STORING Renewable Power

June 2008

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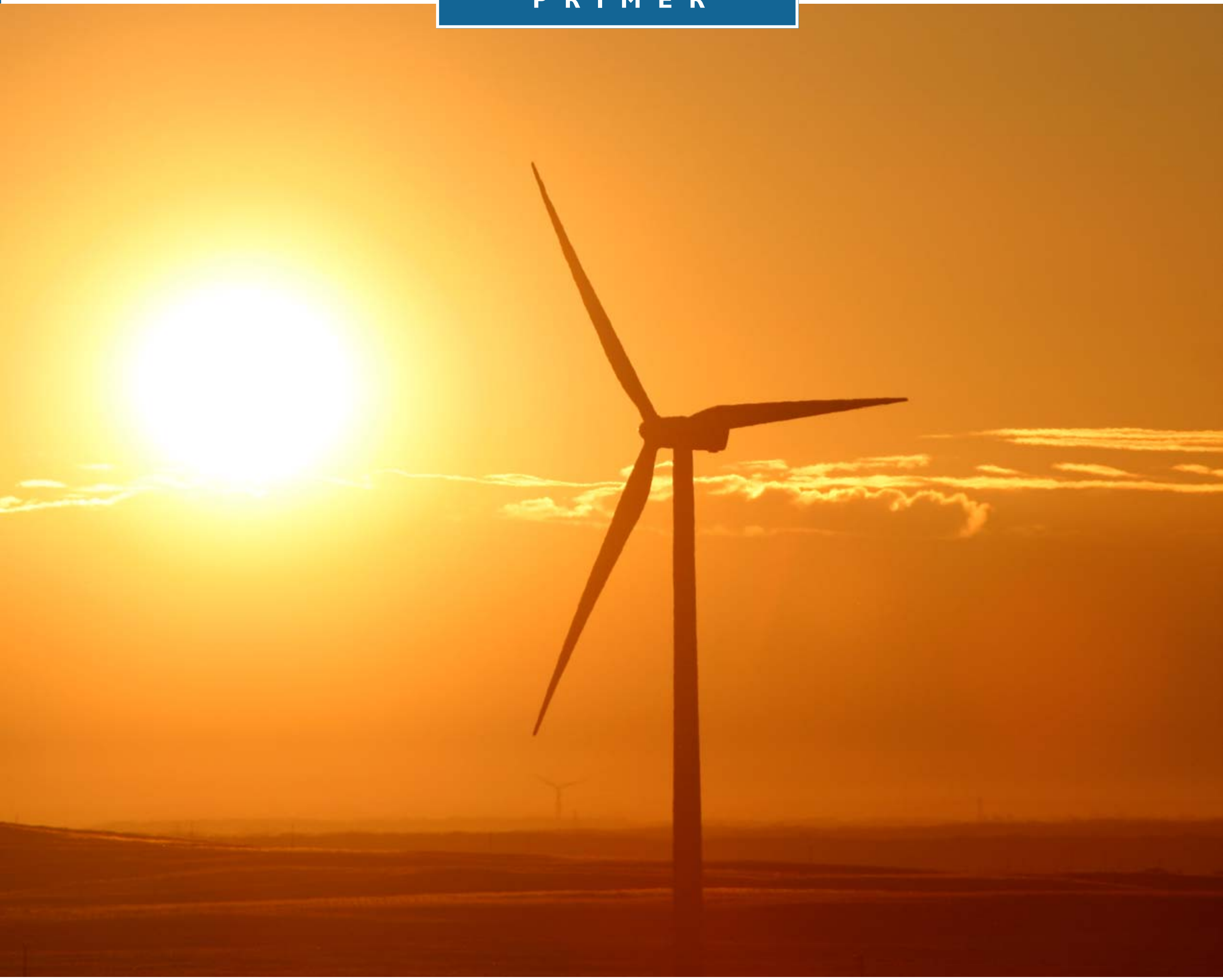

Roger Peters, P.Eng. with Lynda O'Malley

Renewable. It's Doable!

the PEMBINA institute

Storing Renewable Power

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With Lynda O'Malley, York University

This is the second primer in the series
Making Renewable Energy a Priority

June 2008

The Pembina Institute is a member of the Canadian Renewable Energy Alliance, an alliance of Canadian civil society organizations from the non-profit or voluntary sector that hold a common interest in promoting a global transition to energy conservation and efficiency and use of low-impact renewable energy.

The Pembina Institute is also a member of the Clean Air Renewable Energy Coalition, a group of corporate and environmental non-government organizations formed to accelerate the development of Canada's renewable energy industry.

