

DISPATCHABLE HYDRO-ELECTRICITY

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ABSTRACT

The supply of electricity in Ontario is at a crossroads: The fortuity to have an entirely green electricity supply from completely renewable and sustainable sources is both possible and affordable. The recent rapid proliferation of gas turbine plants in this Province is seen as a short-run expedient political decision, necessary to quickly replace shuttered coal plants as well as to provide a 100% backup for the equally rapid construction of unpredictable and unfirm wind and solar energy sources (two earlier political decisions). Before the last coal plant is shut down in 2014, gas turbine output will likely exceed the capacity from coal that existed at its peak ten years ago. This will soon result in overall lower air quality as, collectively, these gas plants eventually exceed the peak air pollution and greenhouse gas emissions from coal. When this point is reached, what will we have gained for the environment and for the people in Ontario plus those living downwind breathing this polluted air? A permanent, clean, and sustainable solution is needed.

The author's research will show how *all* the clean and renewable energy can be captured from a river network, and all in a dispatchable form. In doing so, stability in the transmission grid can be maintained through a 100% hydraulic back-up of all the intermittent renewable sources. Then, through eliminating the gas turbine plants over time as age overtakes them, similar to the way that coal is being curtailed today – including the option of no new nuclear plants being required in the future – Ontario will arguably have one of the greenest electricity systems in the world. This Province can enjoy the least expensive non-subsidised renewable electricity of any G8 country.

Keywords: sustainable sources, dispatchable, hydraulic back-up

INTRODUCTION

Water behind a powerhouse represents electric energy not yet produced. The storage “battery” is the headpond. The proposed dispatchable operating method can be described as a distributed energy storage system with similar objectives as other types of energy storage, designed to smooth out the supply of electricity in the grid through accommodating the erratic output derived from wind and solar as well as meeting a constantly fluctuating demand. Other main advantages are:

- (a) It is all renewable energy with little environmental impact since flooding will be minimal;
- (b) It can eliminate the surplus energy issue while providing a 100% back-up for wind and solar;
- (c) Unlike most other storage methods, there are no losses resulting from energy conversions (electricity into another storage medium and back again) since water is a primary source;
- (d) Controlling the flow in these rivers can greatly reduce the risk of urban flooding; and,
- (e) The immense generating capacity possible with northern rivers greatly adds to continental energy security without the depletion of fossil fuel reserves.

With proper maintenance, hydro-electric facilities can last for centuries. There are also profound implications for an improved quality of life for native persons living in the developed watersheds, including road access plus well-paid jobs in an area which has a chronically depressed economy.

This paper will show how a 100% green energy system can be established in Ontario – it is also applicable to any part of the world with a reliable flow of water – and describes the research necessary to prove the case. This approach unlocks over US\$40-billion annually in renewable and dispatchable electric energy in Ontario alone. This energy can be made available for export to the US to enhance the energy security of two countries while improving respiratory health on both sides of the border. Exports of dispatchable hydro-electricity can directly replace energy derived from coal. Half of the air pollution in Ontario is largely from coal plants in the American Mid-West; such pollution is undoubtedly more intense nearer to the sources in those Mid-West states.

HISTORICAL PERSPECTIVE

In the past, locating sites for hydro-electric plants was very easy: Just look for large drops in river elevation at rapids and falls. Then, for engineering efficiency, specify turbine capacity such that they will operate nearly 100% of the time, regardless of the seasonal streamflow. This effectively results in turbine capacity handling about 50% of the average flow or about 20% of the total recoverable energy. Thus, 80% of the energy remains in the river untapped. We can, and must, do better in a world which is calling for more renewable and sustainable, non-polluting energy.

And we can do better. Your author has found a method for capturing *all* of the energy in a river system (except at the highest reaches) without massive flooding along the main river and tributaries on which the powerhouses are located. The water is confined to the established river channel so that no gratuitous flooding can take place. With northern rivers, this means getting all of the energy contained in the freshet (spring flood) as well as deploying a

method for supplementing the flow during the late summer drought (when the streamflow can drop to as low as 50% of its average annual value) thereby keeping generating output stable. In areas which were considered fully developed, the net effect is that the energy yield can climb by five times the present output. All of this energy can be dispatchable, which means that it can directly substitute for coal and gas turbine sources, and with a much faster ramp-up response. All it takes is good geography in a temperate climate zone and a desire to leave a green legacy for generations to come.

