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ALTERNATIVE ENERGY

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Alternative Energy Technologies for BC

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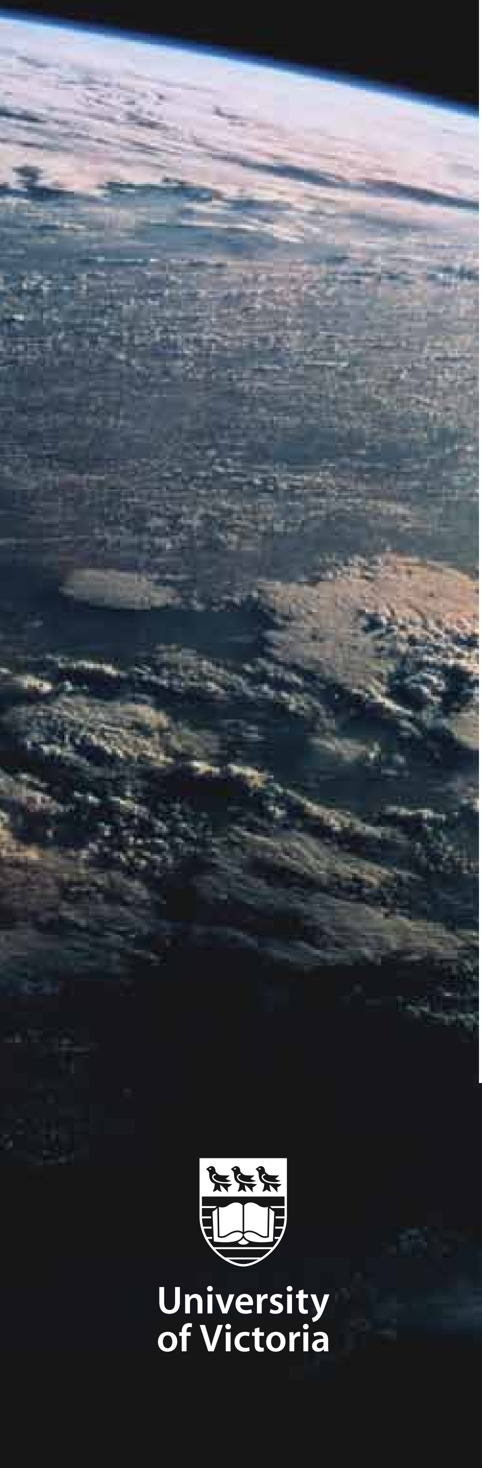

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EXECUTIVE SUMMARY

British Columbia is well-positioned to be a world leader in developing and showcasing alternative and sustainable energy technologies. This would usher in a new “Electricity Economy”, in which electricity is widely substituted for fossil fuels. With a large installed hydroelectric energy base, the province has substantial additional renewable energy resources, including both large-scale and small-scale hydroelectric power, as well as significant potential for wind, geothermal and marine energy. These new renewable electricity resources would be used to power plug-in hybrid electric vehicles and an expanded trolley bus network in the transportation sector, as well as both air-source and ground-source heat pumps for space heating applications. This fuel-switching from fossil fuels to electricity as the energy carrier of choice would necessarily require a large expansion of the electricity generation, transmission and distribution infrastructure. The most cost-effective addition to renewable electricity generation capacity would likely be the Site C project on the Peace River, which could be followed over the longer-term by other large-scale hydro projects after updating environmental and economic feasibility studies. In the near-term, an expansion of small-scale hydroelectric projects and wind power projects developed by Independent Power Producers could be expedited by BC Hydro. An expanded and strengthened electricity transmission and distribution system will also be needed to accommodate the increased demand for electricity resulting from the new electricity economy.

INTRODUCTION

There is general agreement that energy use, particularly the combustion of fossil fuels, is a major source of greenhouse gas emissions. The government of BC has recently announced aggressive targets for reduction of greenhouse gases to 33% below 2007 levels by 2020 (estimated to be 10% below 1990 levels) and to 80% below 2007 levels by 2050. Fossil fuels, including coal, oil and natural gas, are the predominant primary energy sources in most developed countries, and account for some 80% of total energy use in most jurisdictions. In British Columbia, however, we are fortunate in that we generate most of our electricity using hydroelectric power, which reduces our reliance on fossil fuels to some 64% of total energy consumption, as can be seen in Figure 1, taken from the NRCan report “Canada’s Energy Outlook – 2006” [1].

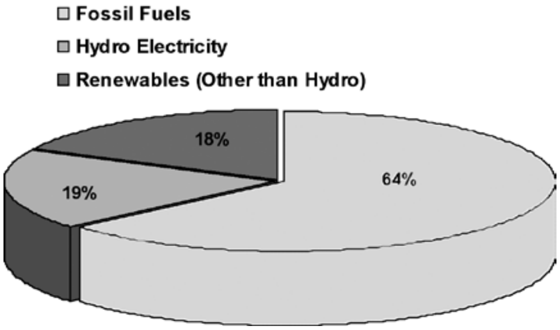

Figure 1 **BC Primary Energy Consumption – 2004** *Source: NRCan*

Nevertheless, in order to meet the stringent greenhouse gas targets, the province will have to significantly increase the efficiency with which we currently use energy, and employ alternative energy technologies to reduce our reliance on conventional fossil fuels even further. Two questions then naturally arise: which alternative energy technologies should be employed in BC, and what will be the cost of utilizing these to reduce fossil fuel use? In this paper we will discuss a range of alternative primary energy sources and alternative energy carriers which may be used to help reach our ambitious greenhouse gas targets.

THE ENERGY CONVERSION CHAIN

In order to understand simply how energy is used, and how this use may be made more sustainable, it is instructive to examine the complete energy conversion chain [2], as shown in Figure 2. The chain starts with the three 'primary' energy sources: fossil fuels, renewable energy, and nuclear power, and ends with end-use applications such as commercial and residential building heating, transportation, and industrial processes. Taking this broad view, our need for energy, which can always be placed broadly into one of the four end-use sectors shown on the far right in Figure 2, anchors the 'downstream' end of the conversion chain. This energy need is always supplied, ultimately, from just three primary sources of energy: fossil fuels, nuclear energy or renewable energy, as shown on the far left-hand side of the diagram. In between the primary source and the ultimate end-use are a number of steps in which the primary source is converted into other forms of energy, or is stored for use at a later time.

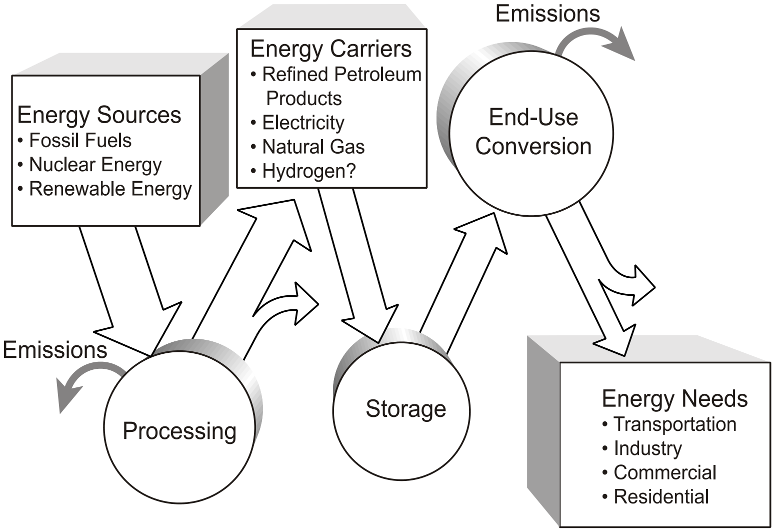

Figure 2 **The Complete Energy Conversion Chain**

To take a familiar example, to power motor vehicles we use a fossil fuel, crude oil, as the primary energy source. Before this source provides the motive power we need, however, the crude oil is first 'processed' by being converted into gasoline or diesel fuel in an oil refinery, as shown in the second step in Figure 2. The result of this processing step is the production of a secondary form of energy, or an energy 'carrier'. Also, in this step, there is usually some loss of energy availability due to inefficiencies in the processing step, as indicated by the branched arrow joining the processing block to the energy carrier block. There are only 3 energy carriers commonly in use: refined petroleum products, natural gas, and electricity. Hydrogen is a potential energy carrier, but is not currently used to any significant extent. Once the primary source has been converted into the carrier of choice, it is usually stored, ready for later use in the final energy conversion step. For the transportation example, this final end-use conversion step is where the chemical energy stored in the gasoline or diesel fuel is converted into mechanical work by the engine to drive the vehicle. In this step there are usually large losses of energy availability, due to the inherent inefficiencies of the end-use conversion step, again indicated by the branched arrow from the final end-use conversion step. For an automobile engine for example, these energy losses may be in the order of two-thirds of the energy in the fuel. In some cases, not all steps in the conversion chain are required, but energy end-use can always be traced back to a primary energy source. For example, in most cases when electricity is the energy carrier it is used immediately upon production, due at least in part to the difficulty of storing electricity. One important lesson to be taken from Figure 2 is that there are only three primary sources of energy, and just three energy carriers in common use. In the remainder of this paper, we will examine the potential for reducing fossil fuel consumption by switching to alternative energy carriers and by expanding the use of primary non-fossil energy sources to reduce the production of greenhouse gases.

