Green Energy Coalition

David Suzuki Foundation

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Sierra Club Canada

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the PEMBINA institute
Sustainable Energy Solutions

OSEA

EB-2007-0707
Exhibit L
Tab 8
Schedule 8

BEFORE THE ONTARIO ENERGY BOARD

IN THE MATTER OF sections 25.30 and 25.31 of the Electricity Act, 1998;

AND IN THE MATTER OF an application by the Ontario Power Authority for review and approval of the Integrated Power System Plan and proposed procurement processes.

Storage Options in Planning

Prepared by Tim Hennessy
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prepared for:
Green Energy Coalition
(David Suzuki Foundation, Eneract, Greenpeace Canada, Sierra Club of Canada, World Wildlife Fund Canada)
Pembina Institute
Ontario Sustainable Energy Association

Storage options in planning

Tim Hennessy, VRB Power Systems Inc.

1 August 2008

1. What are your qualifications?

I am Chairman and CEO of VRB Power Systems Inc., a Canadian listed company manufacturing proprietary energy storage systems, based in Vancouver, Canada. I hold a B.Sc. Eng. and Masters degree in Electrical Engineering and several business qualifications. I have been involved in power engineering for 25 years including senior management roles in some of the world's largest utilities (see biography attached).

2. What concerns do you have with the IPSP?

I have been involved directly and in review of various IRP's across the world over the last 20 years. Invariably they are produced based on limited technological scope and certainly using the classical risk averse utility approach. In general this approach has been the same throughout the history of utilities which was the original directive and mandate of an electrical utility. They deal with a public good.

Having said this however, there are certainly several new considerations from technology as well as economic and environmental perspectives that need to be factored in any plans, and which are radically different from classic planning methods. Just as with the acceptance of stochastic planning as opposed to deterministic methods used as recently as 15 years ago, the expansion of the planning considerations means that a revision of the current approach is in order.

Specific amongst these new considerations are:

- Environmental and socially responsible planning along with associated macro-economic costs
- New technologies such as large scale distributed electrochemical and other storage, fast acting communication and controls, dynamic intelligent protection systems and refined computer modelling for system stability. The whole concept of the self healing or intelligent (smart) grid which allows for distributed generation is totally foreign to most utilities.

- Renewable large scale intermittent generation such as wind and solar power now create a complexity of both supply and demand side variability making conventional approaches outdated and steady state power flow modelling a part of the overall as opposed to a majority of the whole planning process.
- Deregulation has led to the break up of vertically integrated utilities and a balance between supporting innovation, economic returns and grid security is now sought.

The net effect of these additional factors is that a paradigm shift in utility long term planning must occur. There of course must be a balance between the pace of change versus security of supply, but certainly it is both sensible and publically responsible to begin this process immediately.

It is also critical to consider the markets as a whole not in isolation and thus involve these markets in defining and developing solutions. Utilities seldom innovate nor develop new ways of doing things – unless policy is set and then markets are allowed to drive and develop the correct solutions which must encompass all aspects including social factors, economics and security of supply. For market participants to offer innovative services like storage, planners and regulators must place appropriate value on the various benefits that the system and society accrues from such technologies. Planners must anticipate the changing make up of generation resources and the changing role of the grid and plan to procure or enable markets to provide technologies that address the changing reality.

By omitting anticipation of distributed storage and the other innovations referred to above, OPA is effectively promulgating the status quo.

Despite including some pumped storage in the preliminary plan OPA includes no new storage in the IPSP. In answer to I-22-63 OPA declined to evaluate the value of storage to the system. In answer to I-22-61 OPA notes:

> ...Storage resources would provide additional capacity (MW) but no additional (net) energy (in fact, they would tend to reduce energy production because of losses). The value of storage relative to other resources would therefore depend on overall system needs for capacity and energy, which in turn depend upon forecast load and baseload resources, as well as other resources such as Conservation. The future needs for capacity relative to energy are judged insufficient to warrant the inclusion of storage in this IPSP.
>
> The IPSP does not preclude the development of pumped storage facilities by project developers in order to increase the economic value of their wind generation projects. If pumped storage for a particular project at a particular site would make that project more economical than a competing project, then presumably this would provide a

competitive advantage in a procurement process. However, due to the limited knowledge of specific sites and their costs, the IPSP does not speculate on which projects and sites, and with what timing, this may materialize.

This illustrates how OPA's planning:

- fails to consider and evaluate the range of benefits that storage offers in addition to peaking capacity
- fails to consider the combined benefits of storage and increased renewables
- allows that generators could bundle in storage but offers no means for developers to be compensated for the added benefits (apart from capacity) it would bring to the system
- does not consider storage that is procured or developed and located separately from generation to address a variety of system needs
- fails to consider the cost and technology improvements that can reasonably be anticipated
- appears to consider only pumped storage

3. Please describe the benefits of electricity storage for electricity systems.

Energy Storage Systems (“ESS”) absorb energy during times when excess capacity exists so that it can be released later when needed. The fundamental requirement in any electrical grid system is a balance between the power demanded by the loads and the power that is generated. It has not been practical to store energy to any appreciable extent until recently, the exception being pumped storage hydroelectric systems. The advent of other large scale, high capacity energy storage options has and will increasingly support a fundamental shift in the way that power system grids can be designed or modified and operated. Power is stored during periods when excess generation is available and released when excess demand exists. When released, the power can either be delivered as real power for consumer use, or it can be delivered as reactive power to support and stabilize the grid or in combinations of the two. In this way storage provides several benefits:

- From an economics point of view, a commodity is transferred to periods when its value increases, and
- Physically the maximum output of the system is increased through the decoupling of supply and demand - akin to inventory in business
- Electrical networks can be optimised to closer match loads without having to design excessive spare capacity both on a transfer capacity and on a generation basis (less wire in the sky). This implies better returns at no reduced level of security of supply as well as huge social implications in terms of physical resources economics and idle capacity.

