Abstract

This paper provides a broad overview of a coupled Wind-Power and Pumped Storage electrical generation system. The limitations and advantages in terms of costs, profitability and externalities of each system are discussed, and potential synergies are examined. Arguments for the coupling of the two systems are explored, and an economic model using two electrical generation assets in Alberta, Canada, to determine whether this coupled system is more profitable than wind-generation alone. It is shown through this model that wind generation alone is approximately four-times less profitable than a linked wind-power and pumped storage system. Additionally, the coupling of these two types of generation provides a solution to some of the limitations inherent in wind. By making wind more profitable, this model provides means for the proliferation of wind-power generation and thus mitigating some of the externalities inherent in conventional electrical generation.

Wind-Power Generation

What is Wind-Power Generation?

Generation of electricity by mechanically capturing the kinetic energy of wind is the fastest growing method of electrical generation worldwide. Though wind generation still only accounts for a very small percentage of the world’s electricity supply, it is a desirable addition to the energy mix because of the very small environmental impacts, and the relatively low operating costs.

The energy contained in wind is a product of the sun’s energy. As solar energy contacts the atmosphere and ground, warming occurs. Because this warming is not uniform, and because (as predicted by the second law of thermodynamics) heat energy generally moves towards areas where it is less concentrated, in this case carrying along a volume of air with it, a current of air is created.

The Three Laws of thermodynamics are integral to any discussion entailing energy, and most specifically any discussion about the generation of storage and electricity. For consistency’s sake, they are paraphrased below:
The three laws of thermodynamics apply to the generation of electricity from wind. First, incident energy from the sun strikes the earth, warming it. This transformation of radiant energy to heat exemplifies the first and second laws. Heat rising from the warm ground towards the cool sky exemplifies the second law, and this process carries air molecules around as a consequence. These air molecules, now moving in heat convection currents have a different sort of energy, kinetic (movement) energy. At first, this seems to contravene the first law, however, if we take into account the fact that a very large amount of heat must move from the ground to the sky in order to move a very small amount of air, we see that this transformation of energy does indeed satisfy the first law.

Now the moving air organizes into currents on a larger scale, losing some energy to friction (lost as heat) but also combining many smaller currents into one larger kinetic energy flow. It is this energy that is captured from the wind, through the employment of a turbine, and transformed into electrical energy (with another loss of heat).

Now, all this sounds terribly inefficient, and begs the question, “why bother to capture energy from the wind at all?”

The answer is somewhat complicated. It is true that in terms of thermodynamic efficiency, electrical generation from kinetic energy in wind is very inefficient. Fortunately for the developers of wind...
farms, there is an incredible amount of energy coming in from the sun every day, which, inefficiently or not, is transformed into an equally incredible amount of kinetic energy.

To put this in perspective, plants capture a few percent of the sun’s energy and transform it first into proton motive force (electrical) and then into sugars (chemical energy). Millions of years ago, plants were doing the same thing, and some of these plants were buried in river deltas and were slowly transformed into more complex chemicals like coal and oil (another form of chemical energy). We can now mine a piece of coal, turn it into thermal energy by burning it, heat water into steam (kinetic energy), and use the steam to drive a turbine to make electricity. There are at least five transformation steps in generation of electricity from coal, whereas from wind, there are only three.

Adding to this the fact that plants only capture a few percent of the incident energy in sunlight, and solar panels the world over even less, most of the energy coming in to the surface of earth becomes heat and through convection, wind. Wind is actually one of our most efficient ways of getting energy from the sun.

In fact, wind carries a large amount of energy, for every cross section of a wind current of a given area, the amount of power, or wattage, that that current carries is determined by:

\[ P_o = \frac{1}{2} \rho A U_o^3 \]

Where \( P_o \) is the power in Watts/M\(^2\) contained in the wind  
\( A \) is the cross-sectional area of the wind current  
\( U_o \) is the speed of the wind current  
\( \rho \) is a function of density, which can usually be ignored as the variation in density is insignificant next to the variation in speed\(^3\)

We can see that the variation in power in the wind is largely due to the speed of the wind current, which is cubed in this function. This makes intuitive sense; most of us would agree that wind blowing harder is more energetic.