Alternative Energy Carriers for Transportation

As we can see from Figure 2, the only energy carriers used today are fossil fuel based, in the form of refined petroleum products and natural gas, and electricity. Switching to alternative energy carriers may make the complete energy conversion chain more efficient, or enable a switch from a fossil fuel primary energy source to renewable or nuclear energy. The transportation sector accounts for some 30% of total fossil fuel consumption globally, and is a major contributor to greenhouse gas emissions. The impact of transportation is even higher in BC, however, since we use very little fossil fuel to generate electricity, and nearly 40% of all GHG's produced in BC are from transportation sources [3]. The overall energy efficiency from primary source to end-use is very low for motor vehicles using conventional internal combustion engines, with only about 20% of the initial primary energy being actually used to drive the wheels. This makes switching to a non-fossil fuel based energy carrier an important goal for this sector. Both electricity and hydrogen have been proposed as alternative transportation energy carriers, and we will examine both of these alternatives in more detail.

Electricity as an Energy Carrier for Transportation

While electricity is an important energy carrier in the transportation sector for rapid transit and electrified railways, it has not been widely used for cars and trucks since the earliest days of the automobile. Its widespread use as an energy carrier for motor vehicles would be novel and could have a significant advantage, both from the perspective of energy efficiency and greenhouse gas emissions. Engineers have long recognized the benefits that electricity could have as a transportation energy carrier, with the ability to provide much higher drive-train efficiency without any exhaust emissions. The major problem, however, has been the very real difficulty of storing sufficient electrical energy on-board a motor vehicle to provide a reasonable vehicle range. This can be clearly seen in Table 1, which shows the energy density and specific energy of gasoline compared to a conventional lead-acid storage battery and the advanced battery goal established by the US Department of Energy. It can be seen that the storage of a given quantity of energy in a lead-acid battery requires a volume of 100 times and a mass of nearly 400 times that of an equivalent amount of gasoline. This has been the overwhelming obstacle to making battery electric vehicles competitive with conventional gasoline and diesel fuelled vehicles.

Energy Carrier	Energy Density MJ/l	Specific Energy MJ/kg
Lead-acid Battery	0.32	0.11
Advanced Battery Goal	1.08	0.72
Gasoline	31.54	45.72

Source: DOE

Although specialized battery powered vehicles have been used in low-speed off-road vehicles, such as golf carts, for many years, attempts to introduce fully electric road vehicles have been unsuccessful. The overwhelming problem has been the very limited range that could be provided by conventional batteries and the need for long battery re-charging times, typically several hours. However, recent progress in battery energy density and automotive control systems has resulted in the successful introduction into the marketplace of hybrid-electric vehicles. These combine the use of a conventional internal combustion engine and a storage battery to provide a much more efficient vehicle drive-train. The engine can be de-coupled from the wheels and used to charge the battery for much of the driving cycle, and together with regenerative braking the overall vehicle efficiency is increased significantly. Probably the best-known vehicle in this class is the Toyota Prius, although most manufacturers now have hybrid vehicles available as part of their offerings. With the recent increase in gasoline prices, and concerns about climate change, hybrid vehicles have become very popular in the marketplace. Of course all of the energy still comes from conventional fossil fuels, but the increase in powertrain efficiency does provide a very useful reduction in GHG production of around 30%.

The next iteration of hybrid vehicles now being developed by most auto manufacturers will include better batteries, providing significantly more electrical energy storage capacity, and the ability to re-charge the battery overnight from the electrical grid. These so-called "Plug-In Hybrid Vehicles", or PHEV's, will still include an internal combustion engine, although this will now be smaller than before, and will be used mainly as a "back-up" generator to charge the battery pack when needed. They will in many ways incorporate the best of both worlds, in that they will have the zero-emission capability of all-electric vehicles, but the extended vehicle range provided by conventional fossil fuelled vehicles. The introduction into the marketplace of these vehicles will be the first step in large-scale "fuel-switching" from fossil fuel based energy carriers to electricity. Over time, this will result in a substantial increase in the demand for electricity, as more and more PHEV's take to the road. Of course, if the increase in electricity generation comes primarily from fossil fuels there will still be emission of GHG's from the complete energy conversion chain; it will simply be moved from end-use up to the primary energy processing step. However, it is likely that much of the new generation capacity required will be obtained from either renewable energy, or nuclear power, which could result in greatly reduced GHG emissions from the complete transportation energy conversion chain.

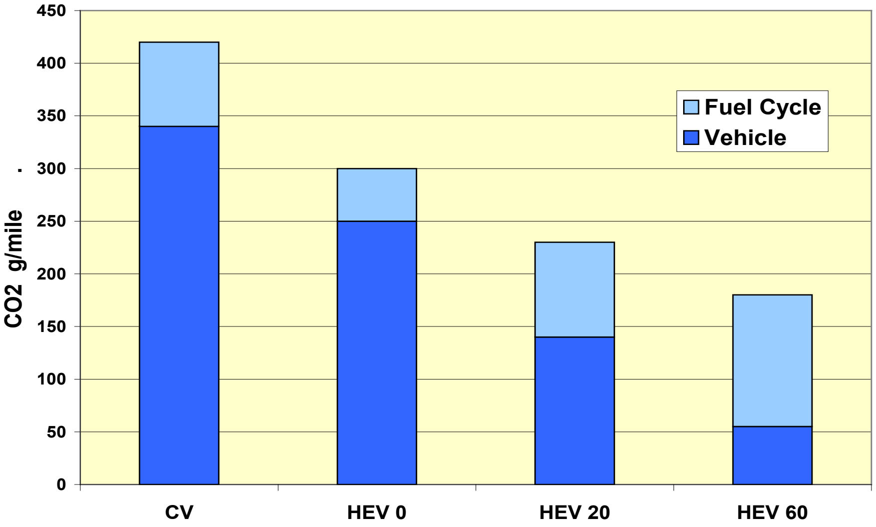

Figure 3 CO$_2$ Emissions from EPRI Study *Source: EPRI*

Even if all of the additional electrical capacity were to be obtained from fossil fuels, however, there would still be an advantage from using PHEV's because the overall drive-train efficiency will be much higher than for a conventional vehicle. This point is illustrated in Figure 3, which shows the results of a study by the Electrical Power Research Institute [4]. The figure shows estimates of the CO$_2$ emissions, in g/mile, of four different vehicles over a typical combined urban/extra-urban driving cycle. The four vehicles are described as follows: CV, a conventional gasoline powered vehicle; HEV 0, a hybrid-electric vehicle with no capability to re-charge the battery from the grid (the 0 indicates zero "all-electric" range); HEV 20, a plug-in hybrid-electric vehicle with a 20 mile (32 km) all-electric range; and HEV 60 with a 60 mile (97 km) all-electric range. In all cases the CO$_2$ for the complete energy conversion chain is shown, with the dark part of the bar representing the emissions from the vehicle, and the top lighter part from the fuel processing, whether it is gasoline or electricity generation. In this case the electricity generation is assumed to be from a natural-gas-fired powerplant, with an overall efficiency of 50%. The switch from a purely gasoline-fuelled CV to a conventional hybrid vehicle, HEV 0, results in a reduction of about 30% in total CO$_2$ emissions, as we have discussed, with proportionate reductions in both the fuel processing and vehicle emissions. For both of the plug-in hybrids, however, the proportion of emissions from the "fuel" processing is higher, since electricity is produced with an efficiency of only 50%, compared to about an 80% efficiency for gasoline production from crude oil. For the PHEV with a 60 mile all-electric range, the total CO$_2$ emissions are reduced by nearly 60% compared to a conventional gasoline powered vehicle. On its own this would be impressive, but what is even more interesting is the emission reductions which would occur if it is assumed that all of the marginal increase in electricity generation is provided from renewable or nuclear energy. In this case, only the dark part of the bar is applicable, and the CO$_2$ emissions would be reduced by over 80% compared to the gasoline powered vehicle! It is no wonder, then, that auto manufacturers are excited about this new generation of vehicles which will make a major contribution to reducing GHG emissions from transportation. This has major implications for BC, since with a predominantly hydroelectric power supply system, a transition to PHEV's will have a major impact on reducing GHG emissions.

