

Reference List - Issue 5.1(a)

EB-2013-0321

Sustainability-Journal.ca
(613) 271-9543

Issue 5.1 - Is the proposed regulated hydroelectric production forecast appropriate?

Issue 5.1(a) - Could the storage of energy improve the efficiency of hydroelectric generating stations?

OPG have stated that apart from some pumped hydro storage (174 MW at the Adam Beck site) they do not employ storage or plan to use it in the near future. The OPG documents consequently provide almost no evidence on the merits of employing energy storage even though it is widely used by other organizations in Ontario and elsewhere. The ground under just the city of Ottawa is capable of storing over 5,000 petajoules of thermal energy (that compares to a total electricity production of 1,237 petajoules in all of Canada) so there is no problem in providing sufficient storage capacity. The daily IESO data shows that if we used storage to flatten the power demand then we could store about 3,000 MW over a 5 hour period on most nights in Ontario, resulting in electric storage capacity of $3,000 \times 5 = 15,000$ MWh per day, or 5,475,000 MWh over the course of a year, or 19.7 petajoules/year. That relatively small amount of storage would make dramatic changes in the outcomes of all four of the questions listed below, and at minuscule risk inasmuch as OPG could start with very small installations to evaluate the performance.

Correspondence, Sustainability-Journal.ca re. eb-2013-0321, Nov 21, Dec 16, Mar 31, Apr 4, 14, 16, 28 (4 reports), May 7
OPG letters to OEB, Apr 3, 10
Wikipedia, "Sir Adam Beck Hydroelectric Generating Stations", accessed Jun 9/14
Appendix A
IESO site, ieso-public.sharepoint.com
Appendix B
Wikipedia, "Energy Storage", accessed June 9/14
KT 2_2 "Long Term Energy Plan"

Four general questions will be addressed:

- 1) Could the existing hydro stations be more productive?
- 2) Could the planned OPG capital expenditures be reduced?
- 3) Could the system reliability be improved?
- 4) Could Ontario's GHG emissions be reduced?

General - Question 1 - productivity

The output from run-of-the-river hydro stations can be cut back to meet diminished demand (unlike nuclear stations) so in practice they tend to operate with low capacity factors. Adding storage enables such stations to continuously operate at full power.

a) Run-of-the-river vs. high dams in Ontario

OPG Application

b) Current capacity factors for the OPG hydro stations

Not provided in the OPG application

c) Potential capacity factors for stations that always operate at full power

Not provided in the OPG application

d) Generates thermal outputs in addition to storing power

3rd World Sustainability Forum, "Exergy Storage", Tolmie and Rosen

- e) Utilization of energy sources that are normally wasted (air-heat and cold, AC heat)
S-J letter, "Storage", S-J.ca, Mar/14
- e) Integrating intermittent energy sources like wind without impacting hydro generation
S-J.ca, Mar/14
- f) Potential for uses in northern communities
S-J.ca, Mar/14

General - Question 2 - capital costs

Instead of needing to generate power to meet peak loads (with a contingency margin) storage can be used to collect power, particularly at night, and meets the peak demands from storage instead of via generation. Our estimate is a reduction of about 11,000 MW in the required generation from all sources, with a commensurate reduction in the cost of the facilities that would have been needed to generate that amount of power.

- a) Target cost per MWh of storage capacity
Appendix C
- b) Target cost per MW of power capacity
Appendix C
- c) Lifetime
Appendix C
- d) Labour cost
Appendix C
- e) Approvals plus construction times
Appendix C
- f) Space occupied, noise, visual or real pollution, etc.
Appendix C
- g) Avoidance of future "carbon tax"
Pembina Institute, "Putting a Price on Carbon Pollution"
- h) Avoidance of peaking power import costs
Appendix C
- i) Levels seasonal and diurnal price fluctuations for power
Appendix C
- j) Adaptable to differing regional energy supply (nuclear, wind, hydro or solar)
S-J.ca, "Storage", Mar/14
- k) No decommissioning cost
Appendix C
- l) No drowned land, destruction of waterfalls
Appendix C
- m) No nuclear, fire or explosion hazards (or related costs)
Appendix C

General - Question 3 - reliability

Exergy stores provide energy on a continuous basis even if the grid, or the generation stations, or the transmission lines or the local switching stations and distribution lines should fail.

- a) Energy is stored at the point of consumption
S-J.ca, Jun/14
- b) Accumulation timing is controlled by grid operator
S-J.ca, Jun/14
- c) Requires very little backup power
S-J.ca, Jun/14

d) Generators can shed demand to match ramping

S-J.ca, Jun/14

e) Generation and transmission line operators can directly control location and amounts of electricity storage

S-J.ca, Jun/14

f) Repairs to generators or lines can be carried out without loss of service (or loss of revenue)

Appendix D

g) Consumers can run on local energy supply for many days

Appendix D

General - Question 4 - emissions

Ontario is emitting about 105 million tonnes of GHG from natural gas that is used for both electrical and thermal energy supplies for buildings. That could progressively be reduced to zero via the use of exergy storage systems, which provide a solution for GHG emissions from both power generation and from thermal energy supply.