In generating electricity from the wind then, we are limited in the electrical power we can produce by 1) the amount of energy lost in the transformation of kinetic to electric energy, in other words, the
efficiency of the generator, 2) the cross sectional area of wind that our generator can reach, and the portion
of this cross-section that it can access at any given time, and 3) the speed of the wind.

We are fortunate that engineers are very close to maximizing the efficiency and cross-sectional
access of wind turbines, but the most we can do about the speed of the wind is to gamble with the statistics
of meteorology. Investors in wind generation must take this risk into account, the operators of electrical
grids must consider this risk when allocating reserve units, the owners of transmission assets must consider
the variability of use that a wind operation will provide, and operators of wind generation facilities must
consider their revenue stream, which, after all, is dependant on whether the wind blows.

Or is it?

This article intends to show that there is a method of neutralizing much of the risk in the great
meteorological gamble of wind-electrical generation. In fact, for all parties, investors, systems operators,
transmission operators, and wind-farm owners, there is a relatively simple way of alleviating much of the
uncertainty in wind generation, and at the same time, perhaps maximize profits.

**How does Wind Electrical Generation work?**

Before we get too far into the economics, it is perhaps germane to this discussion to briefly examine the
mechanical side of electrical generation from wind. We have already discussed the physical theory behind
this, but the practical application of solutions to the physics problems posed above are quite elegant and
very interesting.

Later on we will examine an economic model for a wind farm in southern Alberta that uses the Vestas 660
turbine, so we should examine one of a similar type.
The Vestas V66-660 Turbines are very similar to the one above (a Vestas V80-2.0MW, from the Vesta website). They appear quite impressive, about the size of a city bus, standing on a pillar that rises 50m above the southern Alberta grassland. The 660 generates a maximum of 660kW, or 0.66MW. It has a cut-in wind speed of 4m/s and reaches maximum generation at a wind speed of 16m/s.

Many of the other types of turbine on the market are similar in design and features, though there is one alternative design that bears mention, the vertical (or eggbeater) turbine uses an interesting arrangement of vanes to accomplish very much the same job, just at 90 degrees to the example shown above.
A turbine is essentially a giant windmill. Except that the windmills of the past, were actually used to turn mills to grind grain into flour or to saw wood into lumber. The same principles apply here; the wind blows through the propeller-like blades, making them turn. The shaft that they turn on also turns, and in doing so, drives a massive coil through a set of massive magnets, which generates an electrical current. This electrical current, is then sent out on a wire, and after a few adjustments, is combined with the electrical flow on the grid. A single turbine is good, but a large group of turbines, 60 or more, working together in the same wind flow (generating synchronously) is much better.

**Economics & Future Outlook**

In recent years, much has been made about the idea that wind electrical generation is not as economic as other forms of electrical generation, that perhaps, without government subsidies, it is not economic at all.

Though throughout the 1980s and much of the 1990s, this may have been the case, it is now coming clear that wind-power is economic or very nearly so the world over. Though there are still dissenting opinions on the matter, it is clear that if an investor is willing to put forward the initial cost, a steady stream of revenue can be produced from a wind operation. In order for this revenue to be economic, it must be greater than the costs involved (accounting profitability), and greater than the amount that investor could generate by investing in the “next-best-thing” (economic profitability).

If we look at the investment in these terms, wind-power does not always look so rosy. It does usually generate income and generally this income outstrips the inherent costs. But it may or may not cover the risk-free investing rate of return, and even more worrisome, it rarely, if ever, generates a higher return than if that money were invested in a ‘dirtier’ form of energy generation.

As an example, for a single wind turbine, the investment is roughly $1,500.00/kw, so for the Vestas 660 turbines, a price tag of $990,000US ($1,319,967.00CDN) is not unreasonable. On top of that,
there are some maintenance costs, and generally a lease arrangement with the owner of the land that the
turbine is placed upon, generally on the order of $2,000 per year. So this one turbine has to cover the
$2,000, plus a portion of the $1,319,967.00 (a good estimate is 1/17, about $77,645.18) yearly. And as we
will recall, this revenue is entirely dependent on the wind, and also on the price that the electricity
generated will get when sold into the power pool. Further on in this paper we will model the economics of
this situation in detail, for now, let us presuppose that this turbine generates a revenue stream of
$470,000.00/year, a number, we shall see, that is quite reasonable.