Electricity is also a viable energy carrier for long-haul freight transportation, through the use of electrified railroad lines. This is already standard in densely populated regions of the world, such as Europe and Asia, but is not commonly used in North America, other than to support passenger transportation in the heavily populated US East Coast region. The major rail lines in BC all rely on conventional diesel-electric locomotives to provide motive power. The only exception was a short 130 km length of the BC Rail Tumbler Ridge line which used electric locomotives, partly due to the presence of two very long tunnels, until the line switched to diesels in 2000, and then closed in 2003. With low-cost hydroelectric power available in BC there is considerable potential for moving to railroad electrification, although the economic viability of doing so with relatively low load factors would need to be carefully studied. Feasibility studies would also need to consider the cost of providing the additional electricity generation and transmission capacity that would be needed. For passenger transport, BC already makes use of an extensive network of electric trolley buses in greater Vancouver as well as the Sky-train rapid transit system. Expansion of trolley bus service in Vancouver to replace many of the diesel buses still in operation on busy routes, would be a relatively easy way for the mass transit system to shift from fossil fuels to renewable energy for passenger transportation.

Hydrogen as an Energy Carrier for Transportation

Hydrogen has also been proposed as an alternative energy carrier for transportation to eliminate the production of any harmful exhaust emissions from vehicles on the road. This would be true for the vehicle itself, but if we consider the complete energy conversion chain, hydrogen is just an energy carrier, and would need to be 'manufactured' from one of the three primary energy sources. If produced from hydrocarbons, such as natural gas or coal, all of the carbon in the primary energy source would still end up as CO_2 at the point of hydrogen production. If, on the other hand, the hydrogen was produced from a more sustainable primary energy source, such as renewable energy or nuclear power, then there would indeed be no production of greenhouse gases anywhere in the energy conversion chain. Research studies are underway to investigate the production of hydrogen using photoelectrochemical processes to convert solar energy directly into hydrogen, as well as on the use of thermonuclear energy sources to produce hydrogen directly. This research is at a very early stage, however, and there is not enough data available about the overall efficiency and cost-effectiveness of such processes. Using currently available technology in the production of hydrogen from renewable energy or nuclear power would most likely involve electrolysis of water, since these primary energy forms are nearly always used to produce electricity as an initial energy carrier.

If hydrogen is produced using electrolysis of water, the first step in the energy conversion chain is the generation of electricity as an initial energy carrier. The hydrogen would then be compressed, or converted into liquid form, for storage on board the vehicle, and then a fuel cell would generate electricity on-demand from the hydrogen to power the vehicles all-electric drivetrain. In this case there are two energy carriers involved, electricity as the first carrier, and then hydrogen as a secondary carrier. In other words, there is a "double conversion" into energy carriers, first from electricity into hydrogen, and then from hydrogen back into electricity again by the fuel-cell. A battery electric vehicle takes a much simpler approach, with a battery used on-board the vehicle to store the electricity directly. The two approaches can be summarized by comparing the partial energy conversion chains shown in Figure 4. This shows the two different approaches, starting from the point at which the primary energy source produces electricity, and ending where electricity is again used to power the vehicle's electric traction motor. It can be seen that the equipment required for the fuel cell vehicle, including hydrogen production and storage, as well as the fuel cell, is really just an electrical energy storage device. The advantage of this approach over that of using a simple electrical storage battery, however, is the fact that the energy storage capacity on-board the vehicle can be much greater using hydrogen.

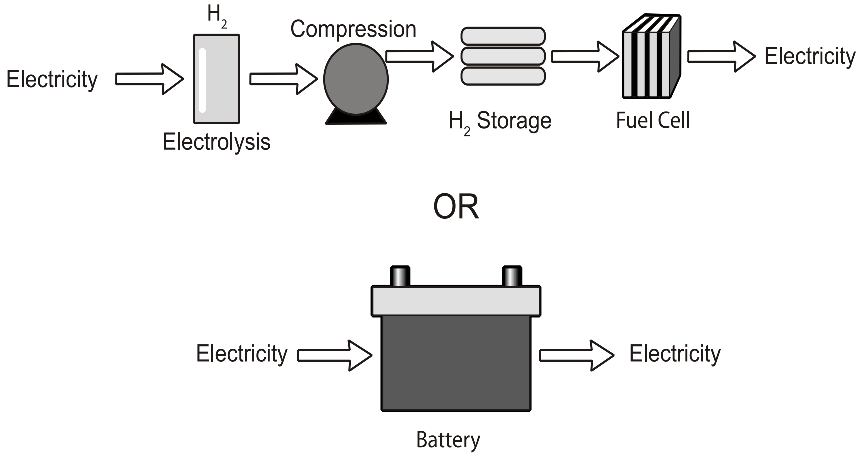

Figure 4 **Alternative Electrical Energy Storage Concepts**

Although strictly speaking not all of the process steps shown in Figure 4 are energy conversion processes, there is a loss of available energy associated with each step in the chain. To account for these energy losses we may assign an "in-out" efficiency value to each step in the two equivalent conversion chains. The efficiency for each of the steps for the complete hydrogen "electricity storage" process is then shown on the left-hand side of Table 2. For example, electrolysis of water has an efficiency of nearly 75%, while compressing hydrogen to a pressure suitable for the storage cylinders has an efficiency of about 92%. The efficiencies of each individual step are then multiplied together to get the final "overall efficiency" of the complete process, going from electricity "in" from the primary source to electricity "out" to the traction motor. With an assumed fuel cell efficiency of 50%, the overall "in-out efficiency" for the hydrogen energy conversion chain is approximately 34%. For the battery, there is only one step between the input to the energy storage and output to the vehicle, as shown on the right-hand side of Table 2, and since about 10% of the input energy is normally lost in the form of heat during the battery charging process, we can assign an "in-out efficiency" of 90% to the battery. This simple analysis indicates that if a battery with sufficient energy storage capacity to provide a reasonable vehicle range were available, then battery electric vehicles would require much less primary energy. It seems that the use of hydrogen as an energy carrier for transportation will not be competitive with using electricity unless the production of hydrogen directly from renewable or nuclear energy becomes a technically and economically viable.

Efficiency Comparison of Equivalent Energy Storage Schemes			
Hydrogen and Fuel Cell		**Battery**	
Electrolysis	75%	Battery	90%
Compression	92%	▬	▬
Fuel Cell	50%	▬	▬
Overall Efficiency	***34%***	Overall Efficiency	***90%***

ALTERNATIVE PRIMARY ENERGY SOURCES

Renewable Energy Sources

Renewable energy sources are primarily those that utilize the energy of the sun, either directly in the form of solar energy, or indirectly in the form of hydroelectric, wind and wave power, as well as biomass energy. The two non-solar renewable energy sources are tidal and geothermal energy. Two key characteristics of all of these sources is that they are essentially inexhaustible and they produce no greenhouse gas emissions. With the exception of hydroelectric power, however, the energy density of most of these sources is low, which has made them uncompetitive with conventional fossil fuels. With the increasing concerns about GHG emissions, however, together with the realization that fossil fuels are a finite resource, there is great interest in expanded use of renewable energy. In this section we will briefly examine the major renewable energy sources, from an expansion of conventional hydroelectric power to the longer range prospects for tidal and wave energy extraction.

Large-Scale Hydro Power

British Columbia is very fortunate to have the geography and climate that provides extensive potential for the development of hydroelectric power. BC Hydro and its predecessors, BC Electric and the BC Power Commission, were established to develop large-scale hydro power facilities and to distribute electric power throughout the province. The development of major hydro power facilities has been undertaken primarily on both the Columbia and Peace river systems, which has resulted in some of the lowest electricity rates in the world. Although the development of these sources has not been without some public concern about the conflict between energy production and the local environment, many would argue that they have been of great benefit to the people of BC. No significant new facilities have been built for many years, however, and with steady growth in demand for electricity the province is now in a position where it is a net importer of electricity. With the likelihood that demand growth rates increase, due in part to "fuel switching" in the transportation sector from gasoline and diesel fuel to electricity, there is a need to build new power generation facilities. One way to accommodate the increase in demand for clean power is to build new large-scale hydroelectric plants, or to essentially expand existing ones.