a) Although they do not themselves emit GHG's, both RoR hydro and nuclear require large scale backup from natural gas fired stations

Appendix E

b) A "carbon tax" of \$50 to \$200/tonne can be permanently avoided if natural gas is eliminated

Pembina Institute, "Putting a Price on Carbon Pollution"

c) The pending switch from domestic to imported natural gas is avoided

NEB annual Report, 2013, "Natural Gas"

d) Storage makes it feasible and economical to employ clean but intermittent energy sources like wind

S-J.ca, Jan/14 "Wind powered energy stores"

e) Cheap, clean electricity will be needed to implement GHG reductions for transportation

Appendix E

Many of the references are statements of facts, logical conclusions or straightforward calculations based on elementary principles and widely available data so they do not rely on expert opinions. Where possible these are covered in the following appendices. Other references do require expert knowledge and are drawn from the exhibits from the hearing where possible, or failing that from peer-reviewed science literature, or from Sustainability-Journal.ca articles (referred to as S-J.ca). Sustainability-Journal.ca does not have the resources needed to prepare detailed written exhibits for formal filing or for providing expert witness testimony at the hearings, but given the importance of storage to the goals of the hearing we hope that this inconvenience will be tolerated under the circumstances.

Appendix A

How much thermal energy can we store in the ground?

Let us take the City of Ottawa as an example:

The City of Ottawa has an area of 2,778 square kilometres

If the boreholes are drilled 200 m deep the volume is 5.6×10^{11} cubic metres

If the rock type is granite (one of several types in Ottawa) the mass is 15×10^{14} kilograms

If the average temperature swing is 5 degrees C the heat capacity is 5.93×10^{18} watt-sec

Converted to kWh = 1.65×10^{12} (or 1.65×10^9 MWh, or 5,940 petajoules)
(for limestone the storage would be 1.79×10^{12} kWh or 6,415 petajoules)

That compares to 1,237 petajoules of energy from all of Canada's hydro power stations per year

If the heat is being stored from summer to winter (or vice versa) the energy storage capacity of the ground under Ottawa would be sufficient to store all of the hydro energy produced in all of Canada, regardless of what mix of rock types is encountered.

Actually, the storage will be repeatedly used 365 days per year because we would be running the heat pump at night (when surplus power is available) and recovering the energy throughout the day, thus ensuring that no power is drawn during the peak (daytime) demand period. The consequence is that we really only need a small storage capacity for the diurnal portion of the storage cycle so the storage volume needed for a building is much smaller than the storage volume that would have been needed by a ground source heat pump system. That means that exergy storage systems are much less expensive to build than GSHP's.

Similar simple calculations demonstrate that the amount of available energy that can be extracted from the air, from the ground, from the buildings themselves and from relatively small solar thermal collectors is orders of magnitude greater than the amounts of energy needed for the thermal demands of the buildings.

The limiting factor for the amount of electricity that can be "stored" (i.e., its demand shifted) is the amount of electrical energy needed to run the heat pumps. That implies that exergy storage is most attractive in places where the winter and summer thermal demands are high, corresponding to a substantial electrical input for the heat pumps. Some countries make very little use of air conditioning because their cool summer air can cool even large buildings, and some of them have relatively moderate winters as well, so exergy stores will be less attractive in those countries as compared to Canada.

Appendix B

Daily storage of electricity (in the form of exergy)

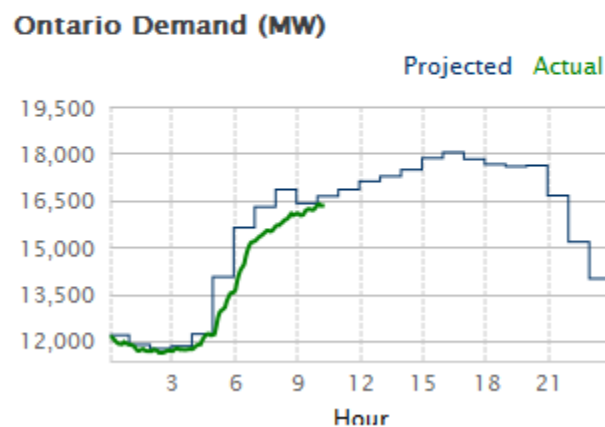
To store exergy a heat pump is used to boost the temperature and store the heat in a smaller volume at the center of a concentric heat store. The heat pump is operated only when there is a surplus of power available (defined by the grid operator) but the duration of the heat pump's operation is determined by a HUB operator who ensures that sufficient heat is stored to meet the needs for space heating, cooling and hot water for the buildings being served.

The heat pump can be used to either boost the core temperature or to chill the core, thus saving cold for

use in the summer for air conditioning. (There is an alternative available for storing cold that is useful for smaller buildings.) In either case power is used only when there is surplus power available and it is effectively recovered when the stored heat or cold is used for one of the thermal applications. The primary demand occurs during the summer cooling period and the winter heating period, which nearly always correspond to peak power demand periods, but to cover all eventualities the HUB also limits the power consumption during the peak periods (a backup supply capability is also incorporated).