This turbine then has an accounting profitability of:

\[
\begin{align*}
\text{Revenue} & = 470,000.00 \\
\text{Less Maintenance} & = 77,645.18 \\
\text{Less Lease} & = 2,000.00 \\
\text{Total} & = 390,354.82 \\
\text{Tax~30\%} & = 117,106.45 \\
\text{Net Profit} & = 273,248.37
\end{align*}
\]

And on this basis, appears quite profitable. Extended over the expected 17 year life of the turbine,
this translates to a profitability of $4,645,222.36. If we consider this against an average market return (from
a Market risk premium of 7%, and a risk free rate of 6%) on investment of the same capital amount for 17
years, we see quite a different story.

\[
NPV = -Co + \sum (CFAT_t) \frac{1}{1+RRR},
\]

\[
NPV = -$1,319,967.00 + $329,000.00PVFA(17,13\%) + ($990,000*0.30*0.2)/(0.13+0.2) - $2,000PVFA(17,13\%) - $100,000.00/1.13^{17}
\]

\[
PVFA(17, 13\%)= 1/0.13-1/((0.13*(1.13^{17})) = 6.729092978
\]

\[
NPV = -$1,319,967.00+$2,213,871.59+$180,000-$13,458.19-$12,521.79
\]

\[
NPV = \$867,924.61
\]

Greater than 0, and thus profitable in an economic sense, however, this calculation does not take
into account the profit that could be achieved by investing in another project in the electrical generation
industry. The opportunity cost is where investors in this type of project get hung up. Typically, a coal-
-fired power plant in Alberta generates a return on assets quite a bit higher than wind generation (Costs
about 2.8c/kwh\(^7\), whereas sales are near 35c/kwh, by contrast, wind-power generates for about 4.2c/kwh, or
nearly double the cost) and higher than the market itself. This is simply due to the lower capital cost per
Megawatt. Though, running costs in coal fired plants are higher, the question of economics lies here (externalities, while very important in this discussion, will be addressed in the following section).

In fact, for base-load applications (where the electricity is sold into the grid as it is being generated) wind generation cannot at present compete with cheap, base-load coal fired generation. There may be a way, however, to increase profitability on a fourfold scale, which is more than competitive with any other form of electrical generation.

This very profitable model will be discussed in detail below, briefly; it is the linking of the wind-power generation with a storage method, it this case water, pumped uphill into a reservoir, all of this coordinated with the sale of electricity in times of peak demand (high price).

In the future, in Alberta, it is suggested that more than 700MW of wind generation will come on line. Globally, wind-power generation continues to grow at rates approaching 20% annually, and with each new generation of wind turbine designed, costs go down and power generation goes up. It may be conceivable to use wind as a base-load generation asset as costs continue to drop, however, there are several problems inherent in wind generation that will require some form of storage and release system (capacitance), to balance the inherent uncontrollability of the wind itself.

**Problems**

There are several problems facing investors in wind-power generation. Several were discussed above, such as the inherent variability of wind, the high capital cost of investment in wind generation, the profitability issue, and externalities.

Variability in the speed and thus the power available in the wind can only be partially avoided by perfect siting of the wind-turbines. While this mitigates some of the risks, and at least statistically can provide some surety that the turbines will spin for a predictable portion of the year, it cannot predict
precisely when these turbines will spin, and if this happens to be a time when the power pool price is high enough to make selling the electricity worthwhile.

This is a problem that flows from the nature of electricity; once generated, it must either be used, or lost. With little or no capacitance in the system at present, and no storage, this single fact is responsible for vast amounts of wasted energy, and the need to have large amounts of reserve generation ability standing by. Wind generation, at present makes up only a small portion of the generation assets in Alberta, but if 700MW come on line within the next five years, this proportion will change dramatically. The problem presented by this is that the Alberta Electric Systems Operator will very likely need to balance the riskiness of these 700MW with an equivalent reserve. This will present a large cost to all electricity consumers in Alberta, and, as we will show, is entirely unnecessary with a relatively small amount of storage in the system.

