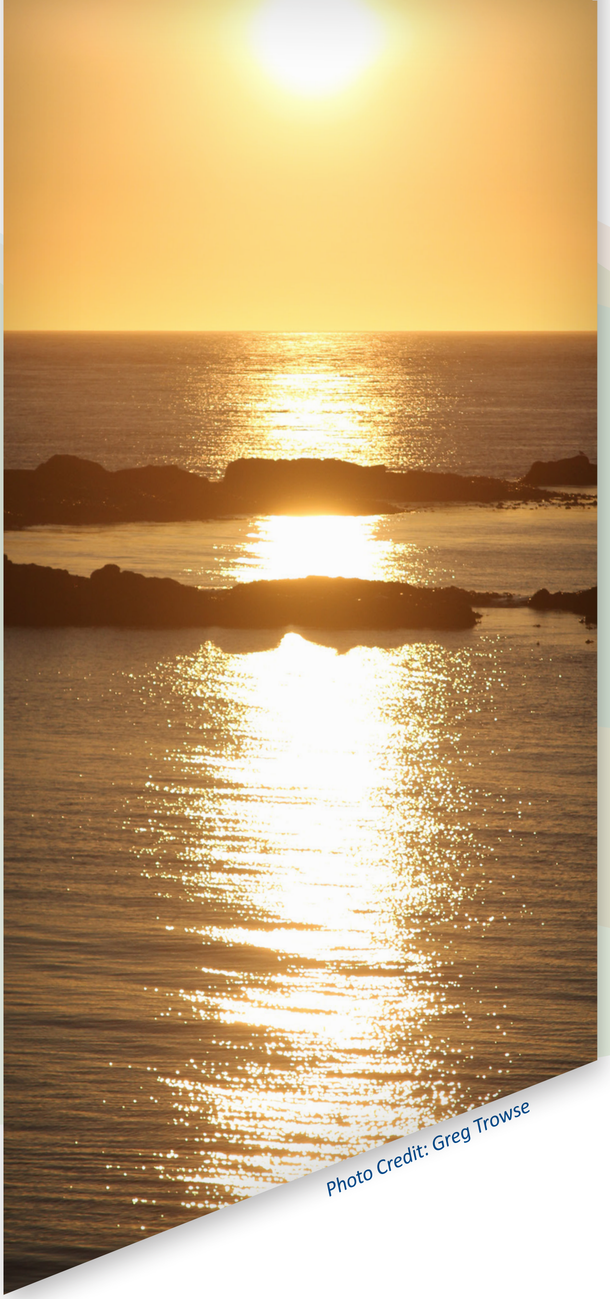


Photo Credit: Greg Trowse

1 | OVERVIEW OF TIDAL ENERGY

Concerns over climate change and the increasing costs of non-renewable fossil fuels to generate electricity have resulted in a major shift in thinking about how we can meet our future energy needs.

1 - OVERVIEW OF TIDAL ENERGY

Author: Dr. Graham Daborn

WHAT DOES THIS MODULE COVER?

This module provides an introduction to the subject of tidal power – a form of marine renewable energy that depends upon the flow of tidal waters. Here you will find a brief summary of the history of tidal power in Canada, an outline of some of the devices that are being considered for generating electricity from tidal waters, and an indication of the technical, environmental, and social issues that surround tidal power. It is intended for the general reader and will serve as a guide to the more detailed information contained within the *Community and Business Toolkit for Tidal Energy Development*.

Using the energy of the tides is a very old human activity. The power in flowing tidal waters has been used for about two thousand years: the Egyptians, Greeks, and Romans used tidally-driven water wheels to grind grain, and remains of a tidal mill dating to 620 AD have been found at a monastery in Northern Ireland. Even the famous London Bridge contained four tidal wheels that drove pumps providing water to the city in the 17th century. In Canada, Champlain built a tidal mill at Port Royal (Nova Scotia) in the early 17th century and other mills existed in New England and Passamaquoddy Bay (New Brunswick) in the 1800s. These were all mechanical mills; the energy of flowing water being used to turn wheels for grinding grain or pumping water.

1.0 - INTRODUCTION: WHY CONSIDER TIDAL ENERGY?

Concerns over climate change and the increasing costs of non-renewable fossil fuels to generate electricity have resulted in a major shift in thinking about how we can meet our future energy needs. There is no doubt that the planet is getting warmer and little doubt that the extensive use of fossil fuels (i.e. oil, coal and natural gas) is playing a role in global warming. These fuels are non-renewable and have very high value for other uses (e.g. plastics and pharmaceuticals). Consequently, major efforts are being made to shift towards greater use of renewable energy sources, particularly for the generation of electricity.

There are several renewable sources available: solar, wind (both on land and offshore), waves, tidal and river currents, and biomass. Solar power is, of course, only available during the day and must be stored, or an alternative found to provide energy needs during the night. In the far north, it may not be available for months at a time. Much effort has been put into the use of wind and wind farms are now regularly appearing over the landscape and nearby sea. The limitation of wind, apart from the relative cost, is that it is not very predictable. There are times when the wind appears to blow everywhere, so that all wind farms are operating; but at other times, when it does not blow at all, electricity generating companies have to find an alternative source. Tidal flows, however, are eminently predictable: one can forecast exactly when the tide will be running, and roughly how fast, for years in advance. It is a clean energy source in the sense that it does not contribute greenhouse gases and may be tapped in ways that do not result in flooding of land. (This is unlike traditional hydro power, where land flooding associated with hydroelectricity developments can result in increased release of greenhouse gases such as methane and carbon dioxide, so that although the generation phase may not release GHGs directly, the development is not strictly 'green').

Additional benefits that could come from tidal power include:

- Reduction of the environmental effects of energy production by other means, including fossil fuels, hydro, or nuclear power;
- Enhancing regional and national energy security by minimizing dependence on sources of fuel from other countries;
- Long term price stability;
- The ability to build generating capacity in an incremental way (unlike a dam-based system that requires the dam be completed before any electricity is generated or revenue earned); and
- The potential for building supportive industries (e.g. associated with turbine manufacture, etc.) that could develop exportable products and skills.

Many of these advantages are explored in this toolkit.

1.1 - TIDAL POWER

For the last hundred years, tidal power proposals have been aimed at generating electricity. This reflects the versatile nature of electricity as a form of energy, the importance of electrical devices in our lives, the developing expertise in hydroelectricity in the 19th and 20th centuries, and the ability to transport electricity over considerable distances. Electricity's major limitation, however, lies in the fact that, once generated, it is difficult to store in large quantities; consequently, it needs to be fed into an electrical grid, where it may displace some other energy source or be used immediately to drive machines or produce heat, etc. In some situations, excess electricity is used to pump water up into a reservoir ('pumped storage') from which it can be used to generate electricity again when needed.