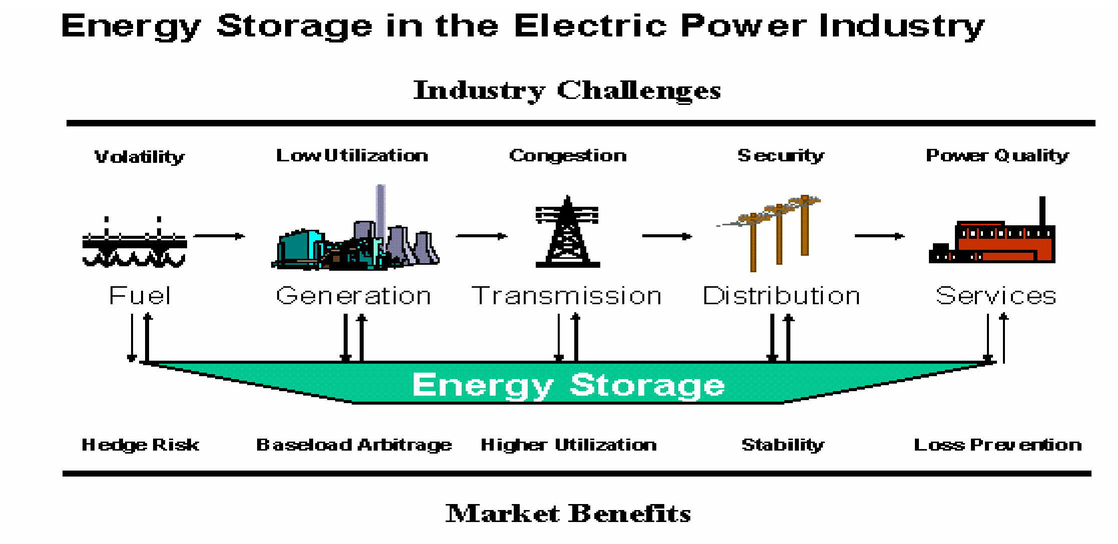


Figure 1. The Application and Market Benefits for Energy Storage –The Values Stream (Jason Makansi: Pearl Street 2002)

Without energy storage, the power market will never function properly. Increasing demand, price spikes and energy shortages have created three chronic problems: higher volatility, reduced reliability, and threatened security. By utilizing energy storage technologies, each of these challenges facing the industry can be greatly diminished—in effect, acting much like a 'shock absorber' for the electrical grid system. Figure 2 shows that by selectively releasing power during periods of high demand, significant price reductions can be achieved.

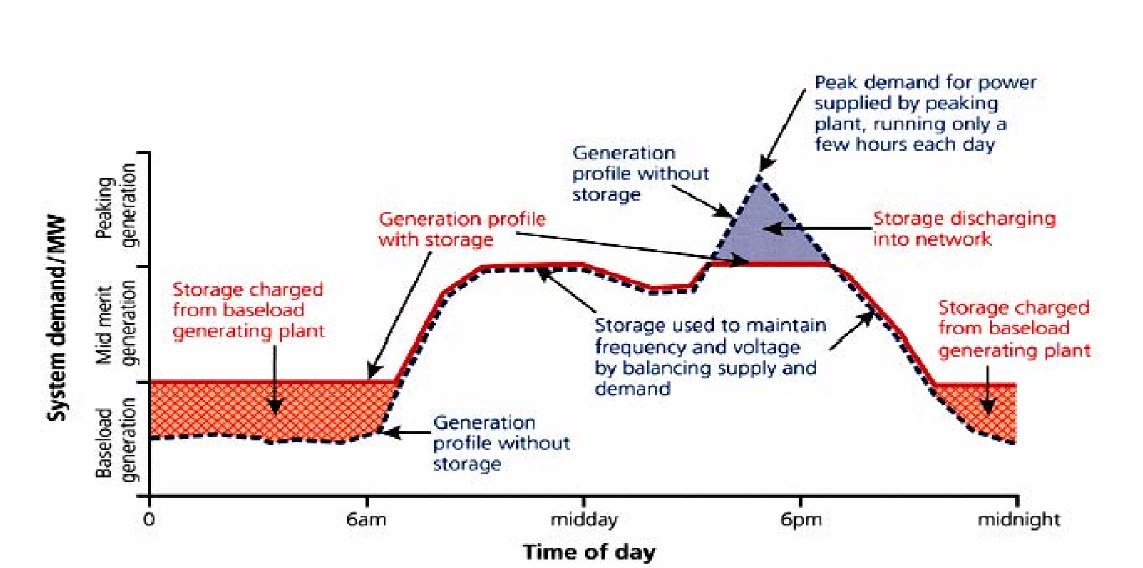


Figure 2. Energy Storage and Decoupling of Demand and Supply in Utility Networks

Energy Storage Systems (ESS) can be applied at different stages in the electrical power delivery chain. The benefits that arise from storage at all levels including at the distribution/sub transmission level, also affect the transmission and generation levels thus allowing multiple value streams to be recognised. Applications include:

Load Levelling (Peak Shaving)

- The ESS can reduce the peak of a customer's energy load as seen by the Distribution system. This improves utilization of assets on the electrical grid and manages customer energy demand to average instead of peak load resulting in reduced Maximum Demand charges. The utility load factor is improved, capital equipment utilisation factors are increased (load factors raised) and system losses reduced by up to 7 or 8% depending on where the storage is installed.

Intermittent generation firming

- An issue with adding wind and solar generation in very large amounts to a utility grid is that of intermittency. ESS will increasingly be able to cost-effectively address this concern and reduce the need for alternative dispatchable capacity such as gas.

- In a market based system energy storage also provides a mechanism to reduce risk in energy contracts when intermittent renewable sources are committed to firm supply agreements. The energy storage provides a base of firm supply which added to the variable supply will always guarantee a certain minimum output.

Ancillary Services for Utilities

- ***Reserves* -** Spinning, Standby, Replacement - In the event of the loss of output from a supply source or an unexpected change in system demand, the energy storage can immediately provide the required power to make up the shortfall. Energy Storage provides the most flexible response due to its flat efficiency curve and fast reaction time.
- ***Reactive Power* -** Is required to maintain voltage balance on the grid on a local area basis. Both static and dynamic provision of reactive power can be provided.
- ***Black Start* -** The energy storage can be utilized as an energy source to provide electricity to the transmission system without access to the normal grid power supply. It is used to power grid controls so that a "black" grid can be re-energized.
- ***Frequency Control* –** Regulation of frequency on a local area basis through injection of reactive and/or real power can be provided.

Electrical Power Arbitrage

- Utilizing energy storage can take advantage of price differentials between Peak and off-Peak pricing of electricity. Power can be bought and stored during off peak times and sold back into the market during peak price times – ***buy low, sell high***. In addition unused off-peak renewable energy (wind often blows more at night) can be shifted to daytime use gaining added value.

Constraint Relief & Capital Deferment

- Energy storage can be a means of saving peak demands on otherwise underutilised power lines thereby increasing the associated delivered capacity in MW on a network path that is otherwise constrained. This would also apply to generation peak demands enabling deferring capital expenditures. Power system capital costs have doubled over the last two years driven by many factors from materials shortages due to excessive demands to fuel cost convergences as well as facing increasing environmental permitting restrictions and costs.

Relief for Weak Distribution systems connecting Distributed Generation

- The majority of distribution systems are passive with a unidirectional flow of power from the high voltage transmission grid to the low voltage loads. The increase in the amount of generation being connected to these distribution grids is changing this paradigm. As more distributed generation is connected the flow of power is no longer from high to low voltage but can often flow back up into the main grid. Distribution systems are sometimes weak at the locations where it is most suited for renewable generators to connect. The main technical limitation is often the steady-state voltage level of the grid due to the power flow from the new generation. Distributed locationally specific storage resolves this. In addition in several cases where distributed generation is connected in weak grids, it has to be curtailed during periods of high supply or low load – the coincidence issue. When this applies to renewable energy this is wasted or spilled. Again storage resolves this.