Throughout the year the daily pattern of power consumption is similar to the following graph. There is a period of 5 hours in the middle of the night when the consumption is very low, often giving rise to a need to dispose of some of the excess power, so this is the time when the heat pump is operated, raising the consumption at that time and reducing the high consumption value during the day, so the store acts like a giant electric battery.

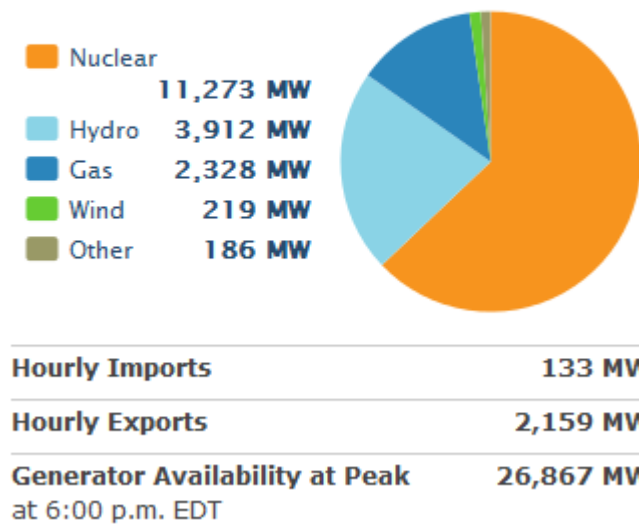
MONDAY, JUNE 9, 2014



Three of the four energy sources lack the ability to store any energy if they are not always operated at their full output. In some countries hydro power incorporates storage via the use of dams that accumulate water when power demand is low but in Ontario the hydro stations are nearly all run-of-the river stations that operate with a fixed head so they cannot store potential energy. Consequently the Ontario system depends heavily on the use of natural gas powered generators, which tend to be expensive to run (because they are nearly always running at part load) and that generate GHG's. Exergy stores provide a means of storing energy on a large scale that makes it much easier to handle nuclear, water and wind power. Exergy stores also make it possible to utilize low grade energy recovered for the cooling systems in the buildings and from air around the buildings. Potentially these low grade energy sources could become Ontario's primary sources of energy.

SUPPLY

Hourly Output by Fuel Type at 10:00 a.m. EDT



Appendix C

The capital cost of storing energy (MWh) with exergy stores is two to three orders of magnitude lower than the cost of alternatives like batteries. Moreover, the storage facilities have a very long lifetime (up to a century) and very low operating costs, and offer many additional advantages outlined below.

The capital cost per MW of thermal power capacity is also attractive (roughly \$1/watt) but the electricity storage capacity is lower than the thermal storage capacity so the economic advantage for power is not so large, although the lifetime, low operating costs, good space utilization, lack of hazards, etc. mitigate that effect. Such systems operate unattended to the labour costs are very low. There are no drowned lands or destruction of natural sights like waterfalls, and the decommissioning costs are nearly zero.

There are no major hazards involved in building and using exergy stores so the approval processes are much faster and simpler than those for nuclear, fossil-fuelled or hydro stations, and a new exergy storage facility can be built in a few weeks. They can be installed under buildings or streets, they are invisible, create no noise, and once the ground loops have been installed they are permanently sealed so they do not require subsequent access. At some point in the future it is likely that some form of "carbon tax" will be implemented in Ontario but exergy stores will be exempt from such "taxes".

Ontario presently needs to import power during peak demand periods and also to export power to get rid of it when the fixed output sources are generating too much power. Both operations are sometimes very expensive, and they can be eliminated if sufficient storage is incorporated into the system. The cost of a Smart Grid to handle the power balance is likewise greatly reduced.

The concept can be optimized for areas that predominantly use hydro power (boosting the generator efficiency), wind power (handling the seasonal and weather related fluctuations), nuclear power (making the stations load following) and for solar thermal power, which is particularly attractive for

northern applications.

Appendix D

During peak demand periods exergy stores do not consume power except for a small amount needed to operate the circulation pumps, but that is small enough to make it possible to use batteries for that power, recharging the batteries at night. Since most of the buildings' energy demands are for thermal energy, with only about one quarter being used for the electrical functions, the backup supply can optionally be made large enough to provide backup for the electrical functions as well. That type of backup will be particularly attractive once primary (air-AI) plus secondary (Li-ion) battery combinations become commercially available. In the meantime motor generators are suitable, and since they can be controlled as a part of the grid control the strategies can virtually eliminate even brief power interruptions.

If the grid supply is not functioning for any reason the exergy stores can be run for a matter of weeks without using the relatively power-hungry heat pumps.

Appendix E

Exergy stores both reduce the summer and winter demand peaks and at the same time provide power storage to flatten the power load even more, so as they are deployed the load fluctuation problem rapidly diminishes. Such stores can cover a single residence (at a cost penalty) or they can be used for multi-megawatt facilities, again with a practical limit that is determined by the velocity of the heat flow in the ground.

Developing the means for limiting the cost of electricity is fundamental to the potential for dealing with the other primary source of GHG's - the transportation sector.