This is a time when environmental externalities are being considered quite heavily. With the implementation of the Kyoto accord and international focus on the emissions of Carbon Dioxide and Methane gas, wind-power generation may seem to be a good way for some corporations to manage their public image and carbon credits. While this has and will continue to stimulate investment in wind farms in Alberta by companies that are otherwise large industrial emitters, this has led to a marginalization of wind-power generation as just a good way to get some social equity and carbon credits. This does nothing to manage the emissions of greenhouse gases in Alberta. It is simply a manifestation of the fears that some policy analysts have stated that Kyoto may cause short-term changes with little long-term investment.

Long-term management of emissions in Alberta is important. And generation of a large portion of our electricity through wind-power can go a long way to achieving this. But to do so, it has to be economical. While Kyoto may allow investors and operators of wind facilities to trade their carbon credits and perhaps create some value for the investors in that way, long-term profitability at a level that competes with other electrical generation assets will do far more. If wind generation is truly more profitable than
other means, there is a great incentive to retire more environmentally damaging electricity generation assets and invest in new wind-power generation assets.

Beyond emissions, there is the onus on Albertans for the long-term management of our endowment of natural resources. The value that is contained in coal, oil, and natural gas is not simply the heat that it can produce when burned, there is far greater value to humanity in other chemicals produced from these products. Take oil for example. In the past three years, the world has experienced a higher demand for agricultural products than farmers were able to produce. World grain reserves are now drawn down to critical levels. Fertilizers are not only important for the profitability of farming ventures, but for the continued existence of humanity. Industrial fertilizers are a downstream product of oil. Similar examples are plastics, made from natural gas liquids, and hydrogen, made largely from natural gas. The removal of some of the burden of electrical generation from natural gas, coal, and oil by installation of wind-power generation allows a greater proportion of the higher value downstream products of these resources to enter the value stream.

Wind-power generation, coupled with a form of storage, holds the promise of solving not only the problems inherent in wind generation, but also some of the problems posed by the externalities of traditional thermal power generation.

Pumped Storage

What is it Pumped Storage?

Pumped Storage (PS) is one of only a few ways of storing energy for easy use as electricity. Of course, the energy is not stored as electricity, but in another form easily convertible to electricity. Pumped Storage uses water to store kinetic potential energy, and works much the same way as a hydroelectric dam. In fact, a hydroelectric dam is easily converted to a pumped storage facility.
The physics of pumped storage are not nearly so complex as those of wind-power generation. Water, raised to a height, has a certain amount of kinetic potential energy. This is because of the force of gravity pulling it down. If this water is stored and channeled properly, it can do some useful work with its kinetic energy as it flows from high to low. Essentially, the current of water drives a turbine, very much the same way that a current of air drives a wind turbine. This is where pumped storage diverges from traditional hydro-electrical generation. In the traditional model, the water would simply flow away, down channel and if supply of water is large, or if the hydro-generation facility is intended as a base-load unit, then this is perfectly appropriate. However, if the supply of water is limited, or if the hydro-generation facility is intended to operate more as a peak-load facility, the loss of this water can be a problem.

An appropriate for-instance is the contract that the Alberta and Saskatchewan governments have to ensure that 50% of the flow of the Oldman River flows to Saskatchewan. In dry times, this can impact the ability of the Oldman Dam and Reservoir to generate electricity. For this reason, the Oldman Dam is a prime candidate for conversion to a Pumped Storage Peaking Facility.

The critical difference between conventional hydro-generation and pumped storage is the pump. In times when it is economical to do so, the PS facility runs the generation turbines in reverse, using electricity to pump water back up the channel and into the reservoir, in doing so, storing some of the electricity used to run the pump. Of course, due to the laws of thermodynamics, there is a loss, but the efficiencies are quite impressive\textsuperscript{10}, up to 80% overall efficiency.

The ability to generate electricity in any hydro system depends on the amount of energy in the flow of water, which itself depends on the difference in height (head height) between the top and bottom of the system. Where conventional hydro facilities seek to maximize head height, with pumped storage there is an upper limit to the height that water can be pumped economically, so a system with less than 600m head separation is desirable.
How does it work?