Power Quality & Reliability - demand side and supply side management

- Uninterruptible Power Supply (UPS) – Emergency Power Backup
- Voltage Support & Flicker Compensation. It is possible to provide power quality improvements through local voltage support and active filtering which is intrinsic to power electronics converters provided by some forms of storage
- Ride through for Voltage Sags

Remote Area Power Supply (RAPS)

- The integration of a ESS can reduce run time, fuel consumption/costs and minimizes pollution emissions from diesel generation.
- The integration of a ESS within a hybrid system – combined wind and diesel – can enhance efficiencies and improve reliability

Emission Controls

- Emission reductions for nations ascribing to the Kyoto principles is a very real challenge. The nature of power demand is such as to require peaking generation for short periods during each day, typically provided by natural gas plants. (In remote areas or islanded grids this is often provided by diesel generation.) This results in extensive greenhouse gas and particulate emissions. Storage provides a way to reduce this generation need and hence achieve Kyoto protocol and climate change objectives. In addition to these emission reductions the use of storage acts as a pure economic driver reducing the exposure of utilities to natural gas price rise and volatility.

4. What are the common forms of storage?

Storage is separated into four broad types:

- Hydroelectric –pumped storage
- Mechanical – flywheels and compressed air energy storage
- Thermal – molten salts, hot water
- Electrochemical – batteries and hydrogen

Electrochemical

The biggest challenges that have faced electrochemical storage technologies up until recently have been their inability to cycle repeatedly in a deep discharge fashion, with sufficient reliability, efficiency and cost effectiveness. Today and for the foreseeable future (likely 10 years), there are only two systems that can achieve scale in the MW range. VRB-ESS™ and Sodium Sulphur (NAS). There are several mechanical systems such as flywheels and Compressed air energy systems (CAES) that have been around for many years but have either low energy storage capacity (MWh) or are inefficient or require geological formations to enable scale. Only electrochemical storage is suited to distributed application on any meaningful basis.

VRB Flow Battery - VRB-ESS

This technology falls into the category of flow batteries. The VRB-ESS is an electrical energy storage system based on the patented vanadium-based redox regenerative fuel cell that converts chemical energy into electrical energy. Energy is stored chemically in different ionic forms of vanadium in a sulphuric acid electrolyte. The electrolyte is pumped from separate storage tanks into flow cells across a proton exchange membrane (PEM) where one form of electrolyte is electrochemically oxidized and the other is electrochemically reduced. This creates a current that is collected by electrodes and made available to an external circuit. The reaction is reversible allowing the battery to be charged, discharged and recharged tens of thousands of times. It has no emissions and its electrolyte never wears out making it the lowest cost storage system on a life cycle basis. It is between 65 and 70% efficient round trip and has very low maintenance costs through its use of plastic piping and tanks. It does not burn and can be scaled to hundreds of MWh by adjusting the amount of electrolyte independently of the power. Its capital costs range from $500 to 800/kWh at present.

The VRB-ESS can effectively smooth wind intermittency, as proven in several installations over many years. It has achieved over 270,000 cycles on a 32 MW wind farm using a 4MW VRB-ESS. No other storage technology can do this.

Its drawback is that it is less energy dense than other technologies so occupies more space but when coupled to wind farms this is not of consequence.

Lead Acid Batteries

Lead acid batteries have been in use for 100 years, primarily in motor vehicles and UPS systems. They are unable to cycle more than about 2500 times and cannot be deep discharged without severe damage and life cycle reduction. As a result they are not really applicable to large scale deep cycling storage. The initial acquisition cost for a multi-megawatt hour system is around $1550/kWh with 5 to 7 year replacements. It is a mature technology with very little room for any price reductions or performance improvements.

Zinc Bromine- ZBr

This system is produced by two companies, a private USA company and ZBB, an Australian public company. It falls into the category of flow batteries since the electrolyte (energy) is separate from the power generation component. There are several worldwide demonstration installations. One of a 400kWh system in the Detroit Edison area, a joint effort of ZBB and Sandia National Laboratory, and a system in California sponsored by the California Energy Commission. In each cell of a ZnBr battery, two different electrolytes flow past carbon-plastic composite electrodes in two compartments separated by a microporous polyolefin membrane. Its operation involves the plating and removal of that coating on an electrode during each cycle. This limits the life and size of the system. Bromine gas is also a difficult chemistry to manage. The number of charge-discharge cycles is limited to about 2,500. The net DC efficiency of this battery is about 75%.

Sodium Sulphur(NaS)

A NaS battery consists of liquid (molten) sulfur at the positive electrode and liquid (molten) sodium at the negative electrode as active materials separated by a solid beta alumina ceramic electrolyte. The electrolyte allows only the positive sodium ions to go through it and combine with the sulfur to form sodium polysulfides. During discharge, as positive Na+ ions flow through the electrolyte, electrons flow in the external circuit of the battery producing about 2 volts. This process is reversible as charging causes sodium polysulfides to release the positive sodium ions back through the electrolyte to recombine as elemental sodium. The NaS battery operates at high temperatures (350C) and its roundtrip system efficiency is approximately 60 to 65%.

The cost of the NAS battery produced by NGK of Japan is $2500/kW for a 3.5 hour system. It is capable of about 3000 deep cycles. It has two application sites in the United States and about 200MW installed in Japan. The NAS battery has a high energy density but comes in fixed sizes of 3.5hour 50kW and 7hour 50kW modules. The NAS battery has limitations with charge monitoring and partial charge/discharge cycling making it less suitable for wind type applications. Its current costs have arguably been driven down through Japanese subsidies and the 66MW volume, so further major reductions are likely limited.

Lithium-ion

Lithium-ion has high energy density, both gravimetric and volumetric, but presently requires more development for stability in large systems. Manufactured product requires significant protective and control system functions, and is of small size cells for electronic product applications. The battery is limited in size and is currently priced at about $1,200/kWh. It is expected that its primary application will be in small telecomm applications and portable systems.

NiCad

A very large NiCad energy storage system has been operational for 3 years in Alaska for the Golden Valley Cooperative. It is rated 40MW 7 minutes, has an intended life of 20+years, and uses ABB power electronics. It occupies 4000 m^2 of space and has as its objective to provide total utility system support for short periods while diesel engines are started up. Its cost is estimated at being >$1470/kWh. Cadmium is a restricted chemical and banned in several jurisdictions.

Nickel-Metal Hydride

Many companies are producing or developing NiMH batteries. The NiMH battery combines high energy density and good power density with good cycle life, making it the current potential favourite for electric vehicles. Cycle life may increase to up to 2000 cycles in the near future. Manufacture is metallurgically complex, and present low-volume production is of small size cells for electronic product applications. It is also being adopted by the motor industry so cost reductions due to volume can be expected.