The expansion of existing facilities, rather than constructing new facilities on undeveloped river systems, is likely to be the most cost-effective and environmentally benign approach.

BC Hydro conducts extensive planning of possible new hydroelectric development. These include detailed planning for near-term projects such as the addition of turbines to existing powerhouses, and for medium-term projects, such as building a third dam on the Peace river (at "Site C") which would make use of the extensive energy storage capacity of Lake Williston. These projects are likely to provide the most cost-effective new sources of electric power in the province, and will result in relatively small environmental impacts. Three additional 500 MWe turbines have been proposed for the Columbia river system, one at the Revelstoke generating station, and two at the Mica station. These will be installed primarily to provide 1,500 MWe of peaking power capacity, but will add very little additional annual energy generation. This is because the water storage capacity behind the dams is already fully utilized to provide the maximum annual energy capability. Site C, downstream of the existing Peace Canyon power station, is BC Hydro's preferred next project to provide both power capacity and energy capability, and is at an advanced planning stage. This project would provide some 900 MWe of power capacity, together with an additional 4,600 MWh of annual energy generation, which is approximately 10% of BC Hydro's current annual energy production.

Large-scale projects that have been studied by BC Hydro, and included as possible projects in the latest "Long Term Acquisition Plan" [5] filed with the BC Utilities Commission, are shown in Table 3. The ten projects, which include Site C, provide a total installed power capacity, and average annual energy generation capability just about equal to the total currently installed capacity in BC. Before proceeding with these projects there would need to be extensive public consultation before they could be considered to be in the public interest. However, it is clear that there is sufficient large-scale hydroelectric potential available in BC to meet future demand growth for many years into the future. Much of this potential capacity would likely be the most cost-effective source of electricity for the province. The capacity factor, which is an important measure of the viability of power generation systems, is shown in the last column of Table 3. This is a measure of the actual energy generated in one year compared to the maximum possible which could be generated if the station were to operate at 100% capacity for the whole year. High values of the capacity factor show that the capital expended to build a particular plant is well utilized. The values shown in Table 3 are very good compared to most intermittent renewable sources, such as wind and solar power, as we shall see later in this paper.

Project	Power MWe	Energy GWh/yr	Capacity Factor
Peace Site C	900	4,600	58%
Elaho	200	945	54%
McGregor Lower Canyon	360	1,673	53%
Murphy Creek	275	1,794	74%
Border (Columbia River)	275	1,418	59%
Homathko River	895	4,558	58%
Liard River	4,318	24,825	66%
Iskut River	980	4,293	50%
Peace - High Site E	1,800	8,500	54%
Peace - Low Site E	675	3,210	54%
Total	**10,678**	**55,816**	

Note: *Current installed power capacity is 11,322 MWe, and annual average energy generation is approximately 50,000 GWh/yr.*

Small-Scale Hydro Power

In addition to the extensive potential for large-scale hydroelectric development, BC also has a very large potential for development of small-scale, low-head hydroelectric power. These types of facilities are often referred to as "run-of-river" plants, and usually do not incorporate a dam to provide the head and storage capacity which are characteristics of large-scale plants. They are therefore more suitable for development by smaller communities and private companies rather than large utilities. A recent study for BC Hydro by Kerr Wood Leidal [6] has estimated that there are over 8,000 potential sites for run-of-the-river plants in BC. These would provide a total generating capacity of just under 12,000 MWe and generate on average some 50,000 GWh/yr of electricity. This is again similar to the existing installed generating capacity in BC, although many of the projects would have very high unit energy costs and would not be economically attractive. A sub-set of these projects with unit energy costs of less than $100/MWh was also identified in the study, which are quite likely to be competitive with the more expensive large-scale hydro projects or other renewable energy projects. There were 121 such projects, with a power generating capacity of just under 1,400 MWe, as shown in Table 4. It can be seen that if all of these plants were constructed, the average annual energy capability would be over 6,000 GWh/yr, reducing to just under 5,000 GWh/yr as firm energy which would be available in low-water flow years. The capacity factor for most of these plants is lower than for large-scale hydro plants, which tends to make the unit cost of power more expensive. Just under half of the projects are in the lower mainland region of the province, partly due to the fact that these projects would have easier access to power transmission lines than in more remote regions.

Region	No. of Projects	Power MWe	Energy GWh/yr	Firm Energy GWh/yr	Capacity Factor**
Central Interior	1	4	14	14	40%
East Kootenay	12	163	615	522	37%
Kelly/Nicola	17	217	845	723	38%
Lower Mainland	60	665	3,245	2,476	43%
North Coast	14	162	722	589	42%
Peace River	5	89	339	321	41%
South Interior	10	78	294	254	37%
Vancouver Island	2	10	37	27	31%
Total	121	1,388	6,111	4,926	

Source: *Kerr Wood Leidal, 2007* [6]

**** Note:** *Capacity Factor based on Firm Energy*

Wind Energy

Historically windmills were used to provide power for milling grain and to drain low-lying land in the Netherlands and other regions of Europe. In the early part of the 20th century before rural electrification made utility-generated electricity widely available, many farms in North America used small-scale windmills to generate electricity locally. Wind power has made a substantial comeback and is currently the most significant source of renewably generated electricity after hydro power. The new windmills (or wind turbines as the manufacturers now prefer to call them) are much larger than in the past, and are now available in unit sizes of up to 6 MWe peak capacity. Although many wind turbines have been installed as 'one-off' installations, primarily to demonstrate the technology, the trend now is to build 'wind farms' with many wind turbines situated in an area with high average wind speed. These wind farms may be located on land, usually in remote areas where there is little interference with human activity, but increasingly 'off-shore' wind farms are being built in shallow seabed locations in remote coastal areas. There are additional construction challenges with the off-shore locations, of course, as underwater foundations and the towers must be built to withstand severe wave action, as well as high wind speeds. There are significant benefits, however, in that wind speeds are usually much higher in coastal areas where the open water enables the wind to build up with little interference. Off-shore design and construction techniques have also benefited from the large experience gained over many decades in building off-shore oil and gas extraction facilities. Another benefit of off-shore locations is that the turbines are usually located well away from significant human activity, and therefore tend to be more acceptable to the local population.

The global growth in wind power has been very high in recent years, with a 50% increase in installed capacity in just two years. The total worldwide installed wind-power capacity in 2005 was 60,000 MWe, while in 2007 it increased to just over 90,000 MWe [9]. In Europe, in particular, there has been widespread adoption of wind-power as a source of electricity for major utilities, with Germany and Spain leading the way. The United States is rapidly catching up, however, and in 2007 installed more new wind-power capacity than any other country. They now stand second overall installed capacity, with 17,000 MWe compared to Germany with some 22,000 MWe. However, in order to put this in perspective, the Global Wind Energy Council predicts that wind-power will provide just over 1% of the total electricity generated in the U.S. in 2008 [9]. This is also, in part to the low capacity factor of wind turbines due to the intermittent nature of the wind. For example, in 2005 the capacity factor for total global wind energy production was just under 20% [10]. This number reflects the fact that many early wind installations used relatively small and inefficient turbines, however, and many sites were probably not optimum for wind-power generation. More recent estimates by the wind-power industry for new installations is a capacity factor of 30% for onshore wind farms, and 35% for offshore developments [11]. In comparison, most of the large-scale hydroelectric power developments studied by BC Hydro have a capacity factor nearly double that of wind-power, as we have seen. Large fossil-fuel fired powerplants, or nuclear power stations, usually have a capacity factor in the order of 90%, indicating a much better utilization of the capital equipment on an annual basis.