HOW IT WORKS

The factor which started this line of research was the dismay that none of the lesser rapids and falls was developed in rivers otherwise replete with powerhouses. It is obvious that there is energy being released at such locations, but there did not seem to be any concern by the generating authorities to capture this energy. The issue for them was cavitation: At heads below seven metres (about 23 feet), cavitation problems can arise which, over time, can destroy a turbine in a cloud of shrapnel. None of the commercial turbines in use in Ontario are at heads below seven metres.

While this could have remained an insurmountable physical barrier, a careful examination of the situation reveals that cavitation is caused by insufficient pressure in the water column to suppress the creation of tiny low-pressure bubbles. What was needed was an efficient turbine which did not rely on hydraulic pressure: Effectively, the solution is a water elevator which is always in the “down” direction. The author, along with a partner (now deceased), devised such a device and installed it at a private lodge in 1988 – it has operated continually ever since and is sufficiently robust to survive the cold northern winters over all of these years. At this demonstration site, the turbine drives a 25 kW, three-phase generator. The turbine technology is believed to be scalable to about 1,500 kW and can effectively handle heads from two metres to more than six metres.

It has taken over two decades to find a proper use for this turbine technology, but that issue has now been solved. The problem was an initial promotion of this turbine as a stand-alone technology when it properly belongs as a part of

a system as described herein. The lesser heads below seven metres between the high-head sites can be outfitted with various designs of this low-head turbine which can then capture the energy otherwise lost in the present hydro-electric configurations which only address the higher heads. But in doing this, certain synergies were unexpectedly discovered.

At a discussion with Ontario Power Generation officials in May, 2008, it was noted that at their Lower Notch GS, the turbines only operated about 16% of the time (under four hours a day)

because they could not get sufficient water to the penstocks. The next site upstream was too far away for the water to cover this distance in a timely manner. Lower Notch is higher than Niagara Falls and has two 138-MW turbines; the loss in capital efficiency was duly noted at the time. With the possibility of interstitial low-head powerhouses, water can be advanced closer to the next downstream high-head site, as shown in Figure 1. This approach could make it possible to operate Lower Notch perhaps 50% or more of the time, covering most of the daily peak demand hours.

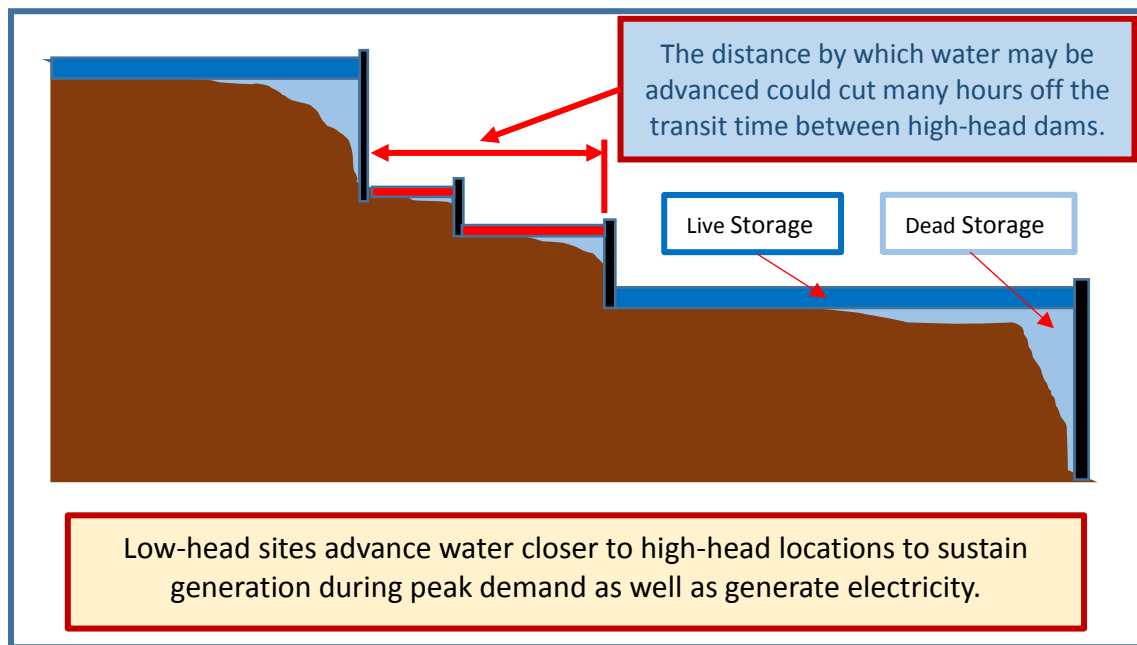


Figure 1: Approach of operating Lower Notch at 50% or more.