As described above, the PS facility is quite similar to a conventional hydroelectric dam. The only major difference is that instead of a single reservoir at the top, there are two, one at the top, and one at the bottom.

The turbines used for pumped storage are slightly more complex than those used in conventional hydro, since they can run in both directions, but the differences are really quite minor.

The illustration above (from the TVA website\cite{1}), shows a typical pumped storage system. This is a rather large facility in Tennessee called Raccoon Mountain, it can generate up to 1,532MW for 22 hours, and its upper reservoir can be refilled in 28 hours. This illustrates the scalability of pumped storage.

\textit{Figure 2 – Pumped Storage Installation at Raccoon Mountain, Tennessee}
Most facilities follow this pattern, however, recently there has been a movement to build “In-Ground” PS. This is essentially a mineshaft between two underground reservoirs (or a surface reservoir and an underground reservoir). This type of construction may be quite a good fit for an area such as Alberta, which has limited topology suitable for pumped storage—or even conventional hydro. As an example, the 28 million liter cooling water reservoir recently constructed on the University of Alberta Campus could provide 40MW for approximately 29 minutes if there were an underground reservoir of the same size below it, with a head separation of about 300m. The value of any such facility does not simply depend on the generation capacity, for it is obvious that the ability to generate 40MW for half an hour when the price of electricity spikes to over $1000/MW could be a revenue source. We must also consider that this provides a large measure of insurance in the system, which would allow the systems operators to keep smaller reserves spinning on standby. We must also consider the costs of such a system.

**Economics and Future Outlook**

Cost analysis of a pumped storage facility involves the capital costs, which can be around $2,000,000/MW, and also the costs of purchased electricity to pump the water up to the upper reservoir. The goal of the operator of such a facility is to pump when electricity is cheapest, and to generate when electricity can be sold for the highest price.

The beauty of the system is that it matches very well the patterns of generation and use of the power pool in general, and even better with the characteristics of wind-power generation. While the pumped storage facility may be profitable as a peaking facility on its own, it may run into problems of consistently running down the reservoir (which would occur if the power pool price remained too high too long), and of infrequent use (if the power pool price remained too low too long). Both of these situations are unprofitable.

The future outlook for pumped storage looks good. Currently there are only very few options for storing energy on a large scale for release over a period of hours. While Hydrogen and Hydrogen fuel cells
may well be used as an energy storage system at some point, currently the best system with proven and
efficient technology is pumped storage. Adding to that, the ease of creating small or large pumped storage
facility in Alberta using the in-ground type is apparent, and will allow Alberta’s electrical system much
needed flexibility as more than 700MW of potentially intermittent wind power come on-line in the next
several years.

**Solving the problems by tying the two together**

The idea that the intermittency in wind-power generation can be smoothed out with the use of hydroelectric
power production is not a new one. In fact, the Province of Manitoba has been studying this for the past
several years, but their model includes little if any pumped storage, as Manitoba has a large resource for
hydroelectric generation.

Several researchers have proposed models using pumped storage, including scientists at GE
Global Energy\(^{15}\), and other experts in power generation\(^{16}\). In all cases, the findings indicate that using
hydropower to balance the intermittency of wind-power generation allows greater economic profits from
wind and provides incentive to entry in the wind-generation market.

**The Proposed Model**

The model I am proposing here is a pilot scale project, but it is highly scaleable. I have used the Castle
River Wind Farm\(^{17}\), owned by VisionQuest, a subsidiary of Transalta Utilities and the Oldman Dam\(^{18}\),
owned by Atco Power. The Castle River installation has a 40MW generating capacity from 60 installed
Vestas 660 turbines. The Oldman Dam is currently a 32MW opportunistic facility, but with some
modification such as the creation of a lower reservoir and replacement of the turbines, and extension of the
east diversion way to create a bypass, can easily be transformed into a 40MW pumped hydro peaking
facility, the Oldman PS.
I have chosen these two facilities for their close proximity, and the approximate evenness of scale of their generation capacity. This model is intended only to show the potential economics of pumped storage in Alberta.