The intermittent nature of wind power also necessitates that substantial reserves of 'back-up' power, or energy storage is available to ensure reliable electricity supplies during periods of low wind activity. This will usually not be a major issue when the wind power capacity is a small fraction of total system capacity, as there is usually sufficient spare capacity to ensure that the total power demand can be met. In order to replace the firm capacity of fossil-fuel or nuclear plants with wind turbines, the installed capacity needs to be much greater than that of the plants they are replacing. A study by Grubb [8] has shown that the 'capacity credit' for wind power used to replace baseload thermal powerplant capacity should be proportional to the square root of the load displaced. For example, it would require approximately 9 GWe of wind capacity to replace 3 GWe nuclear or coal-fired power capacity. However, BC has an important advantage for intermittent sources of energy, such as wind-power and solar energy, in that BC Hydro has a large energy storage capability in the form of the very large reservoirs behind major hydroelectric dams. This means that hydro power can be used to generate power at times when intermittent sources are not available, and then shut down or run at reduced capacity when the intermittent sources are again available. This advantage is difficult to quantify, but is due to the "energy critical" nature of hydroelectric based systems compared to the power "capacity critical" nature of primarily thermal based systems.

There is a considerable wind-power resource available in BC, both for onshore and offshore applications, although little development has taken place so far. This appears to be primarily due to the very low cost of the historic installed hydroelectric capacity in the province, which makes it very difficult for new energy sources to be competitive. However, BC Hydro is now pursuing new sources of renewable energy from Independent Power Producers through its "Clean Power Call" process. Following the 2006 call, BC Hydro entered into contracts for 3 wind farms in the province, as shown in Table 5. Two of these in the Peace river region are quite large, while one near Prince Rupert is smaller. The capacity factor for all three is around 35%, which indicates that they are all in areas of high sustained winds. The price offerings for some of the wind-power projects proposed to date have been competitive with many of the small-scale run-of-river hydro projects. This will no doubt lead to increased interest in wind-power development in the province. On a less positive note, however, there are likely to be questions of public acceptance from a visual pollution perspective, for very large wind farms, particularly in undeveloped areas of natural beauty. This is already happening in Europe, where protesters regularly oppose plans for new wind farms in countries such as Germany and the UK.

Wind Energy Projects from BC Hydro Clean Power Call - 2006

Project	Power GWe	Energy TWh/yr	Capacity Factor
Dokie Wind Project - Chetwynd	180	536	34%
Bear Mtn. Wind Park - Dawson Creek	120	371	35%
Mt. Hays Wind Fm. - Prince Rupert	25.2	72	33%
Total	325.2	979	

Source: *BC Hydro - 2007*

Ocean Energy

As a maritime province with a very long coastline BC is well-placed to take advantage of ocean energy. At this time, however, ocean energy in the form of wave and tidal power is at a very early stage of development. Although there is a great deal of energy contained in ocean waves and tidal currents, it is very difficult to extract this energy in a useable and economic form at the present time. Of the two main forms of ocean energy, tidal power is the more advanced in terms of harnessing energy for the production of electricity. Most of the installed tidal power capacity operating in the world is in the form of tidal barrages, or barriers, which trap water at high tide and then let the water return to the lower tidal level through turbines in order to generate electricity. Canada is actually one of the few places in the world to utilize this technology, with the 20 MWe tidal powerplant at Annapolis Royal in the Bay of Fundy. This plant generates some 50 GWh of electricity per year, with a very good capacity factor of nearly 30% due to the very high tides in this area. The largest tidal powerplant currently in operation is LaRance station near St. Malo on the coast of France. This plant, which entered service in 1966, takes advantage of a nearly 8m tidal range, and has a peak generating capacity of 240 MWe. The turbines generate approximately 610 GWh of electricity per year, which again results in a capacity factor of just less than 30%. With much lower tidal ranges in BC, it is unlikely that this type of large-scale tidal barrage plant could produce electricity at a price competitive with other renewable energy options.

BC is much better placed to extract useful energy from tidal currents, as the many inlets and narrow passages on the BC coast provide a large potential for generating electricity using tidal current turbines. There are two different power generation techniques for extracting tidal energy; horizontal axis turbines which can be completely submerged, or vertical axis turbines which may be incorporated into a "tidal fence" arrangement. The most well developed technology at present appears to be the horizontal axis turbines which has been developed to commercial scale by Marine Current Turbines in the UK [2]. Several studies of the potential for marine current energy have been conducted for BC waters, including a detailed one by Triton Consultants for BC Hydro [12]. This study concluded that the average maximum power available in tidal current streams in BC is about 3,000 MW. However, this is the total power contained in tidal currents, and not the electrical power which could be provided by actual tidal turbine installations. Assuming the use of horizontal axis turbines, such as those developed my Marine Current Turbines, the study estimated the total average electrical power generation capacity from tidal currents in BC would be approximately 300 MWe, or some 2,700 GWh per year. This is a relatively small capacity, and about equivalent to one large hydroelectric turbine. The report also presented the results of two site-specific studies, one for a 160 MWe average installation at Discovery passage, and one for the much smaller potential of 8.7 MWe average at Race passage. The estimated cost of electricity generation for Discovery passage was $110/MWh while for Race passage it was estimated to be $250/MWh, which in part appears to be due to the much smaller scale at this site.

There is a great deal of energy contained in the ocean waves off the BC coast, but experience in other countries has shown that is very difficult to extract this energy and convert it into electricity. The monthly mean wave power contained in waves off the Pacific coast varies from 10 kW/m in summer up to 100 kW/m in winter [13]. The annual average power contained in Pacific waves is approximately 43 kW/m 150 km off shore, while it reduces to 25 kW/m at the coast. Using these numbers, the average available wave power of 25,000 MW per 1,000 km of coastline is more than twice the present installed capacity of the BC Hydro system. Of course the practical extraction of energy from this source will be very difficult, so that the realistic electricity generation potential might be even less than 10% of this amount. A wide variety of machines for extracting some of this energy in a practical way has been proposed, but none have so far reached a commercial scale of operation. Wave extraction devices may be broadly classified into on-shore developments, aimed at extracting energy as waves impact the shoreline, and off-shore devices which rely on wave action further out to sea. Although on-shore devices are attractive due to their simplicity, they suffer from significant reduction in power generation potential due to the attenuation of energy as the waves reach the shore. One of the best developed on-shore technologies is the use of wave-action to compress air in a partially enclosed cavity. Most of these devices, known as 'Oscillating Water Column' (OWC) devices, first focus the incoming wave energy in order to generate an oscillating column of water in a shore-based facility.

The best-known on-shore OWC wave energy conversion device is the experimental "Limpet" [14] installation which was completed in 2000. Initial results from the plant have been disappointing, however, as the power output has been much lower than originally expected. The final measured power output of the Limpet was 21 kWe, compared to an initial design estimate of some 200 kWe. The reasons for this appear to be due to several factors, including reduced wave energy reaching the Limpet device and inefficiencies in conversion of the wave energy to pneumatic power and in the air turbine itself. Although this has been an early experiment, it has shown that the conversion of wave energy into useful electrical power is likely to be challenging and expensive. Many off-shore wave energy devices have also been proposed, and most of these rely on the conversion of wave action into a partially rotary motion in devices such as the "Salter Nodding Duck" [15] or the "Pelamis Sea Snake" [16]. Another approach is to convert the simple heaving motion imparted to a floating buoy into electricity using a linear generator. Off-shore devices suffer from the challenge of constructing very large devices that can withstand severe storms, and from the need to generate power at sea and transmit it back to shore. Another issue that needs to be addressed is the potential hazard to shipping that would be caused by large-scale deployment of off-shore wave energy conversion devices. On-going research and development will no doubt provide a better estimate of the unit cost of electricity from such devices which at the moment is very high compared to many other renewable alternatives.

Solar Energy

Solar energy can be used directly either to provide space heating and domestic hot water, or to generate electricity using photovoltaic cells. For some time both 'passive' and 'active' solar energy systems have been used by architects to provide space heating and domestic hot water in high energy efficiency buildings. In its simplest form passive solar heating uses small north-facing windows to reduce heat loss and enlarged south-facing windows (in the northern hemisphere) to directly heat walls and floors. More complex design ideas have also been utilized to increase this passive heating, including the use of 'Trombe walls', for example. These are heavy, usually black-painted concrete walls placed just behind south-facing glass that are used specifically to absorb as much heat as possible from the sun's rays, so that this thermal energy can be released over periods of several hours.