Batteries provide a means of storing small quantities of electricity, but have so far not been developed to handle large amounts. There have been suggestions for storing unused electricity as compressed gas (e.g. compressed air or hydrogen), but these have yet to prove economically or environmentally feasible.

FOUNDATIONAL CONCEPT: WHAT IS A WATT?

Electrical power is commonly expressed in terms of watts (W), kilowatts (kW), megawatts (MW), or gigawatts (GW). A watt is a measure of power equal to one joule per second.

1,000 W = 1 kW;
1,000 kW = 1 MW;
1,000 MW = 1 GW.

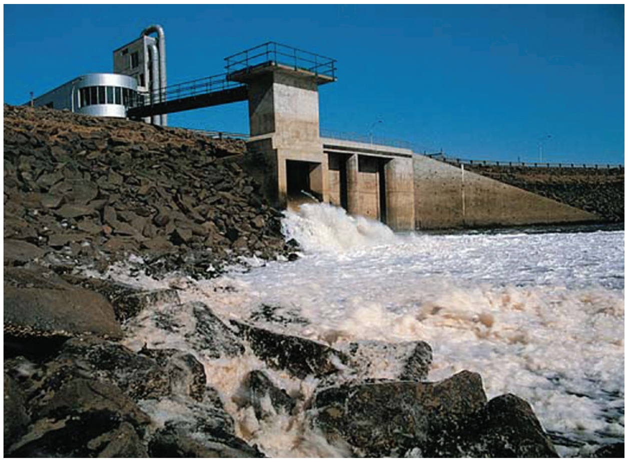
Typical power ratings for familiar electrical devices are as follows: an incandescent light bulb might be 60W; an equivalent CFL light bulb of the same light output might be 18W. A small television and your refrigerator might be rated at 60 – 160 W, the water heater in your house might be about 3,800 W (or 3.8 kW), and your electrical oven about 2,000 watts (or 2 kW).

The energy consumed depends upon the length of time that any device is working, so the important figure is a combination of the power of the device and the number of hours it is running. Power usage (which is what the electricity company charges you for) is measured in kilowatt-hours (or kWh). For example, a 60W light bulb left on for 5 days (120 hours) will consume 7,200 watt-hours, or 7.2 kWh. The average household uses about 1,500 kWh per month (and about 18,000 kWh per year), provided the house is not heated electrically; if it is, the consumption will obviously be much higher.

Proposals for generating electricity from tidal flows began in the early 20th century for the Bay of Fundy, Canada, and the Severn Estuary, Britain. Most of the proposals have resembled a dam-based hydroelectricity station: a dam was to be built across one or more tidal channels to create an impoundment (the 'headpond'), which could be filled by the rising tide. At high water, all gates would be closed, keeping the water in the head-pond. When the sea level had fallen sufficiently outside the dam, turbine gates would be opened, allowing the water to flow through and the turbines to generate electricity. Until recently, when South Korea opened a 250MW tidal power project, the largest dam-based tidal power stations were a 240 MW plant at La Rance (France) and the 18 MW plant at Annapolis Royal, Nova Scotia (Figure 1-1).

In Nova Scotia: Annapolis Tidal Generating Station.

The Annapolis TGS was opened in 1984. It has a single 'Stra-Flow'™ turbine with a rated capacity of 18 MW and generates 80-100 MWh per day. The station was installed in a pre-existing causeway built in 1960 to provide a river crossing and flood protection for agricultural land upstream. Research has included studies of fish mortality, the effects on shoreline erosion, and salt water intrusion into groundwater. Fish mortalities were found to be higher than predicted as a result of physical contact and pressure changes occurring as the fish pass through the turbine. There have been no documented effects on marine mammals, although seals and whales occasionally find their way upstream of the causeway, presumably in pursuit of fish.



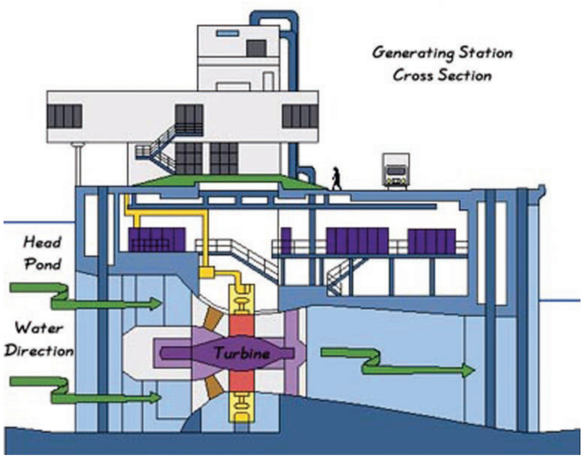


Figure 1-1: Annapolis Tidal Station, Annapolis Royal, Nova Scotia

Source: Kids Encyclopedia Britannica
http://kids.britannica.com/comptons/art-126923/The-Annapolis-Tidal-Generating-Station-in-Nova-Scotia-successfully-harnesses

Source: Library and Archives Canada
http://www.collectionscanada.gc.ca/eppp-archive/100/200/301/ic/can_digital_collections/west_nova/tidal.html

Such dam or barrage-based hydro and tidal electricity generation enables the conversion of the potential energy stored in the water held in the reservoir or headpond; however, when water is flowing, it has kinetic energy that can also be captured in the same way the kinetic energy of the wind is captured and converted by a windmill. Tidal power projects that convert the potential energy of the water are referred to as tidal range developments, whereas devices that generate electricity from free-flowing tidal water are often generically called tidal energy converter– or TEC -- devices. (See the box titled Concept: Tidal Range vs. Tidal Stream, for the distinction between tidal range and tidal stream approaches.)

1.2 - ELECTRICITY FROM WATER

About 60% of the electricity generated in Canada comes from water through numerous hydroelectricity stations, commonly called 'hydro plants' (NRCan 2011; Environment Canada). Typically, a hydroelectricity station is constructed on a river system by building a dam that holds the water back in a reservoir. In most cases, the site chosen for the dam is where the elevation of the land changes suddenly, such as at a waterfall, and the dam creates a large impoundment, often resulting in an increase in the distance through which the water will fall. The difference in water levels provides the force needed to drive the turbines (Figure 1-2).