For the model to work, we will put the two facilities under one manager, either by creation of a joint venture between VisionQuest and Atco, or outright purchase by a third party. The primary generation facility will be the wind farm, and electricity generated by the wind farm will be sold onto the grid at market rates, and exactly the same amount of electricity will be purchased by the Oldman PS, unless the reservoir is full. At a certain trigger price, the PS will begin to generate electricity and sell into the power pool, the wind farm will also sell what it is generating when the price is high. The PS will also come on line whenever there is a sudden failure of wind, or the transmission lines leading from the wind-farm are tripped. *This means that there will rarely, if ever, be an outage due to variations in the speed of wind.*

Is all of this necessary? Or would the PS be a moneymaker all on its own? Would the wind farm? Well, we have already seen that the wind-farm will be slightly profitable, but not at the level of conventional thermal electrical generation, and while the PS may be able to make money purchasing power when the price is low and selling when the price is high, it is together that they maximize the profitability. In fact, we will see that there is nearly a fourfold increase in profits over straight wind generation using the combined Wind-PS system.

**An Economic Model for Alberta**

**Assumptions**

Any statistical model must make some assumptions and this one is no exception. First, the average wind speed and variability at the Castle Lake wind farm was provided by another statistical model, Environment Canada’s Wind Energy Simulation Tool (WEST)\(^9\), and given the Weibull\(^10\) distribution shape from WEST.
of 2, it was assumed that the distribution of wind at Castle River approximated a normal distribution around its mean, with a slight modification to ensure that the lower bound for wind-speed was zero. As a check, the usage rates provided by the model I generated closely matched those provided by the Weibull distribution model offered by WEST.

The price of electricity in the power pool was determined statistically by researchers at the university of Calgary\textsuperscript{21}, their conclusions formed the mean and standard deviation of the model used here, though again, a lower bound was applied, which approximately matches the kurtosis in their observations while still allowing a normal distribution.

Pricing was modeled on a daily high and daily low basis, with the daily high receiving a weighting of 4 corresponding to the observed values on the Alberta power pool, while the daily low received a weighting of 20. This approximation allowed a vast simplification of the model without great sacrifice in results, though if this model were to be used for a shorter time scale than 1 year, it would be of value to determine hourly rates and to include seasonal variations.

The characteristics of the as yet unbuilt PS facility are based on a 40MW turbine with the ability to replenish its displaced water in a 5/1 time ratio, that is, for four hours of running, 20hrs of pumping will make up the water used. This is quite conservative, as is the efficiency number of 75\% used for this facility.

In this model, inflation is ignored. And it is assumed that the purchase of this capital is financed with equity as interest rates at this time in Alberta may be uncharacteristically low. Also, an arbitrary corporate tax rate of 30\% was used, as this was an appropriate scale for taxes, and the specifics of how wind farms are taxed are quite complicated.
The Model

Three scenarios were examined. An arbitrary sell price just below the average daily high price was used as a threshold value for sales in the first scenario, where the PS will always pump for the 20 low hours, but if the price is below the threshold, it will hold. Wind is always sold during the high hours.

In the second scenario, both wind and PS are sold during the high 4 hours, and pumping occurs every day.

The third scenario is a control scenario, where the PS is not part of the operation. Wind is sold onto the grid as it is produced.

Each scenario was modeled for an entire 365 day year, and each year was modeled several hundred times. The data from a single year was used to calculate summary results, as the variation in the model at that scale was quite low.

The summary results of this model are presented below (complete model is available in Appendix 1). As you can see, the best solution, by far, is to pump storage during the part of the day when the base load is being handled by more economic generators, and to sell power during the daily high.