Active solar heating uses 'solar collectors' usually mounted on rooftops, to heat water which is then used for domestic hot water or to heat a swimming pool. The outdoor swimming pool application is particularly attractive, since these are usually used during the warm summer months when the maximum amount of solar radiation is available. The economics of solar water heating are obviously affected by the cost of alternative energy sources used for this purpose, principally electricity and natural gas, and by the building location. In the U.S., for example, solar heating of swimming pools is particularly attractive in sunny states like California and Florida in which there are many outdoor swimming pools. In most installations, whether they are used for domestic hot water or for swimming pools, a conventional water heating system using natural gas or electricity is installed to provide back-up energy during cloudy periods or when cool weather results in extra demand for hot water. In many cases, however, more than half of the cost of traditional sources of energy can be saved over the course of a year using solar energy, and in some cases much more than this. The solar system costs are also reasonably modest, so that financial 'payback' times can be less than 10 years, making solar energy an attractive investment.

Photovoltaic (PV) solar cells are manufactured from special semi-conductor materials that use the energy of the photons from solar radiation striking the cell to produce an electric current. The most expensive solar cells are made from crystalline silicon wafers which are cut from a single crystal which has been specially 'grown'. These have the highest efficiency of conversion from solar radiation to electricity of any solar cells, although this value may only be around 15%. Research continues on more efficient solar cells, however, and efficiencies of up to 40% have been reported, although these will no doubt be expensive. A typical PV solar panel consists of many individual solar cells connected together so that enough current can be generated to provide power to the external load. A typical solar panel measures about 1.5m x 0.8m which will usually have an output in bright sunlight of around 150W. A solar panel installation of about 30 square metres might have a peak electrical output of around 3.5kW, which should accommodate most of the electrical load from a typical house while it is in direct sunlight. There is usually a mismatch, however, between peak generating capacity and household electrical demand. For example, the generation of electrical power will peak around mid-day on a clear summer day when the house may be empty. Also, peak electrical demand may occur around nightfall on a dark mid-winter day when there is little or no availability of solar energy. There is therefore a need for a battery storage system, or connection to a utility grid, to ensure adequate electricity supply at night and during cloudy periods.

The requirement for either storage or backup from an electrical grid adds an additional complication, and usually significant cost, to the solar PV electricity system. Also, the intermittent nature of the solar energy means that the PV system is only able to generate peak levels of electricity for a relatively short period during any one year. The capacity factor for a solar PV system in mid-latitudes may be as low as 10%, or even lower in cloudy areas, due to the limited availability of the primary solar energy source over the year. In the UK, for example, the UK Energy Saving Trust has estimated that a 1 kW solar PV system would generate a minimum of 750 kWh per year. This corresponds, however, to a capacity factor of only 8.5%. The implication of such a low capacity factor is that the capital equipment is poorly utilized, so that the capital costs per unit output of electricity are greatly increased. This significantly increases the unit cost of solar PV generated electricity in comparison to the costs of conventional generation. As PV cell efficiency continues to increase, solar electricity generation will be more widely used, particularly in low-latitude regions with low annual cloud cover. In BC the use of solar PV systems is unlikely to be competitive with the low historic costs of hydro power for some time, although they will be much more effective in the Okanagan than on the coast.

Biomass Energy and Bio-Fuels

The use of biomass as a source of energy is attractive, since it is usually classified as a 'zero net CO_2 energy source which does not contribute to greenhouse gas emissions. Biomass energy is used in many different forms in a wide range of applications, ranging from combustion of wood and wood-waste in large boilers to the use of bio-ethanol as a vehicle fuel. The direct combustion of wood, and other biomass fuels, such as Municipal Solid Waste (MSW) and agricultural wastes, accounts for by far the largest component of biomass energy use today. As shown in Figure 1, "renewables other than hydroelectricity" provides some 18% of BC total energy consumption, nearly equal to the contribution from hydro power. Most of this is in the form of "Combustible Renewable Wastes" (CRW), primarily the burning of hog-fuel and "black liquor" in pulp mill boilers to raise steam. In addition to the combustion of CRW and MSW in conventional steam boilers, there is increasing interest in the use of pyrolysis, or gasification technology, to produce a combustible gas. This would often be of interest to smaller communities, or small industrial operations, where the volume of MSW or other biomass waste is not sufficient to justify the cost of a large steam plant. The "producer gas" can also be transported by pipelines relatively inexpensively and used as a replacement for natural gas in some applications. The production of methane gas also occurs naturally because of anaerobic digestion in landfills, and this can be collected and used for heating or fuelling an internal combustion engine to drive a generator. On a smaller scale, use can also be made of purpose-built anaerobic digesters, which process a steady stream of biomass waste material such as animal manure. The resulting fuel, or 'biogas', can be used to provide heat in colder climates, or as an engine fuel to generate electricity.

Biomass-derived liquid fuels may be used to substitute for gasoline and diesel fuel in transportation applications. This is now a growing market, with ethanol being used to blend with gasoline, and vegetable-derived oils used to substitute for diesel fuels. Vegetable oil, either in the form of waste oil from deep-fat fryers, or from crops such as Canola, is usually blended with diesel fuel but can also be used on its own. Although early studies indicated that the production of biodiesel might consume more fossil fuel energy than that contained in the resulting fuel, this has been refuted by more recent studies [17]. Ethanol is normally produced by fermentation of corn or other grain crops, just as it is for the production of alcoholic beverages. Some studies have shown, however, that the production of ethanol is itself an energy-intensive process. Life-cycle assessment analysis has shown that large quantities of energy are required for the distillation process to separate the alcohol from water, and also for corn production in the form of tractor fuel and fertilizer production. Pimentel & Patzek [18] found that the production of ethanol required up to 50% more fossil energy than is produced in the form of ethanol, depending on the biomass source chosen. This is clearly not a sustainable process, and means that economic large-scale production of fuel ethanol by fermentation may be in doubt. Recent studies, however, have indicated that the use of cellulosic feedstock, such as switch grass or other fast growing crops, and from waste such as corn stover, for the production of ethanol may be much more energy efficient. This is an area of very active research, with the goal of developing new processes for economic and large-scale production of "cellulosic ethanol" to replace gasoline. There is growing interest in BC in the development of processes to use waste wood and other sources of cellulose to produce alcohol fuels and with very large quantities of pine-beetle killed wood potentially available, this could be an important source of renewable fuels in the future. Much more research needs to be done, but the development of more environmentally acceptable cellulose-based renewable fuels is clearly an area in which BC could take a prominent lead.

Geothermal Energy

Geothermal energy is the only renewable energy source other than tidal power that doesn't depend on the sun as its primary energy source. The high temperatures that prevail deep in the earth's crust have long been recognized as a significant practical source of energy, both for space heating, and in some cases for the generation of electricity. Geothermal energy is currently used to provide heat for buildings and industrial processes, and by the end of 2000 the worldwide installed thermal capacity for heating applications was over 15,000 MW. In some countries, notably the U.S., the Philippines, Mexico and Italy, geothermal energy is also a significant source of primary energy for electricity production. At the end of 2003, the worldwide geothermal electricity generation capacity was some 8,400 MWe, with the U.S. leading the way with 2,020 MWe, closely followed by the Philippines with 1,930 MWe. For the U.S., however, the geothermal capacity provides less than 0.5% of total electrical energy generation, while for the Philippines it represents nearly 22% of total generation. Iceland had a much smaller installed geothermal electricity capacity of around 200 MWe, but because it is such a small country this still accounts for nearly 15% of total electricity generation.

The first geothermal powerplant, built at Larderello Italy in 1904, used ‘dry steam’ (saturated or superheated vapour) to generate electricity. Initially a small reciprocating steam engine of a few kWe capacity was used, and the success of those experiments led to steady expansion so that the installed capacity now at Larderello is some 550 MWe. The only other dry steam power plant in existence today, and the world’s largest geothermal power plant, is ‘The Geysers’ plant located in northern California. This plant began operation in 1960 with an initial capacity of 11 MWe, and today has an installed capacity of nearly 1,700 MWe. Most geothermal sites do not produce dry steam, however, but rather a mixture of saturated water and vapour (usually called ‘wet steam’). For powerplants at these sites a flash-steam approach is used, in which the hot liquid is fed into a vessel which is held at a much lower pressure so that the liquid flashes into vapour for use in a low-pressure steam turbine. Most geothermal power plants operate in this manner, and usually use re-injection wells to return the condensate underground to minimize environmental impacts. Geothermal electricity generation has been studied in BC for many years, principally at the Meager Creek site northwest of Pemberton. This site was found to be a good source of ‘high-temperature’ (greater than 200° C) wet steam, suitable for electricity generation. In the 1970’s BC Hydro carried out extensive resource evaluation studies in this area, and examined the feasibility of building a geothermal powerplant at the site for connection to the BC Hydro grid. The projected electricity costs, however, were higher than for competing hydroelectric proposals, and the site was left undeveloped. More recently the Meager Creek Development Corp., a subsidiary of Western GeoPower Corp., has acquired the lease to the site, and is conducting further exploration and powerplant feasibility studies. Preliminary studies have indicated the potential for a 100 MWe powerplant, and the company expects to submit a proposal to provide electricity to one of the future BC Hydro ‘Green Power’ calls [19].