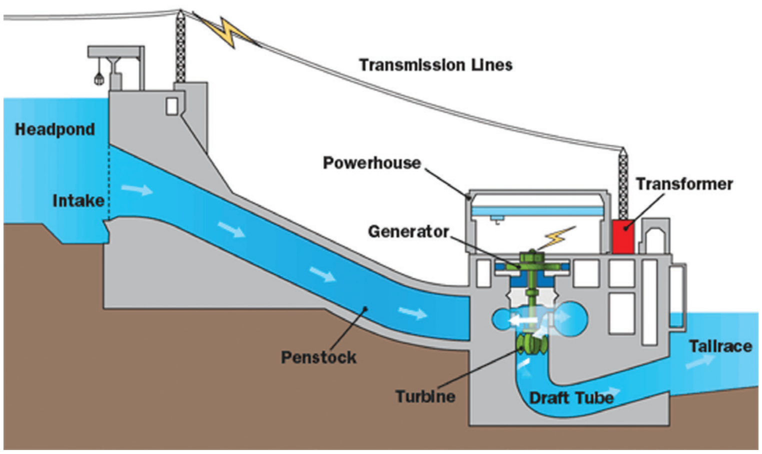


Figure 1-2: Diagram of a Hydro-electric Plant

Source: New Brunswick Power, Hydro http://www.nbpower.com/html/en/safety_learning/learning/electricity_generated/hydro/hydro.html

The amount of hydroelectricity generated depends upon the quantity of water available and – critically – on the height through which the water falls. In most cases, where the dam creates a large water reservoir, the plant can be used to generate electricity continuously and therefore supply a constant amount of electricity that can meet the continuing demand – or 'base load' – requirements.

Large hydroelectricity generating stations of this kind can provide continuous power, but smaller installations tend to be used primarily to meet peak power demands. Thousands of such dams have been created around the world since the latter part of the 19th century.

FOUNDATIONAL CONCEPT: TIDAL RANGE VS. TIDAL STREAM

Tidal range refers to the vertical difference in water level between the times of high tide and low tide. Estuaries or other coastal bays that have a large tidal range such as the Bay of Fundy in Canada, the La Rance Estuary in France, and the Severn Estuary in the United Kingdom have been considered as places to generate electricity for decades. The most common approach considered for these high tidal range locations involves building a dam or barrage across the estuary to create an area for storing water brought in by the flooding tide. Turbines located in the barrage would be turned as a result of the difference in water level between the headpond, upstream of the dam, and the falling sea level on the downstream side (i.e. converting some of the potential energy of the stored water into electricity). This can be done either just on the ebb tide (one-way generation), or on both the rising and falling tides (two-way generation). Such an approach is termed tidal range generation. Building a barrage across an estuary has a number of undesirable environmental consequences and, for this reason, is a less popular solution these days. However, creating a lagoon or shore-connected impoundment in an estuary or bay with high tidal range could provide some of the advantages of tidal range generation with some fewer environmental concerns. (See below for more on lagoons, etc.)

Tidal stream refers to the motion of flowing water. The force of flowing water can drive a turbine just as the wind does a wind turbine. There are numerous different designs for devices that will convert some of the kinetic energy of fast-flowing water into electricity. These are generally called tidal energy converters, or TECs. Further details can be found below and in Module 3 of this toolkit.

FOUNDATIONAL CONCEPT: ENVIRONMENTAL ISSUES OF BARRAGE-BASED TIDAL POWER STATIONS

Building a barrage or dam across an estuary can produce major changes to the ecosystem, with significance for other inhabitants (e.g. marine mammals, birds, fish, and their food supplies) or for other uses of the estuary (e.g. shipping, fishing, or recreation). The dam itself may limit access by migrating fish to spawning or feeding grounds in the upper estuary or the rivers that feed into it, and if they do pass through the dam, they may suffer injury or death because of contact with moving parts of the turbine or changes in pressure, etc. The dam also restricts water flows and so may modify the tidal movements on both the sea and landward sides of the barrage. Changes to intertidal zones may include a reduction in the area exposed at low tide and major changes to sediment distributions, which in turn may affect fish, birds, and other animals that live in or depend on the intertidal zone. In the case of the Bay of Fundy, some of the larger barrage proposals considered in the 1970s would have modified the tidal range throughout the Bay and the Gulf of Maine, with significant changes that could affect fisheries and shoreline properties.

1.2.1 - CURRENT APPROACHES TO TIDAL ENERGY

The present considerations for tidal electricity generation are primarily based upon new designs for tidal energy converters that convert the kinetic energy of the flowing water. TEC devices have a long history at the concept level, including in Canada. Clarkson, in 1915, developed a mechanical pump driven by tidal flows that could pump seawater up to a considerable height, from where it could be used to drive a conventional turbine, and the National Research Council assisted in the development of the Davis vertical axis turbine (based on the Savonius rotor) more than 30 years ago. Most of the more mature TEC technologies are either horizontal or vertical axis designs (Figures 1-3 and 1-4). Converting the kinetic energy of flowing tidal water using TEC devices is the major focus of tidal power investigations in Canada, Europe, and the U.S.A. at the present time and the subject of this toolkit.

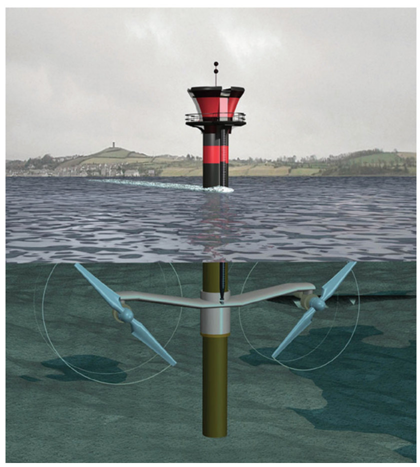


Figure 1-3: Horizontal Axis Turbine - Marine Current Turbines -SeaGen

Source: SeaGen turbine: http://www.alternative-energy-news.info/seagen-tidal-power-installation/

Figure 1-4: Vertical Axis Turbine, New Energy Corporation

Source: New Energy Corporation, http://newenergycorp.ca/Default.aspx

1.3 - WHY TIDAL POWER?