Lithium-Polymer Battery

The lithium-polymer battery has been under development for nearly twenty years, with accelerated development during the last six years by 3M and Hydro-Quebec. The battery is totally solid state, constructed of a very thin sandwich of layers, and offers high energy and power densities. The battery is currently in production under the trade name Saphion, produced by Valence Technology Inc. It is targeting the telecom's sector with a 50 amp-hour battery system that replaces conventional lead-acid batteries. It has had several bad experiences recently due to charge control issues.

Pumped hydro storage

This is the oldest form of large scale energy storage capable of thousands of MWh of storage. Water is pumped from a lower level dam into a higher level one at night and run back during peak daytime loads. It is the lowest lifecycle cost system but has the drawback that siting such dams is very difficult and often cannot be placed where the load requirements are so when additional transmission lines and losses need to be factored in. Their efficiency is in the 70% range.

There is over 90 GW of pumped storage in operation world wide, which is about 3% of global generation capacity. Pumped storage plants are characterized by long construction times and high capital expenditure.

Pumped storage is the most widespread energy storage system in use on power networks. Its main applications are for energy management, frequency control and provision of reserve. Utilities are familiar and comfortable with this technology.

Molten salts and Thermal storage

The principle of this type of storage is that electricity is used to heat a material which has thermal properties that allow the heat to be stored either through a change in state or simply through its thermal properties. In addition this heat is able to be extracted rapidly usually by generating steam which is then used to power a steam turbine or it could be used in district heating /cooling systems. These systems are slow to respond and expensive as well as inefficient but certainly can be sized in the 100MW plus range. Hydrogen energy storage would be categorised as this type of technology. Hydrogen could be generated by electrolysis of water from wind turbines and stored for later burning in a reciprocating engine. If used in CHP mode this would yield net system efficiency of 25% odd. This would deliver green energy but is very expensive compared with alternatives and has short life cycles due to electrolyser limits.

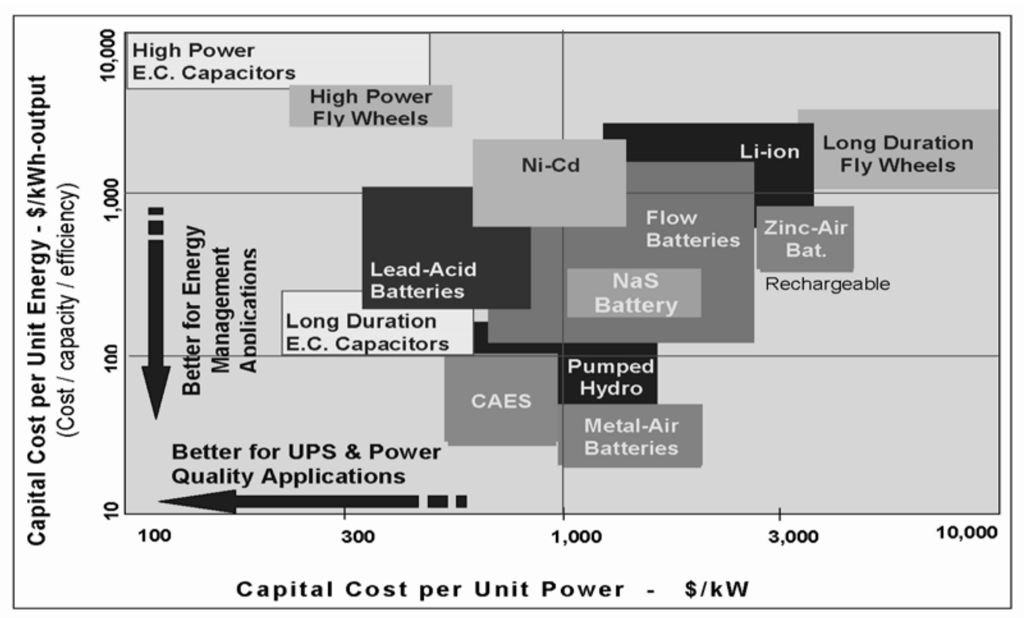
Compressed Air Energy Storage - CAES

CAES is not a simple energy storage system like other batteries. It is typically configured as a peaking gas turbine power plant that consumes less than 40% of the gas used in conventional gas turbine to produce the same amount of electric output power. This is because, unlike conventional gas turbines that consume about 2/3 of their input fuel to compress air at the time of generation, CAES pre-compresses air using the low cost electricity from the power grid at off-peak times and utilizes that energy later along with some gas fuel to generate electricity as needed. The compressed air is often stored in appropriate underground mines or caverns created inside salt rocks. Where such caverns do not already exist, it takes about 1.5 to 2 years to create such a cavern by dissolving salt.

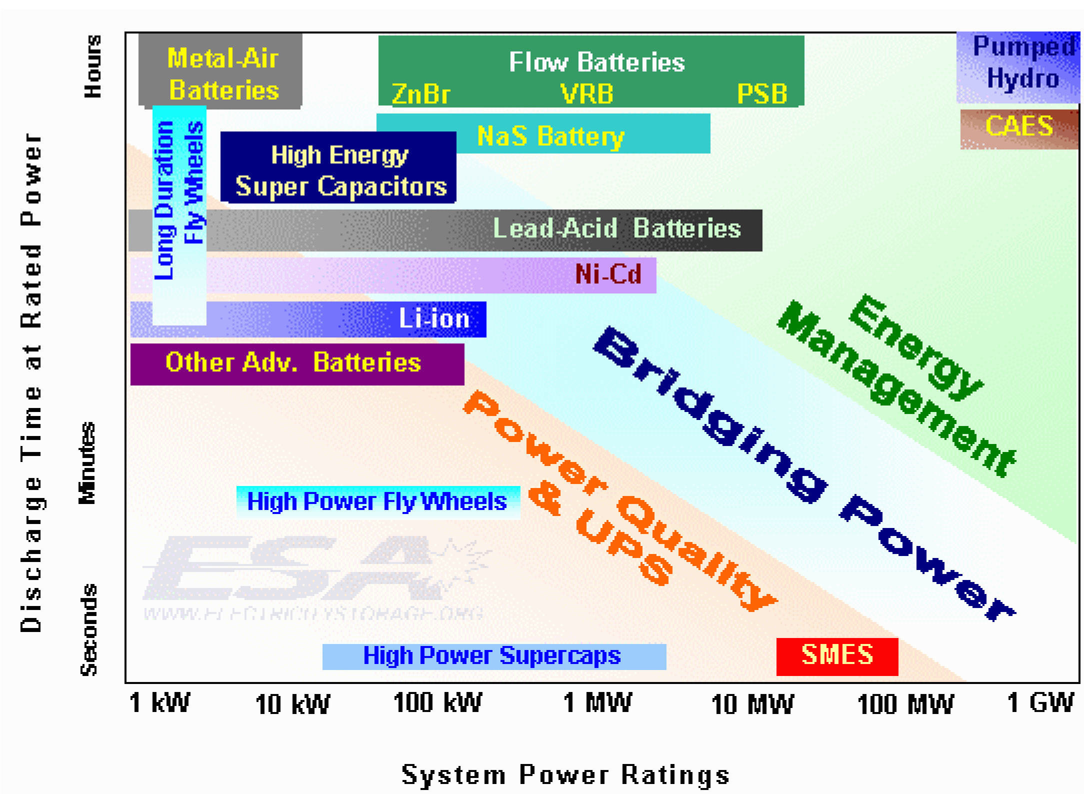
The first commercial CAES was a 290 MW unit built in Germany in 1978. The second commercial CAES was a 110 MW unit built in McIntosh, Alabama in 1991. This unit comes on line within 14 minutes. The third commercial CAES planned, is a 2700 MW plant that is planned for construction in Norton, Ohio. This 9-unit plant will compress air to 1500 psi in an existing limestone mine some 220 metres under ground.