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Storing Renewable Power
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Storing Renewable Power

A global shift to renewable energy systems is now inevitable. Renewable energy systems offer us a way to tap into our vast national supply of sustainable resources and reduce our environmental impact while creating jobs and a long-term, secure energy supply.

This primer focuses on the large-scale storage of electricity in order to bring more renewable power sources onto the grid. Adding power storage to the grid will allow our future base load and peak power needs to be met primarily with renewable power sources, including those that have variable outputs like solar, tidal, wave and wind power.

Power storage can be installed at a power generation site, within the grid itself, or on a customer's premises. Storage provides renewable power generators with the ability to supply power whenever it is in demand. It also provides grid operators with the flexibility to integrate large amounts of renewable energy into the grid and to manage a grid based on a wide variety of distributed sources.

Several new power storage technologies like reversible flow batteries are being tested and are entering commercial use in several parts of the world. Older established storage options like pumped hydro storage are finding new applications. Policy options to support deployment of storage are being identified.

Besides firming up variable power sources, power storage technologies have many other benefits for power grid operators and distribution utilities. These include bringing stability to the entire grid, allowing better management of peak demands, reducing transmission needs and improving power quality and frequency regulation.

Shorter-term power storage technologies like flywheels and capacitors along with heat and ice thermal storage provide options for power consumers to manage their demand to

The ability to store and dispatch the power generated from renewable sources will enable increasing amounts of clean power to supply our energy future.

Photo: Tim Weis

minimize costs, and for grid operators to undertake more "demand response" measures to match demand to a varying supply at any time of day.

The power storage industry is evolving rapidly. Grid operators in jurisdictions like California that need to integrate large amounts of renewable energy into the grid are turning to power storage to play an important role. Technical assessments and financial feasibility studies show that power storage is not only technically sound but also cost effective.

Policies that would accelerate deployment of power storage include feed-in tariffs and storage performance contracts. In competitive electricity markets there is a financial incentive for power storage deployment as it allows renewable energy suppliers to successfully bid against conventional power generators.

Energy storage coupled with other improvements to the grid will therefore help renewable energy become our primary power source.

Storing Renewable Power

1. The Grid of the 21st Century: Making Renewable Energy a Priority

Renewable energy has the promise to become the energy power house of the 21st century, creating jobs and new industries, and bringing improvements in air and water quality, energy security, access to energy and community development. In addition, if significant reductions in Canada's greenhouse gas (GHG) emissions are to be made, low-impact renewable energy sources must become the primary focus of Canada's long-term energy supply strategy.

However, the current electricity system in most of the world is based on large, centralized and often non-renewable energy systems such as coal, natural gas and nuclear. Transforming this system to one based on renewable energy sources will not be without challenges. These challenges need to be identified and systematically addressed in order to foster the rapid and large-scale deployment of renewable energy systems needed to avoid dangerous climate change.

Transforming the Grid

One of the challenges in transforming the grid will be managing power from renewable energy sources like solar, tidal, wind, wave and some hydropower that are by their nature variable. Basing a power grid primarily on renewable sources requires introducing more flexibility into the system. Many renewable energy power systems will also feed directly into the distribution system. The challenge will be turning the current passive distribution system into an active bi-directional system where every consumer is a potential generator. The transmission system will remain the critical link enabling any grid to function effectively. To meet renewable targets being set by many governments, increased investment will be required to strengthen both the transmission and distribution components of the grid and improve its operation to integrate decentralized, two-way energy flows.

These challenges can be achieved through a number of means including

- better coordination of variable power sources with flexible power sources such as combined heat and power and hydro
- increasing operational flexibility of the generation portfolio — quick start, fast ramp up and down, turn down, increased reactive power, and load following
- improving forecasting of power outputs from renewable power sources
- using new grid operating strategies and "smart grid" control systems
- ensuring management of demand to better match supply variations through "demand response" techniques
- increasing the geographic diversity of renewable power systems
- using "grid friendly" renewable power sources that provide high quality power — frequency, power factor, and so on
- introducing energy storage — at renewable power generation sites, within the grid, or at a customer's site to smooth natural variations, both short term and long term — in renewable supplies, and provide other services that help control power quality and match supply and demand.

Detailed studies by both the California Energy Commission and the California Independent System Operator have confirmed that it is possible to integrate a high level of variable renewable resources into the grid.[1,2] A list of recommendations is provided in Appendix A.