The tide, like the wind, is a renewable energy source that does not consume any fossil fuels (after construction, at least) and generates neither greenhouse gases nor waste heat. Unlike the wind, however, the flow of the tides is very predictable. It is possible to forecast the state of the tide and the velocity of the water reasonably accurately for any given place and time, years into the future. This predictability makes it easier to integrate tidal energy into an existing electrical grid system than other intermittent renewable resources such as wind, wave, or solar power. Around Canada and some other parts of the world, there are many locations where strong currents occur as a result of tidal movements. Where these sites are close to cities or towns or near major industrial users of electricity, the predictability of tidal power generation is very appealing. Thus, in addition to the advantages of reducing fossil fuel use for energy production, there may be considerable economic and social benefits from developing tidal power such as: providing a local supply of electricity, rather than transmitting from a distant power plant; providing local employment in the construction and/or maintenance of the devices; or encouraging new industrial development. Many of these aspects are detailed in Modules 8 and 9 of this Toolkit.

1.4 - HOW TIDAL ENERGY CONVERTERS (TECS) WORK.

Tidal energy converters extract some of the kinetic energy of fast-flowing tidal waters. At present, more than 40 different devices are in varying stages of development, but most are still in prototype or demonstration phases. These devices vary significantly in orientation, material construction, efficiency, scale, and power output. In addition, anchoring and deployment details will be highly variable, depending upon substrate and current conditions on site (PCCI, 2009). The present concepts may be classified into several general but occasionally overlapping categories: vertical axis (or axial flow), horizontal axis (or cross-axis), rim generators, venturi devices, paddlewheels and fanbelts, and fluttervanes. A review of some 40 devices was prepared for Natural Resources Canada (NRCan 2011). The more mature technologies, particularly those that are being considered for deployment in Canada, are discussed in more detail below.

Water is more than 800 times denser than air. As a result, moving water contains much more energy than does wind: for example, water flowing at ten knots contains as much energy per unit area (e.g. per square metre) as a hurricane force wind. A TEC device, therefore, can be much smaller than a wind turbine that generates the same amount of power.

1.4.1 - VERTICAL AXIS

Vertical axis TEC devices rotate around a vertical axis, with a gearbox and generator that may be above or below the water level; such devices are relatively independent of changes in the direction of current flow (see Figure 1-4, above), and for that reason are suitable for locations in which the direction of the current changes over time. These devices tend to have rather lower energy conversion efficiencies than do other designs and may also have difficulty starting to rotate again once they have stopped. At the present time, vertical axis devices tend to be of small power yield: in the 50 to 250 kW range. A Canadian company, New Energy Corporation, has tested a 5kW version of its EnCurrent™ device in the outer Bay of Fundy and is working towards testing of devices up to 250kW.

FOUNDATIONAL CONCEPT: 'RUN-OF-RIVER'

Where large river flows combined with a steep river slope are naturally sufficient to run a hydro plant without a large storage reservoir, the development is termed a 'run-of-river' hydro plant (e.g. many places in British Columbia). Since there is no large storage, output from such an installation will vary according to the seasonal changes in river flow. Such 'run-of-river' stations can generally only be used for peaking power, not base-load power.

Thus, in addition to the advantages of reducing fossil fuel use for energy production, there may be considerable economic and social benefits from developing tidal power such as: providing a local supply of electricity, rather than transmitting from a distant power plant; providing local employment in the construction and/or maintenance of the devices; or encouraging new industrial development.

FOUNDATIONAL CONCEPT: WHAT IS A KNOT?

1 knot (1 kt) is a measure of speed: 1 nautical mile per hour.

1 kt = 1.8 km per hour or approximately 0.51 metres per second.

1.4.2 - HORIZONTAL AXIS

Horizontal axis devices (see Figure 1-3, above) include designs with propeller-like blades rotating around a central hub that usually contains the gearbox and generator coils; reorientation of these devices to a variable current direction may be required and designs for self-adjustment of orientation constitute a significant feature of their development. Horizontal axis designs can be scaled up to yield relatively large amounts of power, in the range of 1-2 MW, but there is some opinion that, unlike wind turbines, this will be about the largest scale feasible for tidal stream devices.

A few horizontal axis devices (e.g. Figure 1-5) have dispensed with the gearbox found in wind turbines and some propeller-like tidal turbines in favour of generating electricity in the shroud surrounding the rotating blades. This 'rim generator' design has allowed for the elimination of the bulky central core and for symmetrical aspects that enable the device to operate in two directions without realignment. These may be most applicable in rivers or in reversing-stream tidal situations (where ebb and flood directions differ by 180º); otherwise, they will require arrangements for passive or active re-orientation. Several horizontal axis designs have a bell-shaped entrance (a 'duct' or 'shroud') that serves to accelerate the flow of water through the generator, yielding higher efficiencies and more power.

Figure 1-5: Rim Generation Tidal Device, Clean Current

Source: Recharge News, North America http://images.businessweek.com/ss/09/07/0714_sustainable_planet/7.htm

1.4.3 - TIDAL LAGOONS AND SHORE-ATTACHED IMPOUNDMENTS

Although tidal range energy conversion (see notes above) has been less popular in recent decades, some companies are considering the use of artificial tidal lagoons in coastal areas to create a head of water that can be used to drive conventional low-head hydro turbines. The lagoon (see Figure 1-6) consists of an impoundment created from relatively inexpensive material (e.g. a rubble mound) located in shallow waters of an estuary or bay that has a large tidal range. The enclosing dyke contains a turbine generating station with bulb turbines that can operate in both directions and thus extend the generation time over most of the tidal cycle. By dividing up the inside of the lagoon into separate sections and operating the different sections as high and low basins, it is theoretically possible to provide continuous electrical output from the facility.

An alternative approach is to create an impoundment using part of the natural shoreline rather than completely surrounding a region of the ocean with a dyke, as in the case of a lagoon. These shore-based impoundments (Figure 1-7) would operate in a similar manner to the lagoon. Analogous in some ways to a barrage, especially in the fact that the scheme converts the potential energy of the contained water into electricity, the lagoon and shore-attached concepts differ in that the impoundment does not totally cut off the estuary from the sea, allowing water and marine life to move past the structure. However, in order to capture sufficient water, the impoundments have to enclose a relatively large area and within this area, there will be significant habitat changes. Three projects have been proposed for tidal lagoons of varying sizes for installation in Wales: Swansea Bay (30 MW), Fifoots Point (30 MW), and North Wales (432 MW); other proposals exist for the Canada, Korea, and China. None have yet been built. Further information can be obtained from http://tidalelectric.com/.