5. How do these various storage technologies compare with one another?

For large scale multiple MW and long duration MWH storage there are four technology choices. Pumped-Hydro, CAES, Flow Batteries and NAS. For very large scale systems Pumped-Hydro is most practical. For distributed multiple MW multi-hour systems flow batteries and NAS are practical systems. For rapid cycling wind applications to stabilise wind and to provide ancillary services flow batteries are most practical though grouping of wind generation can improve the applicability of other approaches.



Capital costs on a $/kW and $/kWh basis for different storage technologies (courtesy ESA)



A key benefit when applying electrochemical energy storage is its ability to cycle very rapidly. The ability to operate equally in an up and down ramping manner allows it to provide frequency stability compensation much more efficiently than mechanical systems.

There is no single energy storage system that fits all applications. Just as with generation, a mix of appropriate systems is optimal depending on load shapes, applications and fuel costs.

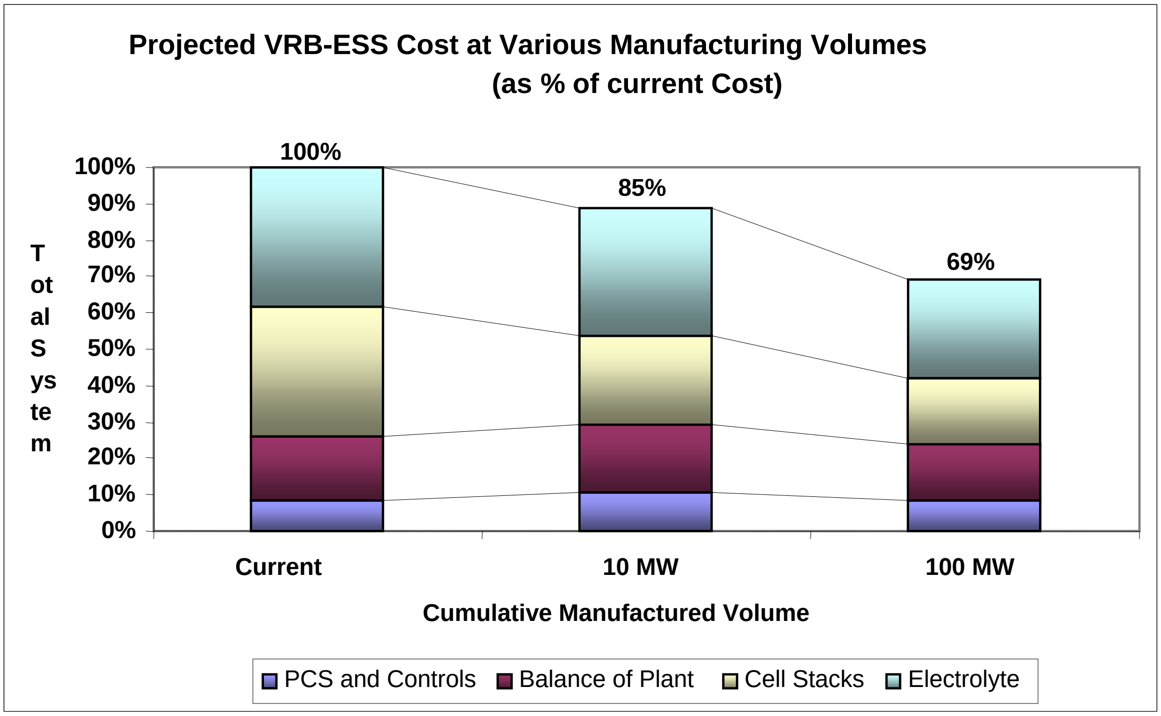
6. Turning to VRB's flow battery technology in particular, what are the costs of utilizing this technology?

Flow batteries like the VRB-ESS are comprised of two parts. The electrolyte storage part (kWh) and the cell stack power part (kW). This is totally dissimilar from other storage systems where the energy and power parts are packaged as a unit. The VRB-ESS is currently priced at between $650 and $850/kWh with a cost of $2,200/kW for the power element. As discussed below, these prices are expected to fall significantly with economies of scale and technological evolution such that the widespread application of the system is foreseeable within the time horizon of the IPSP.

All of the components of a VRB-ESS are commercially available except for the proprietary cell stacks which are manufactured in Canada. There are 4 major component categories:

- cell stacks – reversible fuel cell without catalysts
- electrolyte – vanadium based from waste products such as flyash or spent catalysts
- Balance of Plant – plastic ping, building, steel supports, lighting, pumps and any cooling requirements
- Power Conversion system (PCS) – commercially available from over 20 suppliers but in essence being two back to back wind turbine power converters.

Volumes drive all of the costs down and we see no shortages for any of the materials used in the VRB-ESS technology –certainly there may be competition for immediate supplies but long term they are all readily available. In fact as demand increases for other systems that use the same components, prices will be reduced since none of them are in short supply. Perhaps only the cell stack element holds some mystique but its internal structure relies on Proton Exchange Membranes (PEM) used in fuel cells, plastic frames, and carbon felts used in insulation of



furnaces. Realistically therefore, there are no elements which are in short supply and significant cost reductions can be expected.

In considering costs it is important to recognize that the sizing of the battery will depend upon its application. For example, a VRB system that is sized at only 20% of the capacity of a windfarm can firm up the output of the windfarm to its average capacity factor and can improve predictability of its output to over 90%.