In the past, low-head sites have been shunned in the hydro-electric industry because they are not particularly cost-effective; the money is made at the high-head sites. The discovery that the low-head sites could improve the operation of the highly efficient high-head sites was unexpected, although it seems obvious now. Thus, this synergy changes the view that low-head sites are ineffective. If the low-head sites can advance the position of the water closer to high-head sites that can become starved for water, they can allow such high-head sites to operate more effectively.

Another, related, synergy also appears: With the inclusion of the interstitial low-head sites, the total amount of water which can be stored in the headponds throughout the entire watershed will increase. If the high-head site downstream has an adequate water supply, the extra water stored and release by one or more upstream low-head sites may allow the generating capacity of the high-head site to be cost-effectively increased. All sites below this point may also benefit from an increased capacity, since this stored water, when released, will pass through all of them as well. In the example of Lower Notch, were interstitial low-head sites to

advance the water and increase the operating time to 12 hours, there is the option of constructing a third turbine to boost the power output to 414 MW, allowing the plant to operate flat out during eight hours of the peak demand period. This is twice the present daily operating time along with 50% more generating capacity.

These concepts are most important in a system which is operating primarily in a dispatchable mode, with most generation taking place during the daily peak demand hours and with most powerhouses shut down overnight while the headponds refill. Hydro-electricity, made in a dispatchable mode, is the most useful form in which electricity can be created:

- (a) It is extremely flexible with rapid ramp-up capability (most turbines can reach operating speed within a minute after dispatch orders have been executed);
- (b) Accordingly, it is able to track the load curve quite closely, a very important feature when tracking demand with intermittent sources, such as wind and solar, in the supply mix;
- (c) With interstitial low-head powerhouses, there is more stored water in the system and the average flow can be exceeded for extended periods at times of peak demand;
- (d) Sites with sufficient water capacity can have their generating capacity increased so that they can effectively use the increased streamflow from water released at powerhouses above and though drawdown of their headponds, thereby greatly increasing output during the day; and,
- (e) Output is largely curtailed at night while the headponds refill and little generation is scheduled to take place.

SOME PROBLEMS WHICH HAD TO BE OVERCOME

Were all the energy to be captured, one objective which had to be met is that, clearly, no water can be spilled unharnessed. The present *modus operandi* for hydro-electric plants located only at the high-head sites is to spill copious amounts of water. In fact, about 80% of the water is spilled since, as stated earlier, only about 20% of the available energy is captured

on an annual basis. This immediately introduces two issues which had to be resolved:

- (a) What to do with surplus energy (energy produced when there is no market demand); and,
- (b) How to handle the freshet (spring flood), when the streamflow can temporarily spike to five or ten times its annual average value, if no water is to be spilled unharnessed.

ABSORBING SURPLUS ENERGY

Eliminating surplus energy is particularly important since the Ontario grid has recently been awash with it, largely caused by the myriad of wind turbines coming on-line (by contract, the Ontario Power Authority is obligated to accept and pay at subsidised rates for all wind and solar energy produced, even if there is no market demand) plus soft demand since 2008 which has occasionally dipped below the base load supply at night. During the past few years, the OPA has paid over \$100-million to dissipate this unwanted energy through negative rates; countless other megawatt-hours have been dumped at extremely low prices. The cost of this largess is showing up in consumer electricity bills when this cost is eventually paid by the voting public; rates are up by 20% over the past few years as the Province marches on towards the highest rates in the country.

The research effort has sought a useful application for this extra energy; the present method of disposal will not be politically viable for much longer. The hydrolysis of water meets the necessary criteria – the ability to operate at any power level and to be insensitive to rapid changes in power. But the question then becomes: what to do with the hydrogen and oxygen which are produced? The oxygen will be absolutely pure – medical quality – so a market already exists for it, but the market for hydrogen is less well defined. Certainly it could be used in fuel cells as the automotive market is beginning to adopt this technology, and also by the petroleum industry for cracking heavy oil. However, a more certain method for using the hydrogen in a beneficial way is to create a green chemical industry and fix nitrogen as the first step in manufacturing agricultural fertiliser for which there appears to be an insatiable demand.

Over one percent of all the energy from all sources used by the human race is deployed in fixing nitrogen for making ammonia (NH₃); a new plant is needed somewhere every two to three years to keep up with world demand. The present industrial process uses nitrogen from air and hydrogen from the methane in natural gas, plus a cheap catalyst (iron filings); this is a dirty process which emits copious amounts of air pollution plus methane and carbon dioxide, both greenhouse gases.