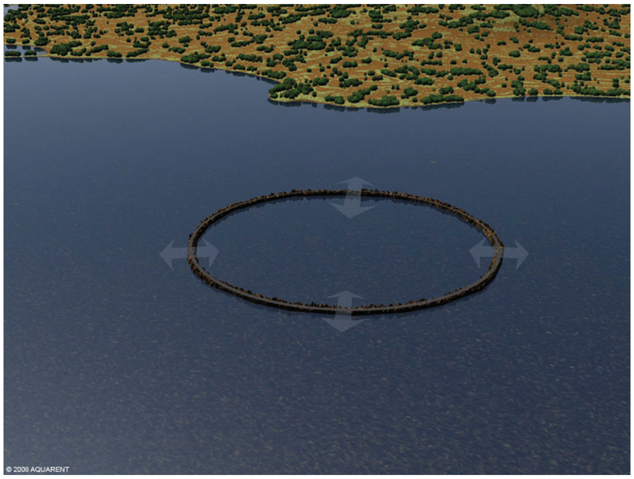


Figure 1-6: Diagram of a Tidal Lagoon.

Source: http://www.wisions.net/index.php?item=6&modus=technology&need_id=3&subneed_id=&start_tech=136&technology_id=77l

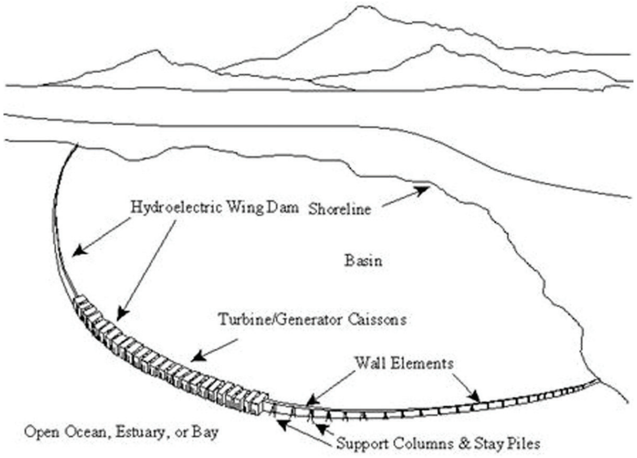


Figure 1-7: Diagram of a Shore-attached Tidal Impoundment.

Courtesy: Halcyon Inc.

Natural Resources Canada identified more than 190 sites on the three ocean coasts of Canada (see Figure 1-9) as having potential to generate more than 1 MW of power from tidal currents.

1.5 - TIDAL POWER OPPORTUNITIES IN CANADA

Natural Resources Canada identified more than 190 sites on the three ocean coasts of Canada (see Figure 1-9) as having potential to generate more than 1 MW of power from tidal currents (NRCan 2006). The total tidal energy available in the country was estimated at more than 42,000 MW. Most of the resource is found in Nunavut, particularly in the vicinity of Hudson Strait and Foxe Channel, and thus relatively remote from major areas of electricity demand. However, TEC devices could be used effectively to provide consistent, predictable, renewable energy suitable for support of local communities that are presently dependent on imported fossil fuel. Most other sites having more than 1 MW potential were found in British Columbia, whereas on the Atlantic coast, a few sites with high potential were identified in the Bay of Fundy and Cape Breton.

In Nova Scotia, there are a number of locations where electricity could be obtained from tidal waters, either using tidal range or tidal stream approaches. If one were to accept the consequences of building barrages, lagoons, or other tidal range structures, it would be possible to generate several gigawatts of power—far more than the current total energy demand in Nova Scotia, which is about 2200 MW (or about 2.2 GW). With tidal stream approaches, however, the potential is much lower because TEC devices can capture only a smaller portion (up to 30%) of the kinetic energy in the water. An early study in 2006 suggested that about 1,000 MW could be generated by arrays of TEC devices in the various portions of the Bay of Fundy (Bedard et al. 2006). More recent work, outlined in Module 2 of this toolkit, suggests that this may be a considerable underestimate. Many of the narrow passages in the Bay of Fundy or around the Bras D'Or lakes in Cape Breton have the potential for producing only a few MW.

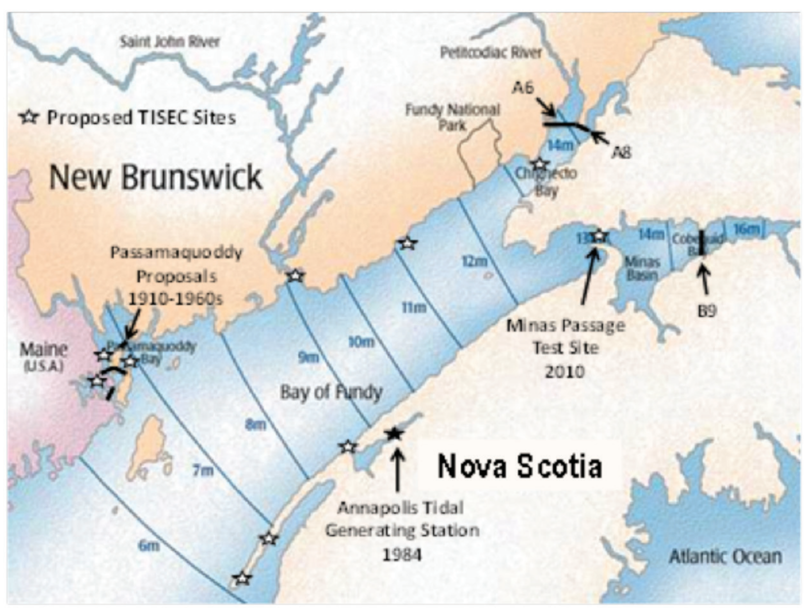


Figure 1-8: Locations of Proposed and Current Tidal Power Developments in the Bay of Fundy, 1910-2010.

Sites A6, A8, and B9 were sites considered for barrage-style tidal power developments in the 1970s. Lines drawn across the Bay of Fundy represent the approximate maximum tidal range (m).