1. What are the costs of flow battery technology expected to be 5 and 10 years from today?

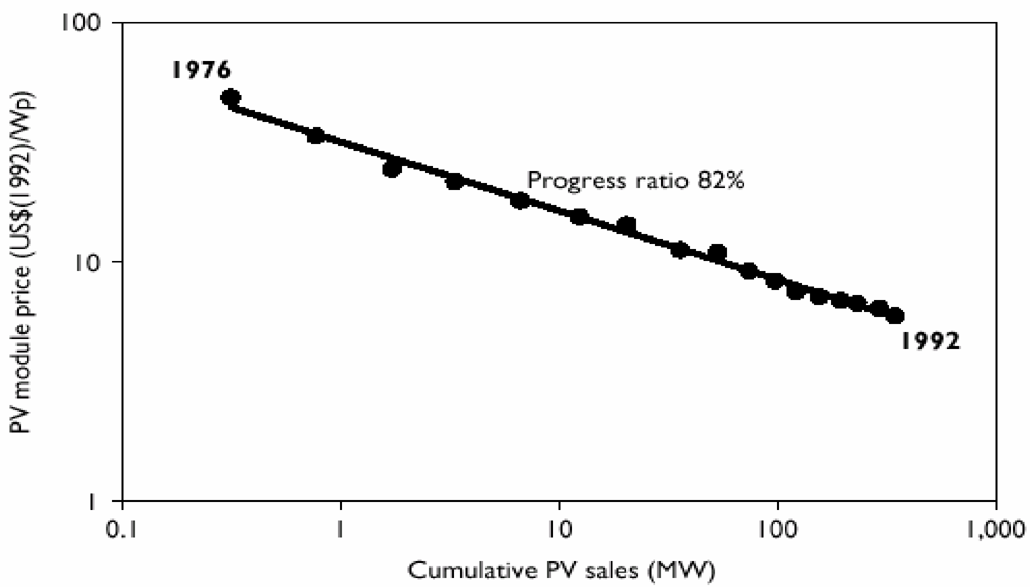
Projected Cost curves for Flow battery Technologies

Detailed design studies are inadequate for deriving long-term cost forecasts for emerging technologies. This is because they rely on specific assumptions about design and performance. A feature of an emerging technology is the opportunity for rapid and radical learning through experience and implementation, which cannot be crystallised into detailed design at an early stage. Experience curves provide a simple, quantitative relationship between price or cost and the cumulative production or use of a technology. There is overwhelming empirical support for such a price-experience relationship from all fields of industrial activities, including the production of equipment that transforms or uses energy[1]. Existing data show that experience curves provide a rational and systematic methodology to describe the historical development and performance of technologies. In this way, they can be used to assess the prospects for future improvements in the performance of a technology.

Experience curves provide tools to analyse the future markets for technologies, to design efficient policy measures and to monitor the effects of these measures. Experience curves can also be useful in assessing the prospects of commercial viability.

The figure below shows the experience curve for photovoltaic modules on the world market for the period 1976-1992.

Experience Curve for PV Modules, 1976-1992



Experience curve for photovoltaic modules on the world market. The price for a module is given in constant 1992 US$ per peak watt, W_p. Peak watts are the power output from the module at optimum solar conditions as defined by certification agencies. Adopted from Williams and Terzian (1993).

The data indicates a steady, progressive decrease in prices through cumulative sales, which are used as the measure of the experience accumulated within the industry. The relationship

[1] See Boston Consulting Group (1968) or Abell and Hammond (1979).

remains the same over three orders of magnitude. This is the standard presentation for experience curves, namely in a double-logarithmic diagram. With this representation it is possible to follow the experience effect over many orders of magnitude.

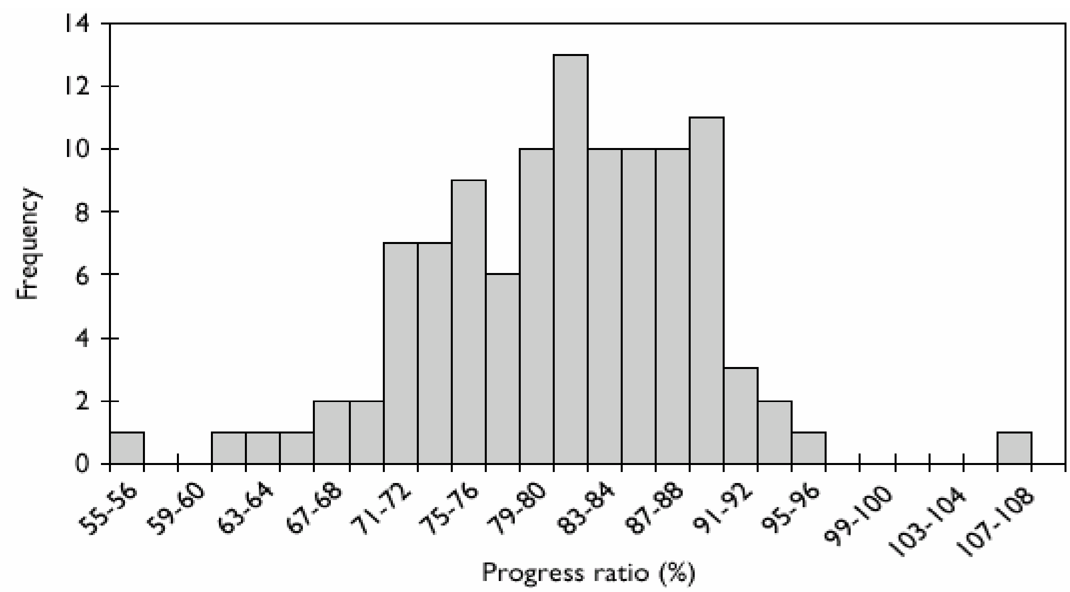
The straight line captures an important feature of the experience curve.

Anywhere along the line, an increase by a fixed percentage of the cumulative production gives a consistent percentage reduction in price. Comparisons between different experience curves can be made by doubling the cumulative volume; the corresponding change in price is referred to as the progress ratio. The experience curve above has a progress ratio of 82%, meaning that price is reduced to 0.82 of its previous level after a doubling of cumulative sales.

The progress ratio is the same for any part of the simple experience curve. This means that young technologies learn faster from market experience than old technologies with the same progress ratios. The same absolute increase in cumulative production will have more dramatic effect at the beginning of a technology's deployment than it will later on. Market expansion from 1 to 2 MW reduces prices by 18% in the example above, but at a volume of 100 MW, the market has to deploy another 100 MW to obtain another 18% price reduction.

The literature on experience curves provides benchmarks for the progress ratio from other fields of technology. The figure below shows the distribution of progress ratios from 108 observed cases in manufacturing firms. The average value and the most probable value for the distribution are both 82%. Industry-level progress ratios have a similar distribution. The average progress ratio at the level of the individual firm is equal to the ratio measured for modules in the photovoltaic industry as a whole in the period 1976-1992. Wind turbines, with a progress ratio of 96%, lie on the upper tail of the distribution. Low progress ratios, or high learning rates, are observed for semiconductor technology, e.g., production of integrated circuits shows a progress ratio of 72% (Ayres and Martinas, 1992). Miniaturisation may partially explain the low progress ratios for the semiconductor industry.