The process advocated here would also use the Haber-Bosch method, but would use pure nitrogen and pure hydrogen – there will be no carbon involved to cause air pollution or greenhouse gases. The nitrogen would be fractionally distilled from liquid air; this would also yield all of the other components of the atmosphere, such as industrial quality oxygen, carbon dioxide, plus the noble gases (neon, argon, krypton, and xenon) which can be purified and sold.

Since about half of the nitrogen fertiliser sold in North America is in the form of urea (carbamide) created by reacting liquid carbon dioxide with anhydrous liquid ammonia under high heat and pressure $\text{CO}_2 + 2\text{NH}_3 \rightarrow \text{CO}(\text{NH}_2)_2 + \text{H}_2\text{O}$. The carbon dioxide segregated by precipitation when creating liquid air will be used here. But this is insufficient carbon dioxide given that the yield might be hundreds of tonnes per day. To correct for this shortage, it should be possible to obtain carbon dioxide sequestered at coal plants, sent by pipeline to the green chemical works; this should be much less controversial than building Keystone XL. In this way, the expense of storing carbon dioxide underground is avoided plus the risk that it might eventually escape into the atmosphere. The carbon locked into urea is generally absorbed into plants as part of their biomass.

MITIGATING THE FRESHET

While the streamflow can spike to between five and ten times the average annual flow during the freshet, it is a relatively narrow peak which lasts at best a day or so before subsiding. This effect is compounded in northern rivers which actually flow north; the freshet can catch up with river ice

(which has not yet had an opportunity to melt) and create ice dams over an extended length of river channel, leading to extensive local flooding. The actual volume of water in the freshet is rather modest; the problem is that this water rushes forth all at once. This points to a solution: Don't let a substantial amount of this water reach the main river. By carefully choosing the location of impoundment reservoirs along the tributaries which are not used for hydro-electric generation, it will be possible to hold back sufficient water so that none need be spilled at the powerhouses.

The question then becomes: what to do with the impounded water? During the late summer, there is a seasonal drought where the streamflow can decline to half of its annual average flow. The impounded water can be released in a planned and controlled manner throughout this period, helping to maintain the streamflow at the powerhouses with a more or less steady rate. It is expected that the impoundment reservoirs will be completely empty by the autumnal equinox when the autumn rains start and the streamflow begins to return to its average rate. But there is more ...

Throughout the year, demand for electricity is less on weekends and holidays. This is not an issue during the summer since there is a water shortage and less demand results in less water used in generation. However, over the fall and winter months, there is more water flowing in the system, and this could result in a need to generate surplus electricity at these times if no water is to be spilled. Extra water can be diverted into the impoundment reservoirs, stored as a reserve against periods of unexpected excessive demand during the winter months. The impounded water will normally accumulate until the spring – but these reservoirs must be empty for the beginning of the next freshet! Starting at an appropriate point before the freshet begins, the accumulated impounded water can be released gradually over several weeks and the extra energy which will result can increase the activity at the green chemical industry. The increase will end when the freshet is over.

In this manner, the impoundment reservoirs can be used twice in each year.

OTHER ISSUES

The watershed which will be modelled is very remote from where the electricity will be needed – in fact, over 2,000 km distant. At 10% or more, line losses in alternating current transmission could be a serious impediment to moving this energy efficiently to market. However, the use of high-voltage direct current lines is a feasible at distances exceeding about 750 km with losses of 3%; Manitoba Hydro has two DC circuits extending over 800 km from the Nelson River to Rossiter (Winnipeg), showing the feasibility of this technology within the temperate climate zone.

Climate change is quite favourable to hydro-electric generation: The temperate zone is expected to have precipitation increase by as much as 10% (according to past articles in *Scientific American* and *Nature*); areas of the globe nearer to the Equator will be drier. Also, a longer growing season will enhance the growth of trees for logging as the commercial tree line gradually shifts northward.

All wind farms in Ontario are land-based – there is presently a Provincial moratorium on locating wind farms in water tracts. Unfortunately, winds blow stronger and more consistently by perhaps 50% over the Great Lakes in the southern part of the Province since there are no hills or trees or buildings to attenuate the strength of the wind. The difference is 200 W/m² compared to 300 W/m². But by far the best sites for wind energy are off the southern coast of Hudson Bay, where:

- (a) There are no people to complain about the location of the wind towers (only polar bears!);
- (b) The energy is about 600+ W/m² gathered from winds that blow consistently strong; and,
- (c) The actual footprint of the wind towers will not be in Ontario, but in the Territory of Nunavut, so the Ontario moratorium will have no effect regardless of how long it remains in place.

Wind energy sources located in Hudson Bay will be included in the modelling process.