Source: Base map: www.thehopewellrocks.ca

Canada Potential Tidal Current Resource Sites

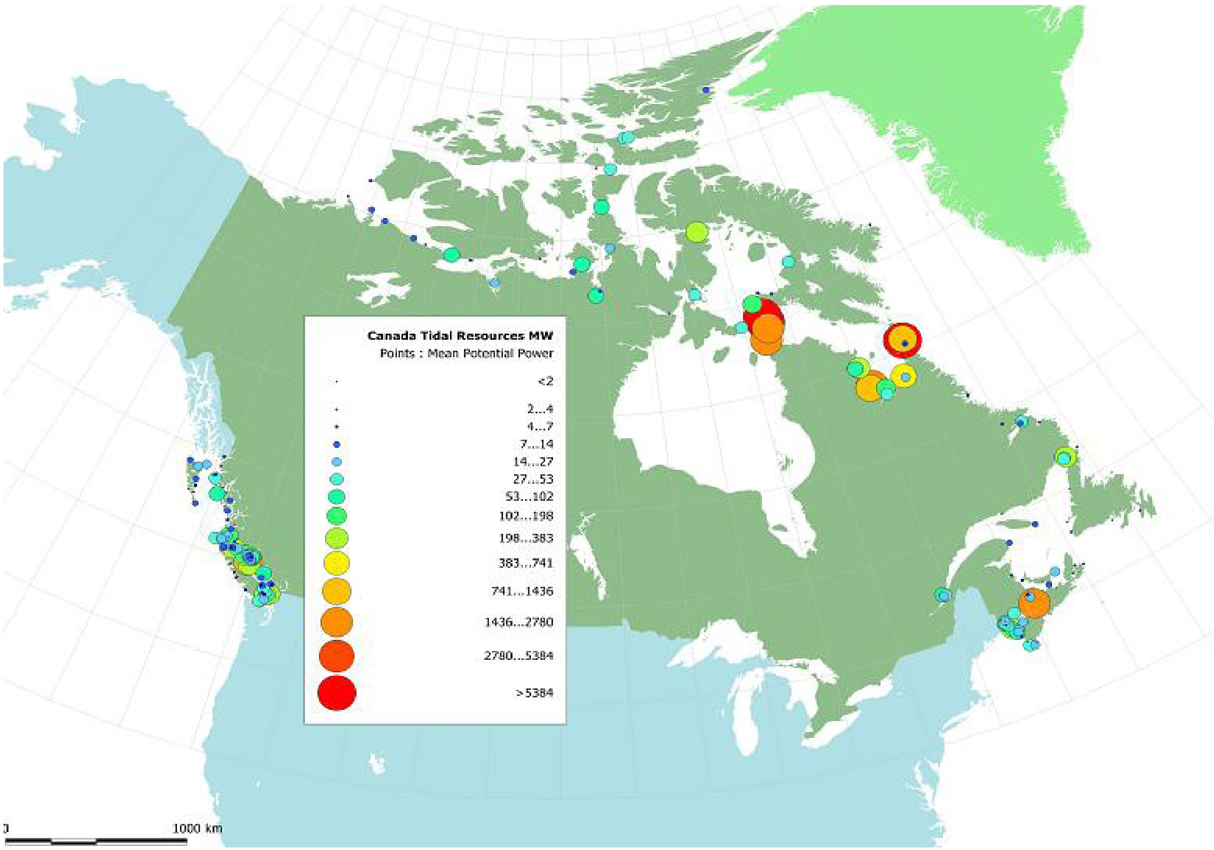


Figure 1-9: Canadian Tidal Energy Resources in MW

Source: NRCan (2006). Canada Potential Tidal Current Sites [Map], Canadian Hydraulics Centre - National Research Council Canada

1.5.1 - GENERATING ELECTRICITY FROM THE TIDES USING TIDAL ENERGY CONVERTERS (TEC) DEVICES

In-stream tidal technologies are diverse, with many design concepts still evolving. Few of these have reached the stage of testing at full commercial size. As a result, sufficient information to assess the environmental risks of TEC developments is currently lacking for the following reasons:

- Few full-size devices have been deployed in natural environments for prolonged periods of time;
- Environmental effects are likely to be technology-, site-, and scale-specific;
- The most favoured locations for deployment exhibit challenging physical conditions – consequently, effective physical and biological data collection and effects monitoring are difficult and sometimes limited by the availability of suitable monitoring technology;
- Absence of monitoring results to confirm predictions of environmental assessments; and
- Many of the sites with highest potential for marine renewable energy are insufficiently studied for the environmental implications to be assessed with confidence.

1.5.2 - SITE CONSIDERATIONS

Sites suitable for tidal in-stream generation must have high tidal flows, both in terms of the speed of the water and the amount of water passing through that location. The power potential of any site is a combination of water velocity and volume, so that wide, deep channels with high flows could be tapped to generate large amounts of electricity. This advantage, however, is counter-balanced by some significant limitations: the forces that the device must withstand and the potential environmental effects that might be associated with converting the energy of the flowing water into electricity.

Most of the horizontal axis turbines are designed to begin electrical generation when the flow reaches 2-3 knots (1 to 1.5 metres per second). The maximum water velocity at which they will continue to operate is very variable, but many of the most advanced designs are controlled to yield a consistent amount of electricity at any velocity above a chosen level. The forces exerted on the turbine increase dramatically as speed increases. If the speed of the water doubles, the forces involved increase by 4 times and the power by about 8 times (see Figure 1-10). Consequently, very high velocities such as those in the Bay of Fundy (up to 10 or 11 knots, or more than 5 m/second), represent extremely powerful locations and demand that the tidal generators be very well constructed.

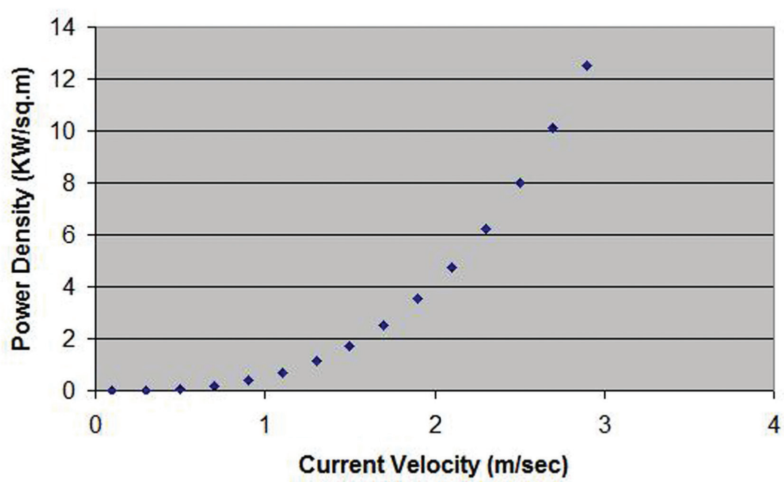


Figure 1-10: Relationship Between Power and Water Velocity.

Much of the attention at the present time is focused on sites like the Minas Passage in the Bay of Fundy, which could support large amounts of electricity generation from arrays of multiple turbines. Such developments would be aimed at feeding electricity into the grid to displace the use of fossil fuels. There are many other sites, however, that would be suitable for one or a few turbines only, providing energy for a more local demand. Obviously, the implications of these different sites and development scales vary. For more information on site and scale relationships see Module 5 of this toolkit.