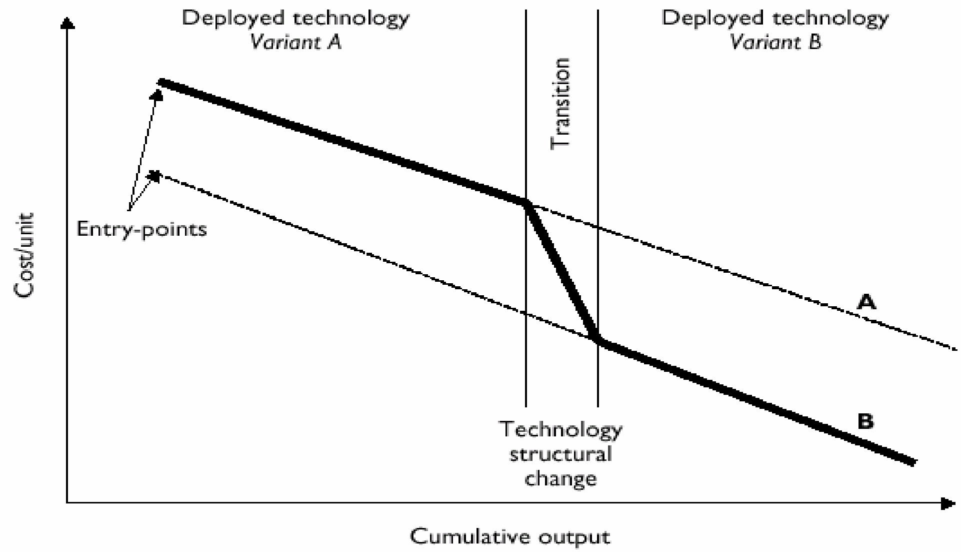
Distribution of Progress Ratios



Progress ratios for 108 cases observed in 22 field studies. The studies estimated the behaviour of cost with cumulative volume in firms and include manufacturing processes in industries such as electronics, machine tools, system components for electronic data processing, papermaking, aircraft, steel, apparel, and automobiles. Industry-level progress ratios are excluded. The outlayers at 55-56% and 107-108% indicate cases where cost decreased by 44-45% and increased by 7-8%, respectively, for each doubling of cumulative volume. Adopted from Dutton and Thomas (1984).

Structural Technology Change

Major technological change can have the effect of changing the progress ratio for a period of time; for example a breakthrough in the production of thin-film photovoltaics or the shift to new temperature-resistant materials for gas turbines. These changes are termed '*technology structural changes'* indicating that there has been a radical change in the content of the development process, e.g., a shift in the technology paradigm leading to a new variant of the technology or a major change in the way the technology is produced. The figure below represents a stepwise shift in the technology, and an increased learning rate in the experience curve for technology costs. The hypothesis is that the changes show up as discontinuities in the experience curve.



The heavy line is the expected behaviour of the experience curve during a shift of technology from variant A to variant B.

Application to Electricity Storage System Costs

Electricity storage systems consist of a number of components, ranging from novel technology at the start of its life cycle, to more mature components associated with the balance of plant. In this way, different elements of the plant will have different experience curves. However, the costs and design of the balance of plant are heavily influenced by the performance of the novel parts of the system, principally consisting of the cell stacks and electrolytes, which together comprise 70 – 80% of the plant cost. The balance of plant is a complex combination of existing technologies, with significant scope for value engineering and design optimization. As such, a robust argument can be constructed that the entire plant can be expected to exhibit the characteristics of the early phases of the experience curve.

At this level of analysis, it is reasonable to expect electricity storage systems to follow an experience curve typical of that seen within the energy industry and across different industries, with an average progress ratio of around 80%, and real opportunity for periods of increased learning and lower progress ratios.

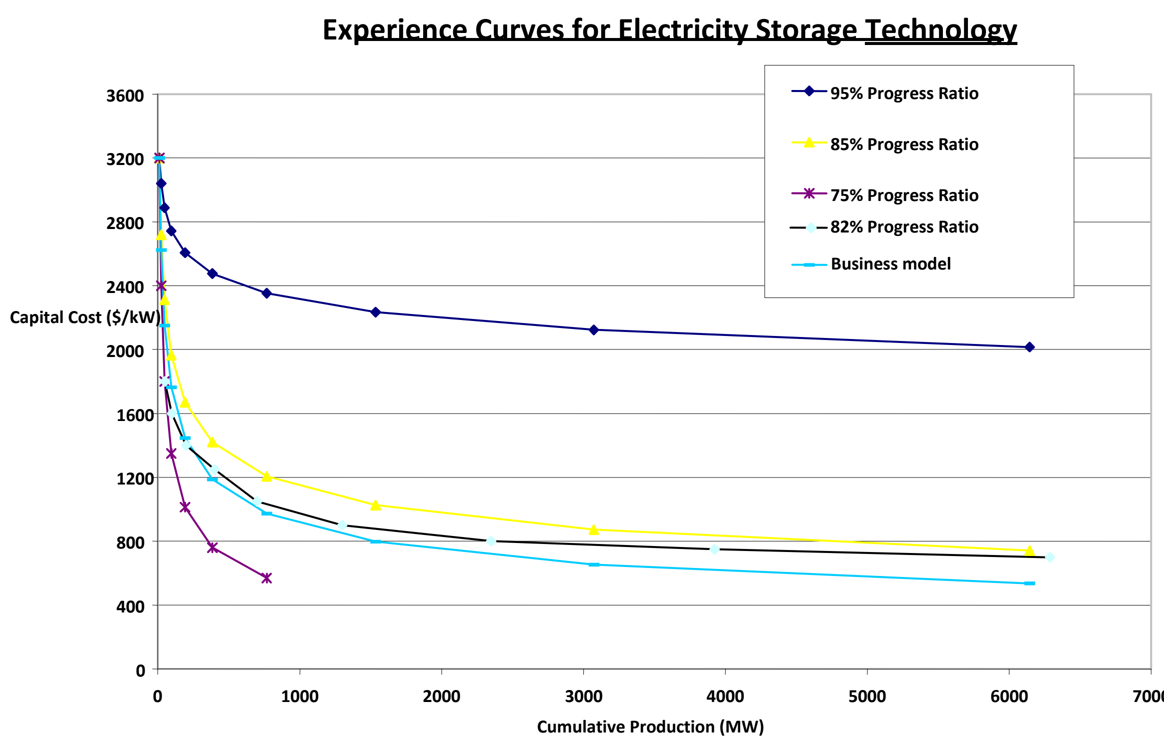
The table below constructs cost curves for the VRB Power Systems Inc.'s electricity storage system, based on early demonstration projects as a start point and applying a range of progress ratios.

The lower progress ratios would only be associated with periods of structural technology change. As such, sustained application of these ratios is not appropriate.