<table>
<thead>
<tr>
<th></th>
<th>Sell above $900.00/MWH</th>
<th>Sell Every High Period</th>
<th>Wind Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profit</td>
<td>$67,789,566.52</td>
<td>$74,658,290.99</td>
<td>$17,943,180.14</td>
</tr>
<tr>
<td>MWH Sold</td>
<td>$100,800.00</td>
<td>$116,800.00</td>
<td>$91,104.00</td>
</tr>
<tr>
<td>Profit per MWH</td>
<td>$672.52</td>
<td>$639.20</td>
<td>$196.95</td>
</tr>
<tr>
<td>ROI</td>
<td>0.5467</td>
<td>0.6021</td>
<td>0.2991</td>
</tr>
</tbody>
</table>

Figure 3 – Profitability Summary from Monte Carlo Simulation of Wind-PS Model

Any investor in electrical generation may take note that while the ROI in all three cases is quite high, it is notable that in the suggested alternative, an ROI of 0.6021 is quite respectable in an highly
capital intensive industry where most of the costs are up-front and after they are amortized, all sales become profit.

ROIs would be double in the system with coupled storage and production of electricity. This may make some investors interested in green energy for ethical reasons, or simply for the access to carbon credits, take notice of this possible alternative.

Conclusions

As we can see from the model above, wind-power generation, while profitable on its own, does not provide the same type of return that conventional electrical generation does, however, coupled with an energy storage device like a PS facility, the profitability of wind-power generation can increase by up to a factor of four.

Though the economics speak for themselves, it may be of use for the government of Alberta to encourage the construction of some pumped storage along with the suggested 700MW of wind-power generation soon to be built. This would allow some leveling of supply in the event that the wind simply does not blow, as well as allow a great economic opportunity for investors interested in encouraging environmentally benign development. This encouragement could be in the form of a tax credit or an extension of the 1.2 cents per Kw now given to wind producers to the operators of PS facilities.

Future Directions

As the Kyoto Accord comes into force and carbon credits begin to have value, and as the general consumer continues to develop an environmental sophistication, more and more governments and developers will rely on the greener alternatives for electricity generation. Because of the amount of energy contained in the
wind, and its proximity in the energy conversion chain to the sun, wind-power generation is a very attractive option.

Whatever the proportion of electricity produced from wind is in the future (these proportions will always change), wind will make up an increasingly important segment. Given the variability in supply that is inherent to the wind, it is only prudent to explore ways of mitigating the risk involved in having such a large portion of our energy mix reliant on it. Traditionally this would mean backing-up wind generation with a quick-start diesel or natural gas, or even coal-fired generators. This counter-productive practice can be alleviated through the use of pumped storage now and in the middle term, and as more electricity storage technologies become viable—such as the electrolysis of water into Hydrogen and Oxygen and the use of hydrogen fuel cells to reclaim that energy—perhaps an even greater portion of our grid can be supported by wind and other forms of renewable energy.
References

1 http://www.physicalgeography.net/fundamentals/6e.html
2 http://www.eng.dmu.ac.uk/~hmc/wetcm1s0_1.html
3 http://www.vestas.com/uk/profile/students_room/products/3d.asp (Public Domain)
4 http://archives.cnn.com/2000/NATURE/06/14/wind.power/
5 http://www.eere.energy.gov/windandhydro/wind_ad.html
6 http://www.techcentralstation.com/070102M.html
8 Doucet, J. The Kyoto Connundrum, May 2003, Backgrounder for the C.D. Howe Institute
10 http://www.edie.net/library/view_article.asp?id=2586&channel=6
11 http://www.tva.gov/power/pumpstorart.htm (Public Domain)
12 http://www.iwk.uni-karlsruhe.de/iwk/aktuelles/temp/Pfingstexkursion/Pumspeicherkraftwerk/Englisch.htm
13 http://www.poemsinc.org/FAQfuelcell.html
14 http://www.edie.net/library/view_article.asp?id=2586&channel=6
17 http://www.visionquestwind.com/existing.asp?pg=castle&mi=04&bdy=castle1&id=existing
18 http://www.atcopower.com/our_facilities/In_North_America/OldmanRiver/oldman_river.htm
21 http://econ.ucalgary.ca/fac-files/fja/FractionalDifferenceModelingFJA.pdf

Other Resources


DeMeo, E., Parsons, B. 2003. Some Common Misconceptions about Wind Power. Presentation to the the All States Wind Summit, Austin, Texas

Appendix A – Monte Carlo Simulation for Profitability of Linked Wind and PS

(Separate File – available from the author)