1.5.3 - ADVANTAGES OF TIDAL POWER

The obvious advantage of tidal power is that it is a renewable resource with no continuing fuel costs and is not associated with emissions of greenhouse gases. Like wind energy, tidal energy is variable over time, but unlike wind, it is eminently predictable. The tides and their movements are well known (see box below); they result from the gravitational attraction of the Moon and the Sun, and we can therefore forecast when the tides will flow with reasonable accuracy for years ahead. Even though predictable, the intermittent nature of tidal stream generation presents a challenge, whether the electricity is fed into the grid where it can displace other forms of energy, or is to be used locally.

FOUNDATIONAL CONCEPT: TIDAL CYCLES

Tides are caused primarily by the gravitational attractions of the Moon and Sun on the Earth and its waters. The Moon is much closer to Earth, and therefore its influence on the tides is about twice as great as that of the Sun.

Most suitable locations in Canada have semi-diurnal tides, which means that there are approximately 2 tides each day; a few locations sometimes have one strong tide plus a much smaller second tide each day as a result of local conditions. The time between one high tide and the next is about 12.4 hours. Because the Moon orbits the Earth in the same direction as the Earth spins, two successive tides actually take 24 hours and 50 minutes, so that the time of a particular high tide on one day is about 50 minutes later than the corresponding tide the day before. When the tide reverses at high water and low water, there is a brief period in which the water is not flowing at all, or is flowing too slowly to drive a turbine. These 'slack water' periods vary in length, being as short as 20-30 minutes (as in the Bay of Fundy) or as long as an hour, and no electricity can be developed from tidal stream devices over this period. Consequently, TEC generators can produce power for perhaps 10 or 11 hours in each 12.4 hour period, and the time of this generation will become later each day by just under one hour.

In addition to the twice-daily rise and fall of the tide, there are longer cycles in which the range of the tide (i.e. the vertical difference in water level at high tide and at low tide) varies over days, months, and years. Some of these variations are related to the interaction between the Moon and Sun; at times they are pulling on the Earth and its waters in more or less the same direction causing larger, so-called spring tides, whereas the next week, their gravitational effects tend in different directions, resulting in smaller tides (known as neap tides). Also, the distance between the Moon and the Earth changes during each month because the Moon goes around the Earth in an ellipse, rather than a circle. As a result, twice each month the Moon is closer to the Earth (the lunar perigee), causing greater tides, and twice each month it is further away (the lunar apogee), resulting in smaller tides. Similarly, the Earth travels around the Sun in an ellipse, so that at two times each year it is relatively close and at other times further away. All of these variations produce changes in the speed with which tidal waters move and therefore will tend to affect the amount of energy that can be captured. However, all of these changes are predictable.

What is not so predictable, however, are the additional effects resulting from wind and river flows, which may increase or decrease the water flows at any given location. In regions with naturally large tides, these are usually relatively minor effects, except during storm conditions.

1.6 - ENVIRONMENTAL ASPECTS OF TIDAL POWER

One hundred years of consideration of tidal power energy as a source of electricity has taught us a great deal about the natural environmental features of these strong tidal areas. The environmental implications vary considerably depending upon the characteristics of the locality chosen for development, whether the approach is based on tidal range or tidal in-stream designs, and the scale of the development. More details on the site and scale issues can be found in Module 5 of this Toolkit. This section will briefly summarize the major issues.

1.6.1 - ENVIRONMENT-RELATED ISSUES OF TEC DEVELOPMENTS

The major environmental questions raised by TEC proposals are as follows:

- What will be the effects of removing energy from tidal waters on the flow and tidal characteristics (e.g. current velocity, timing, turbulence, mixing, temperature distributions, sediment loads), both near to the site of development and further away?
- What are the effects of electromagnetic fields produced by the generators and the cables carrying electrical currents on the organisms in the vicinity?
- What might be the effects of floating debris or ice on the infrastructure?
- What are the risks of corrosion or abrasion to the infrastructure?
- What is the potential for organisms to grow on and interfere with the operation of the TEC device infrastructure? This is referred to as biofouling.
- What risks are posed by the infrastructure for animals (e.g. entrainment, avoidance, and attraction)? Principal concerns relate to marine mammals, turtles, fish, and marine birds.
- What indirect effects might there be on organisms resulting from changes in current flow patterns and timing, turbulence, mixing, sediment transportation and deposition, and habitat changes?
- What will be the effects on marine organisms and habitat as a result of construction, installation, and decommissioning of the infrastructure?

Determining the feasibility of any given location for tidal power development requires an extensive background investigation of the conditions at the site. Surveys of local bottom conditions, flow rates, habitat properties, and the use of the area by organisms will often require investigations that may be both costly and time consuming. Knowing the nature of the substrate is critical for design of the structures that would be used to support the turbines, and the presence of sediments or debris being carried by the water will affect decisions about the materials to be used in construction of the devices. Many coastal sites are used by mammals and fish during feeding or spawning migrations, and thus these animals may only be present for limited periods of time during the year. Methods for conducting such surveys are changing continuously as technologies improve. In order to forecast the risks to such animals, biological surveys may take more than a year to complete. It is, consequently, a feature of good practice to initiate such background studies as early as possible.

Critical information about current flows is obtained from bottom-mounted acoustic devices that record the velocity of the water at different depths at very fine time intervals. Combined with computer-based numerical models, these records provide the detailed information a developer needs to estimate the potential power production at the site. Because tidal movements change over time (e.g. the spring-neap cycle and seasonal variations associated with the distances between the Earth, Moon, and Sun), measurements of current flows need to be made over periods of weeks or months. Fine scale surveys of bottom conditions can now be carried out using acoustic, video, and other imaging devices deployed from boats in place of the traditional sampling techniques using grabs or surveys by divers, but although these new technologies provide an unprecedented level of information, they require extensive analysis and are often quite costly. Monitoring of animal movements, especially fish and mammals, remains a challenge because the high rates of flow and extreme turbulence of TEC sites limits the effectiveness of existing video or acoustic technologies. At present, many studies have to depend upon active acoustic tagging techniques in which fish are fitted with acoustic devices that emit an identification signal that can be picked up if the fish is close enough to a recording device. Some mammals, such as porpoises and dolphins, emit their own sounds that can be picked up by similar receivers and can often provide identification of the species, but such passive techniques have not yet been developed for many of the larger whales. All of this information, however, is necessary in order to assess the risk of a tidal power development to these valued species.