Ground-source heat pumps may be used to obtain significant amounts of thermal energy from very low temperature geothermal sources, or even from sub-soil a few metres below the earth’s surface. Because the ground temperature remains quite constant just below the earth’s surface, this can be used as a source of heat in most parts of the world. A heat pump, working like a refrigerator in reverse, takes in energy from the ground at a relatively low temperature, and then delivers it at a higher temperature, usually for use in building space heating applications. In this type of installation, sometimes called a ‘geo-exchange’ system, refrigerant from the evaporator side of the heat pump is circulated through a pipe loop buried in the ground. The ground heat is used to evaporate the refrigerant, which is then compressed to a higher pressure and temperature before being piped to the condenser. The condenser is a heat exchanger, which then transfers heat to a building heating system as the refrigerant is cooled and condensed back to the liquid phase. Electrical energy is required to drive the heat pump, of course, but with the ‘coefficient of performance’ of the heat pump much greater than unity, this is a much more efficient use of electricity than using conventional electric resistance heating. The capital cost of a heat pump system is much higher than a simple resistance heating system, but as energy costs increase this can usually be offset by reduced operating costs. An added benefit of a heat pump system for building heating is that the heat pump can be run in reverse during the summer cooling season, and can therefore provide both summer air conditioning as well as winter heating. This feature can make ground-source heat pumps an attractive choice in regions with large temperature changes from winter to summer. Heat pumps are particularly beneficial in regions such as BC with renewable electricity generation and very low historic electricity rates.

BC as a Showcase for the "Electricity Economy"

With an extensive inventory of renewable energy resources the province of BC is very well positioned to become a world leader in show-casing a transition from a fossil fuel based economy to one focused on renewable energy. Economically attractive new sources of renewable energy include both large-scale and small-scale hydroelectric power, wind energy, geothermal energy and cellulose-based liquid fuels. Most of these are best used to generate electricity, which would become the energy carrier of choice in many applications previously served by fossil fuels. This fuel-switching will be very effective in reducing greenhouse gas emissions, providing that all new sources of electrical generation are sustainable. This wide-spread substitution of electricity as an energy carrier in applications where fossil fuels have been traditionally used could result in BC becoming a showcase for a new "Electricity Economy" in which electricity generated from renewable resources becomes the dominant energy carrier.

For example, the likely development of a new generation of plug-in hybrid vehicles (PHEV's) will inevitably result in substantial "fuel-switching" in the transportation sector. Over time, we can expect that much of the fossil fuel now being used to power automobiles will be replaced by the use of electricity. The BC residential electricity rate of just over 6 cents per kWh equates to an energy cost of about 60 cents per litre of gasoline. However, with an all-electric drivetrain efficiency at least double or three times that of a gasoline powered vehicle, the effective cost of "filling up" with electricity will be the equivalent of less than about 30 cents per litre of gasoline. With current gasoline prices around $1.00 per litre, the demand for PHEV's can be expected to be high. For heating of commercial and residential buildings, renewable electricity also becomes a much more efficient and attractive option through the deployment of both air-source and ground-source heat pumps. The increased demand for electricity will of course put significant pressure on electricity generators and on the BC Transmission Corporation to provide secure and reliable sources of electricity, as well as the means to get the electricity from generation sites to consumers. With very little investment in the province wide electricity distribution system in the last 40 years, there will be a real need for substantial upgrading and expansion of the provincial grid by the BC Transmission Corporation. There will also be significant opportunities to make the system as efficient as possible by introducing "smart-metering", and modern grid-management techniques to ensure that the electricity generation and transmission infrastructure is used as efficiently as possible. With the wide-spread introduction of PHEV's there will also be a need to expand the availability of electrical outlets for vehicle re-charging, and for an on-board metering and billing systems to ensure that drivers are billed for the electricity used to charge their vehicles.

The province of BC is fortunate to have many options available to ensure that our energy supply is as sustainable as possible. Historically, the province has benefitted from the use of hydroelectric power as the dominant source of electricity generation, providing very low cost electricity without the emission of greenhouse gases. As we have seen, there is substantial potential to build new hydroelectric capacity in the province, both with large and small-scale projects. Large-scale hydroelectric power is likely to be the lowest cost option for sustainable electricity production into the foreseeable future, primarily because most of the other renewable energy options rely on a low energy density source, and are intermittent in nature resulting in a low capacity factor. The average cost of electricity from the 39 projects awarded electricity supply contracts by BC Hydro from its 2006 Call for Green Power [22] was $79.50 per MWh. This is higher than the current residential electricity rate of about $61 per MWh, and more than twice BC Hydro's historic average cost of electricity generation of some $33 per MWh. A range of alternative energy cost estimates for BC is shown in Table 6 [21], which has been developed in part from the 2006 BC Hydro call for green power.

Estimated Electricity Costs in BC - 2007	
Energy Source	**$/MWh**
Energy Conservation & Efficiency	32-76
Large Hydroelectric	43-62
Natural Gas	48-100
Coal	67-82
Biomass	75-91
Geothermal	44-60
Wind	71-74
Small Hydroelectric	60-95
Wave & Tidal	100-360
Solar	700-1700

Source: *BC Energy Plan - 2007*

It can be seen that the average cost of the accepted projects from the 2006 call is competitive with the cost of electricity generated from a new coal-fired powerplant. The 39 projects accepted by BC Hydro in 2006 will provide 1559 MWe of new capacity with an annual energy generation of 7,351 GWh. Out of all the projects accepted in this call for green power, 31 were small-scale hydro-power projects and 3 were wind energy projects. BC is clearly well-positioned for the transition to an "electricity economy". This transition will be made much easier with very low historic electricity generation costs, and a large potential for new sources of sustainable electricity generation. In the longer term, if new cellulosic processes for production of ethanol can be shown to be much more sustainable than current processes, then ethanol may also play an important part in reducing our consumption of fossil fuels.

Carbon Capture and Storage

Carbon capture and storage, or carbon sequestration, refers to a range of techniques which may be used to prevent the release into the atmosphere of CO_2 produced during the combustion of fossil fuels. The development of these techniques is at a very early stage of development, and although tests are being conducted, no commercial-scale facilities have yet been constructed. However, in the longer-term, this could be one way to prolong the continued use of fossil fuels while at the same time reducing the emission of CO_2 into the atmosphere. The full range of carbon storage techniques envisaged by researchers is illustrated in Figure 5. Three of the concepts involve 'geologic' storage of CO_2, while the fourth utilizes the deep ocean as the storage medium. In the first case, the gas can be pressurized and piped into old oil or gas reservoirs. Depleted oil and gas reservoirs are thought to be particularly suitable candidates for this purpose, since they have successfully contained a large gaseous resource for many thousands of years, without significant leakage into the environment. The IEA is currently sponsoring a trial carbon capture and storage project in Canada, in which 5,000 tonnes per day of CO_2 is piped from a coal gasification plant across the border in North Dakota, and is then injected into a disused oil field in Weyburn, Saskatchewan. Ongoing monitoring and data collection will be used to see if this is a suitable site for carbon storage, and to provide some valuable information on the costs of such a process.