Cumulative Production MW	Cost ($/kW)* at Progress ratio of 95%	90%	85%	82%	80%	75%	70%
12	3200	3200	3200	3200	3200	3200	3200
24	3040	2880	2720	2624	1360	2400	2240
48	2888	2592	2312	2152	2048	1800	1568
96	2744	2332	1966	1764	1638	1350	1098
192	2606	2100	1670	1446	1110	1012	768
384	2476	1890	1420	1186	1048	760	538
768	2352	1700	1206	972	838	570	376
1536	2234	1530	1026	798	672	428	264
3072	2122	1378	872	654	536	320	184
6144	2016	1240	742	536	430	240	130
12288	1916	1116	730	440	344	180	90

* At nominal eight hours duration

The VRB business plan incorporates a long term cost track for the VRB-ESS™ technology. The graphs below show the experience curves detailed above against the assumed cost reductions in the business plan. Although the business plan's cost reductions are largely time and event driven, this is combined with assumptions on market penetration and hence it is possible to construct an implied experience curve from these costs.



These curves offer the following conclusions on the electricity storage technology cost curve.

- VRB's next generation design study implies a progress ratio of 70-75%. These ratios are typically associated with a period of structural technology change, consistent with the development of new chemistry such as VRB, a new module design, rapid technology improvements and a number of new design concepts for the plant.

- For the remainder of the business plan period, VRB's assumed costs are consistent with a progress ratio of 80-85%. These ratios are close to the observed average across industries.

The experience curve analysis offers the conclusion that the long-term view is robust and justifiable.

The VRB-ESS is currently priced at between $650 and $850/kWh with a cost of $2,200/kW for the power element. Using the analysis above it would be realistic to see the cost move to $1300/kW and for total energy storage systems to reduce to $500/kWh on volumes of 100MW. Accordingly, in the middle years of OPA's plan we might anticipate that a 100MW wind farm could be firmed by utilizing a 20MW power element and a 6 hour storage or 120 MWh energy storage for a total cost of $70 million. Alternatively, such a battery could ensure on peak availability of over 30MW on a firm basis. These values cannot be directly compared to generation costs as the presence of fast acting storage on the grid would also provide other value to the system such as frequency reserve in proportions far different than generation[2].

7. What are your conclusions?

The benefits for electricity systems from storage arise in several ways and are dependent on the particular circumstances. Time has not allowed me to analyse the full benefits that could arise for the proposed Ontario system. My concern is that OPA's plan has neither anticipated progress in emerging technologies such as storage, nor has it attempted to evaluate the numerous benefits I have discussed above. Had OPA properly done so, I am confident that its plan would have found a combination of these emerging, environmentally preferable technologies is likely to be both available and cost-effective within the time horizon of its plan and the plan would be designed to accommodate that potential. Instead, OPA is proposing a plan that invests heavily in large, long lead time blocks of expensive non-renewable central

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[2] For example, the ability of storage to ramp up and down within a cycle to provide primary frequency reserve instead of requiring fast response alternatives like OCGT. The cost of providing frequency reserve has been evaluated in several countries and in the USA by NREL. Depending on natural gas costs and CAPEX, the value of this reserve is significant and should be appropriately assessed by OPA.

generation and transmission, effectively limiting the potential for these technologies to play a role in reducing costs and impacts as they come to maturity.

Storage will offer numerous system benefits and can help Ontario transition from a polluting, high risk central generation model to a more decentralized, resilient, renewable system. It must be acknowledged that I have a pecuniary interest in the advancement of the VRB flow battery technology. However, I would expect that any application of the VRB system or any other storage technology in Ontario will in fact require contractual promises that ensure performance and an appropriate level of cost-effectiveness. As I noted above, for market participants to offer innovative services like storage, planners and regulators must place appropriate value on the various benefits that the system and society accrues from such technologies. Planners must anticipate the changing make up of generation resources and the changing role of the grid and plan to procure or enable markets to provide technologies that address the changing reality. I am not suggesting that the Ontario Power Authority should procure VRB storage at this juncture. I am suggesting that the failure of the IPSP to anticipate and ensure that it can accommodate the likely availability of cost-effective storage and renewable technologies in the 20 year period seems a major failing of the plan.

Appendix - VRB Projects

Moab, Utah: PacifiCorp has a 2MWh, prototype system which has operated since March 2004 and as an unmanned site.

California: Chevron Energy services were recently awarded a $14million MW scale solar and minigrid project incorporating the VRB-ESS in California. VRB Power is currently engaged in a large MW scale Solar minigrid project with Chevron Energy services in California

20kW 8 hour storage system at RISO in Denmark tied to a wind diesel solar minigrid to demonstrate the viability in mingrids of storage sized as a percentage of installed nameplate wind.

Japan - Sumitomo Electric Industries has a number of installations:

Place	**Application**	**Specifications**	**Start of Operation**
Utility Company	Peak Shaving	200kW x 8h	1996
Utility Company	Peak Shaving	450kW x 2 hours	1996
Office building	Peak Shaving	100kW x 8h	2000
LCD Factory	1) UPS 2) Peak Shaving	3000kW x 1.5 sec 1500kW x 1h	2001
Laboratory	Wind Turbine Stabilization	170kW x 6 hours	2001
Golf Course	Photovoltaic hybrid	30kW x 8h	2001
University	Peak Shaving	500kW x 10h	2001
Tomamae – Japan	Stabilization of wind turbine output	4MW x 1.5h	2005

Other examples:

On smaller scale systems primarily telecoms, we have had 10 x 5kW 4 hour units under field test at multiple sites worldwide over two years. The unit at the NRCC in Canada has over 2000 hours of cycling. Larger 20kW peak shaving systems are planned for telecommunications facilities in California and British Columbia.

Biographical summary

Timothy David John Hennessy

Currently Chairman of the Board and CEO of VRB Power Systems Inc. (VRB: TSXV).

Mr. Hennessy has 25 years of engineering, management and leadership experience relating to power and energy systems throughout of the world. He has held senior positions in two world class utilities firstly at ESKOM and then as VP Energy Services of PacifiCorp. He has held Officer and Board of Directors positions in several energy services and technology companies in the USA, Canada, Australia and Europe. His experience includes power system protection, electrical machine design and application, large, fast track power projects including power-line construction, CHP, DG systems and innovative power quality technology applications (superconductors). He has been involved in large scale energy storage for 10 years. He has experience in pumped hydro storage systems, Sodium Sulphur, Polysulphide Bromine (Regenesys), lead acid and flywheel energy storage. He has 24 international publications primarily in the fields of Power Quality and energy economics and was editor of the Power quality Blue book a text for engineers in industry in South Africa.

Mr. Hennessy holds a B.Sc. in Electrical Engineering and a Masters in Engineering (economic modelling of power systems). In addition he has a Management Diploma from the UNISA School of Business and has completed B. Comm. subjects majoring in Economics and Quantitative Management. He is a Chartered Engineer in the UK and a registered professional engineer in South Africa. He holds 5 patents. He sits on the board of Schmitt Industries (SMIT: NASDAQ).