In addition to the generators themselves, installing TEC devices in high flow areas requires a substantial and varied amount of other infrastructure. This infrastructure includes cables for transmitting the electricity to shore; support structures for the turbines, such as massive gravity bases, pilings, pins, or cables; anchors for monitoring or other equipment, including navigation aids; and various subsurface or surface floating devices. These are described in Module 3 of this toolkit. Depending upon the local site conditions and the choice and number of TEC device(s), all this equipment may be below the surface, essentially out of sight, or some may remain at the surface. Land-based infrastructure will include facilities for landfall of the electrical cable, transformer and transmission lines, and staging and repair areas. These structures need not be near the installation site for the device; however, shorter distances are preferable from a project planning perspective.

All of these structures and facilities have important environmental and socio-economic implications. A summary listing of the issues is included here.

1.6.2 - EFFECTS ON OTHER MARINE RESOURCES

The coastal marine environments where TEC development might take place are often important for other established resource-based industries such as fisheries, aquaculture, mining (including some fossil fuels), and recreation. Whether these activities are compatible with tidal power development will depend upon local conditions at the site(s) and the scale of the development. In particular, exclusion zones created to protect energy developments from accidental interference may represent important limitations for local fisheries, transportation, or recreation. These topics are normally addressed in environmental assessments that would have to be prepared for larger projects, but might be omitted for smaller ones.

IN NOVA SCOTIA: BAY OF FUNDY STRATEGIC ENVIRONMENTAL ASSESSMENT (SEA).

A Strategic Environmental Assessment is a systematic process for evaluating the environmental consequences of a proposed policy, programme, or development so that environmental implications can be incorporated into strategic planning and decision-making.

The Bay of Fundy SEA began in 2007 and was completed in 2008 by the Offshore Energy Environmental Research Association, a not-for-profit corporation dedicated to fostering offshore energy and environmental research and development, including examination of renewable energy resources and their interaction with the marine environment.

“The objective of the SEA [was] to assess social, economic and environmental effects and factors associated with potential development of renewable energy resources in the Bay of Fundy with an emphasis on in-stream tidal. The SEA will inform decisions on whether, when and under what conditions to allow pilot and commercial projects into the water in the Bay of Fundy and under what conditions renewable energy developments are in the public interest over the long term.”

Source: Fundy Tidal Energy Strategic Environmental Assessment: Final Report, (2008) prepared by the OEER Association for the Nova Scotia Department of Energy. http://www.offshoreenergyresearch.ca/LinkClick.aspx?fileticket=DwM56WU51T0%3d&tabid=312&mid=992

A secondary benefit of the Fundy SEA was the opportunity to increase public awareness of the potential and issues relating to TEC development in the Bay of Fundy region, and to enable public input into decision- and policy-making. To that end, several public consultations were held and a representative stakeholder group engaged to review public input and the SEA Report and Recommendations. The Fundy SEA is being reviewed, as planned, in 2013.

Large scale development of electricity using tidal in-stream devices (or lagoons) will have important and varied economic implications associated with the materials needed, the availability of skilled labour for construction and maintenance, and financing.

1.6.3 - SUPPLY-RELATED ISSUES OF TEC DEVELOPMENTS

Large scale development of electricity using tidal in-stream devices (or lagoons) will have important and varied economic implications associated with the materials needed, the availability of skilled labour for construction and maintenance, and financing. The requirements of the early construction phase of a TEC development, in terms of material or personnel, are similar to many other marine construction activities, including harbour construction, off-shore platforms (e.g. for oil and gas development), and offshore wind farms. TEC devices can be installed in a variety of ways: suspended from floating structures, attached to pilings drilled into the seabed, sitting on gravity bases on the seabed, or suspended from cables anchored to the bottom, for example. These installation options are discussed in Module 3 of the toolkit. Once the devices are installed, however, maintenance operations may require availability of several different forms of skilled labour, including a great variety of technology specialists, boat and heavy equipment operators, and even divers (where suitable conditions exist). The supply chain issues and opportunities for local businesses and labour force are explored in depth in Module 9 of the toolkit.

1.7 - FINAL WORDS

In order for tidal power development to become successful, it must be able to generate electricity reliably for a prolonged period of time – generally many years -- under difficult environmental conditions. Estimating the ongoing operational or maintenance costs is difficult at this early stage of the industry, when few devices have been successfully deployed for long periods of time. Nonetheless, it is critical that confidence can be had in the durability and operating properties of the equipment. In this context, it is also important to recognise that tidal ecosystems, no matter how stable or constant they may seem, do themselves change continuously over time as a result of natural events (e.g. storms, shoreline erosion, sea level rise, etc.), and as a result of human intervention (e.g. dredging and harbour construction, bridge and causeway construction, effects of climate change, etc.). These kinds of long-term and large-scale changes require that the assessment of any site for tidal power development needs to be comprehensive and extensive in both space and time.

It is hoped that this toolkit will enable you to understand the issues, to find answers, and to become engaged in the decisions regarding tidal energy.

REFERENCES

Bedard, R., Previsic, M., Polagye, B., Hagerman, G., & Cassavant, A. (2006). North American Tidal In Stream Energy Conversion Technology Feasibility Study. Electrical Power Research Institute. 9 pp. Retrieved from http://oceanenergy.epri.com/attachments/streamenergy/reports/008_Summary_Tidal_Report_06-10-06.pdf

Garrett, C., & Cummins, P. (2008). Limits to tidal current power. Renewable Energy, 33(11), 2485-2490.

Isaacman, L., Daborn, G. R., & Redden, A.M. (2012). A framework for environmental risk assessment and decision-making for tidal energy development in Canada. Report to Fisheries and Oceans Canada. 48 pp.

Khan, M.J., Bhuyan, G., Iqbal, M. T., & Qualcoe, J. E. (2009). Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review. Applied Energy, 86(10), 1823-1835.

NRCan. (2006). Inventory of Canada's marine energy resources. Canadian Hydraulics Centre - National Research Council Canada (Technical Report-04). Retrieved from http://canmetenergy.nrcan.gc.ca/renewables/marine-energy/publications/2888

NRCan. (2011). Sector profile: An assessment of the marine renewable energy sector in Canada—now and in the future. 27pp. Retrieved from http://canmetenergy.nrcan.gc.ca/renewables/marine-energy/publications/2979

PCCI. (2009). Wave and current energy generating devices: Criteria and standards. Report of Minerals and Management Service, Virginia, USA. 138 pp. Retrieved from http://www.oregonwave.org/wp-content/uploads/Wave-and-Current-Energy-Generating-Devices-MMS-2009.pdf