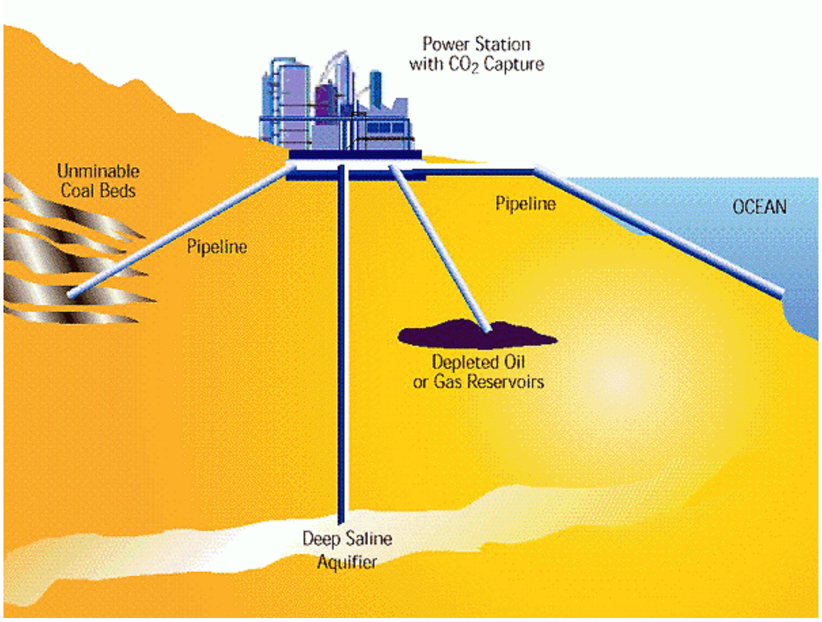

Figure 5 **Carbon Storage Concepts** *Source: IEA*

Another approach would be the use of underground aquifers, with large quantities of trapped salt water, to store CO_2. The gas would dissolve in the water, and in time may also react to form solid carbonate materials that would permanently sequester the carbon. In a trial of this technique, nearly a million tonnes per year of CO_2 is being separated from the natural gas being produced in the Norwegian Sleipner field in the North Sea, and is then being piped into a saline aquifer deep under the sea floor. Coal seams that are too deep, or uneconomic to mine, could also be a possible storage repository. Many coal deposits contain a large amount of methane, or 'coal-bed methane', which is trapped in the porous coal formation. The injection of CO_2 into the coal seam, in conjunction with suitably placed gas extraction wells, could release the methane in a similar way to that used in the enhanced oil recovery techniques. The CO_2 would then replace the methane, which could be used as a fuel resource once it is recovered. Although deep ocean storage has also been suggested by some scientists because of the very large storage capacity of the ocean, there is a great deal of uncertainty and controversy about the environmental effects of doing so. It seems quite unlikely to be seen as a commercially viable technique until after the development of geologic storage methods.

One of the major challenges of implementing carbon capture and storage is the difficulty of efficiently separating CO_2 from the exhaust gas stream. In most coal combustion processes CO_2 accounts for approximately 12% of the total flue gas volume, which consists primarily of CO_2, nitrogen, and water vapour. Nitrogen, which makes up about 79% of the volume of air, does not react in the combustion process, and remains by far the largest component of the flue gases. Separation of CO_2 from the nitrogen and water vapour then becomes challenging due to the very large gas volumes involved and the requirement for large pieces of equipment. There are two main concepts which have been proposed for capturing CO_2 from the combustion process, and these are referred to as 'post-combustion' and 'pre-combustion' techniques. At the present time there is a great deal of research and development being done on these processes, and it is not yet clear which process will be most cost-effective. Also, there is a definite lack of information on the availability of large-scale storage sites which would contain CO_2 without significant leakage over the long-term. It is too soon, therefore, to be able to provide reliable cost estimates of a large-scale carbon capture and storage operation. In initial studies, however, the IEA has estimated that the additional costs of adding CO_2 capture and storage to coal-fired power plants would increase the cost of electricity by between 50% and 100% of the cost without capture and storage, depending on which technology is ultimately used, and on the cost of the fuel. In BC most of the emission of GHG's is from the transportation sector which is the major consumer of fossil fuels. Since it will not be possible to effectively capture and store CO_2 from moving vehicles, it is unlikely that BC will be an early adopter of carbon capture and storage techniques.

Nuclear Power

Nuclear power is increasingly seen internationally as an important resource for generating electricity reliability and economically without the production of greenhouse gas emissions. With limited indigenous energy resources, France has been the leader in using nuclear power, and now provides some 80% of its total electricity supply from nuclear plants. Many people still have concerns about nuclear power, particularly with respect to safety, nuclear proliferation, waste disposal, and cost. Recently a detailed study [20] comparing the costs of nuclear power generation with those from fossil fuel powerplants, has shown that nuclear generated electricity is more expensive than either natural gas or coal-fired plants at current fuel prices. However, with the imposition of even a modest carbon tax on fossil fuelled plants, nuclear generated electricity becomes the least expensive option [2]. However, nuclear power is unlikely to be an attractive option in BC in the near future since there are many opportunities for the cost-effective expansion of electricity generation from renewable energy resources. While these are not without some environmental impacts and public concerns, they are likely to be more acceptable to the public than nuclear power. Although it has been the stated government policy since 2002 that no nuclear plants will be built in BC, the province should at least keep a watching brief on the development of the new generations of nuclear plants that will be built in other parts of the world.

SUMMARY & RECOMMENDATIONS

It is clear that British Columbia is well-positioned to be a world leader in developing and showcasing alternative and sustainable energy technologies. With an electricity supply that is already almost entirely based on renewable energy, the province has substantial additional renewable energy resources, including both large-scale and small-scale hydroelectric power, as well as significant potential for wind, geothermal and marine energy. Since most of these sources are best suited to the generation of electricity as the principal energy carrier, BC could also become a showcase for a new "Electricity Economy", in which electricity is widely used as a substitute for fossil fuels. This new sustainable energy paradigm would include widespread adoption of plug-in hybrid electric vehicles in the transportation sector, as well as both air-source and ground-source heat pumps for space heating applications. An expansion of existing trolley bus capacity and electrification of railroad lines would bring the benefits of electrification to more commuters and to the important long-haul freight sectors.

This "fuel-switching" from fossil fuels to electricity as the energy carrier of choice would necessarily require a large expansion of the electricity generation, transmission and distribution infrastructure. The most cost-effective addition to renewable electricity generation capacity would likely be the Site C project on the Peace River, which could be followed over the long-term by other large-scale hydro projects after updating environmental and economic feasibility studies. In the near-term, an expansion of small-scale hydroelectric projects and wind power projects developed by Independent Power Producers could be expedited by BC Hydro. To accommodate the increased demand for electricity there is also be a need for a greatly expanded and strengthened electricity transmission and distribution system.

REFERENCES

1. NRCan, *"Canada's Energy Outlook-2006",* Natural Resources Canada, 2006.
2. Evans, R.L., *"Fueling Our Future: an Introduction to Sustainable Energy",* Cambridge University Press, 182 pp., 2007.
3. BC Ministry of Energy, Mines & Petroleum Resources, *"The BC Energy Plan: A Vision for Clean Energy Leadership"*, 2007.
4. Electric Power Research Institute, *"Comparing the Benefits and Impacts of Hybrid Electric Vehicles"*, 2001.
5. BC Hydro, *"BC Hydro 2008 Long Term Acquisition Plan",* 2008.
6. Kerr Wood Leidal, *"Run-of-River Hydroelectric Resource Assessment for British Columbia",* 2007.
7. International Energy Agency, *http://www.oja-services.nl/iea-pvps/pv/home.htm,* 2005.
8. Grubb, M.J.*, "The integration and analysis of intermittent sources on electricity supply systems".* PhD thesis, Cambridge University, 1986.
9. Global Wind Energy Council, *"Global Wind 2007 Report",* 2008.
10. International Energy Agency, "*Renewables and Waste in World in 2005",* 2005.
11. British Wind Energy Association, *http://www.bwea.com/ ,* 2008.
12. BC Hydro, *"Green Energy Study for British Columbia – Tidal Current Energy"*, 2002.
13. Canadian Hydraulics Centre, NRC, *"Inventory of Canada's Marine Renewable Energy Resources",* 2006.
14. Wavegen Ltd., *http://www.wavegen.co.uk/*
15. University of Edinburgh, *http://www.mech.ed.ac.uk/research/wavepower/*
16. Pelamis Wave Power*, http://www.pelamiswave.com/index.php*
17. Sheehan, J., Camobreco, V., Duffield, J., Graboski, M., Shapouri, H., *'An Overview of Biodiesel and Petroleum Diesel Life Cycles',* NREL Report: NREL/Tp-580-24772.
18. Pimentel, D., and Patzek, W., *'Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower'*, Natural Resources Research, vol. 14, 1, 2005.
19. Western GeoPower Corp., *http://www.geopower.ca/index.htm*
20. Massachusetts Institute of Technology, '*The Future of Nuclear Power: An Interdisciplinary MIT Study',* MIT press, 2003.
21. Government of BC, *"The BC Energy Plan",* 2007.
22. BC Hydro, *"Report on the F2006 Call for Tender Process Conducted by BC Hydro,* 2006.

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