FURTHER RESEARCH IS NEEDED

Research is needed to provide support for the concepts stated above. A computer simulation program will be needed as a tool to examine the dynamic situation within a watershed as the water flows from one powerhouse to the next. The program will be of a general nature adaptable to any watershed and river network configuration, any streamflow, and with any electricity market demand and supply mix. The program will require the support of an extensive geographic analysis of the watershed being analysed to provide specific input parameters. The simulation clock tick will be five minutes, coinciding with the frequency with which dispatch orders are issued by the Independent Electricity System Operator. *Inter alia*, the computer model is intended to show:

- (a) The maximum amount of energy which can be produced during the peak demand hours between 0600 and 2200, reporting figures divided into five minute intervals;
- (b) The amount of energy produced during the period 2200 through 0600;
- (c) The amount of surplus energy produced throughout the day;
- (d) How much water is spilled, if any, and when;
- (e) The optimal powerhouse and impoundment reservoir locations;
- (f) The optimal number of generating units and their capacities within each powerhouse;
- (g) How a predictive capability will allow an optimum positioning of water at all times;
- (h) How the model responds to tracking the load curve as published by the IESO historic forecasts with the assumptions that:
 - i) Both gas turbine and nuclear output are in the supply mix, but no coal;
 - ii) Coal and gas turbine output are curtailed; and,
 - iii) Coal, gas turbine, and nuclear output are curtailed.

The geographic analysis is needed to develop the parameters for the model (for each powerhouse: its subwatershed drainage area, head, headpond surface area, and allowable surface elevation fluctuation/range). Historic streamflow records are needed to apportion the natural flow at each powerhouse; historic market demand plus the supply mix by segment (coal, gas turbine, nuclear, solar, water, wind, other)

are also needed. The streamflow and market supply/demand data are available from the government, as well as digital and printed topographical maps of the subject area for the geographic analysis. This analysis will also examine methods for the mitigation of flooding along the main river and river branches which are used for hydro-electric generation.

The research will be conducted to a high standard and is expected to take between five and seven years to complete at a cost of about C\$5.5- to C\$7-million, including the complete analysis of one watershed encompassing about 100,000 km². To put this cost in perspective, the facilities which may result are permanent; it is much easier to move a powerhouse *before* it is built than afterwards!

NATIVE RELATIONS

The proposed research regarding the geographic analysis and computer simulation does not take place in a vacuum. There are First Nations people living within the northern watersheds. These settlements are isolated – there are no permanent roads to the outside world (temporary ice roads for a brief period in the winter allow heavy supplies to be brought in). Air transport is the only year-round modes of transportation, fraught with all the dangers that entails in a northern climate.

The political situation requires the consent of the natives in these areas. Developments are welcome provided that they are consulted right from the start and treated fairly. While the exercise at hand only involves research into how to obtain all of the hydraulic energy from a watershed, the native residents within the watershed being used as a model for the simulation program development will be consulted regarding this research and the development which may result.

In large capital projects such as hydro-electricity, it can be said that the contributed capital of the natives is the watershed itself. Accordingly, it is a matter of negotiating what proportion of the project they receive for this contributed capital. It can't be too little because that takes advantage of them, nor can it be too much because the financial viability of the project could be impaired. Finding the sweet spot in the middle is the key to harmonious relations. In effect, they become partners in the project with

the expectation of employment opportunities, adequate training to be able to fill the job opportunities, and a stream of cash dividends to improve their isolated lifestyle.

CONCLUSIONS

It has been suggested that the amount of energy in the northern rivers is a factor of five times more than can be attained using the methods employed at present by just cherry-picking the "best" sites. This can be accomplished by including low-head sites which not only generate electric energy but also advance the water closer to the next high-head site downstream. This makes these high-head sites more effective. Ways of handling the freshet and surplus energy have also been suggested.

The essential issue is showing that the conjecture above is true. The flow and storage of water are dynamic and can only be effectively analysed by using a computer simulation program designed to optimise the energy produced during the peak demand hours of each day while eliminating any lost opportunity from spilling water. The resulting surplus energy from this, as well as from elsewhere in the grid from wind energy sources, can be absorbed in a green chemical industry.

Eventually, we will be judged by what we do: We do this not for ourselves, but for our children.

BIOGRAPHICAL NOTE

John Banka has been researching how *all* of the energy in a river may be captured and converted into electric energy. What started off as a part-time curiosity is now a full-time passion.

John holds a degree in engineering, a certificate in advanced digital geography and GIS, and is presently pursuing a certificate in project management.

John is now creating a sophisticated computer simulation model for his concept which integrates the energy storage and generation aspects of the research. He plans on selling energy, not the technology.