As of 2007, both Germany and Denmark (see Figure 1) generate close to 15% of their annual electricity from wind. On a particularly windy day in March 2008, Spain reached a point where 40% of its power was coming from wind.[3] These countries are leading the world in wind energy development and to date have done so without incorporating energy storage systems, in large part because they are so well interconnected with neighbouring countries to buy and sell power during fluctuations.

However, as variable renewable energy sources play larger roles in supplying power to national or provincial grids, managing these fluctuations will become increasingly important. Short- and long-term shortage systems will enable renewable energy to provide reliable “base load” as well as to be “dispatchable” to meet peak demands on the system.

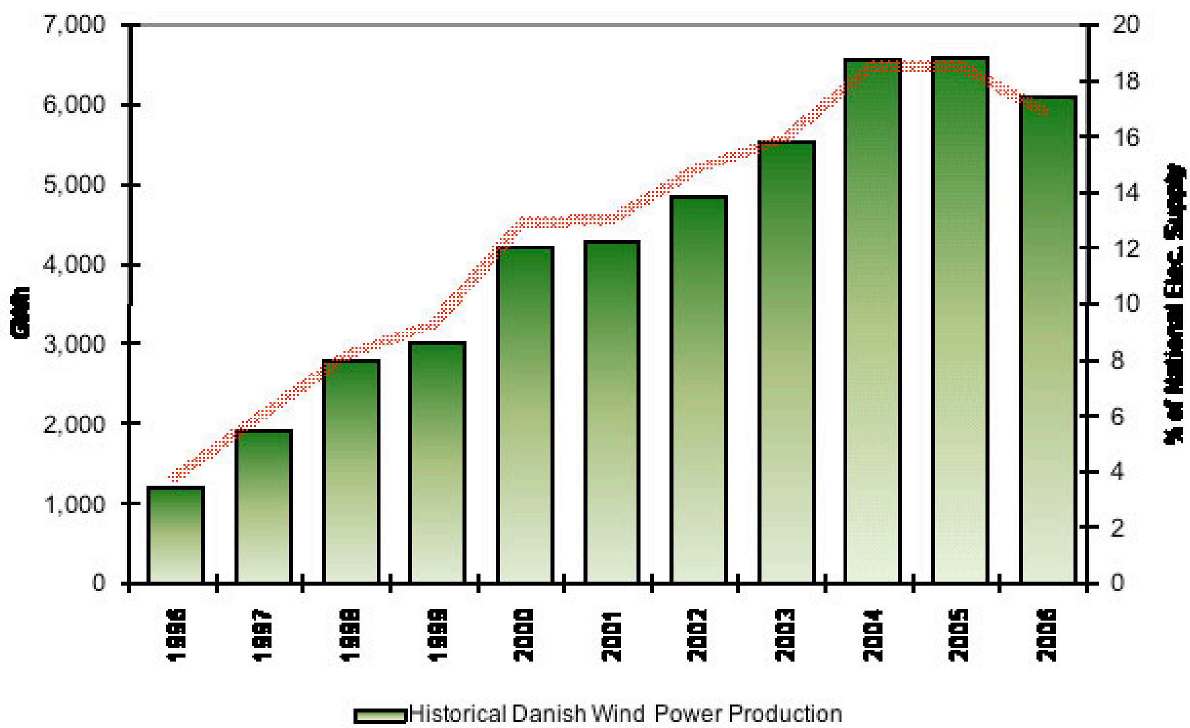

Figure 1: Historical Danish annual wind power production (Source: Danish Energy Authority)

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[1] *Intermittency Analysis Report.* California Energy Commission Public Interest Energy Research Program. July 2007 CEC-500-2007-081

[2] *Integration of Renewable Resources.* California Independent System Operator, November 2007.

[3] Agence France-Press, http://afp.google.com/article/ALeqM5jb_CljIaxmm-5LbeW4Hb0taAY8VA

The Benefits of Power Storage

While the primary benefit of power storage capacity is to enable the integration of more renewable power sources into the grid, storage systems also offer many other benefits that can be summarized as follows:[4]

Benefits for the Renewable Power Producer

- Firmer production, frequency control and power quality of renewable power sources.
- Reduced connection and transmission capacity needed for renewable power sources by up to two-thirds.[5]
- Allowance of renewable power sources to take advantage of competitive power markets, such as offering day-ahead guaranteed contracts.

Benefits for the Grid System Operator

- Flexibility to integrate large proportions of renewable power sources into the grid at all times.
- Ability to purchase low cost power whenever it is available (arbitrage).
- Deferral of investment in transmission and distribution system upgrades and large new central power generators.
- Provision of "ancillary services" including spinning reserve, load following, fast start-up and ramping (up and down), and black start.
- Improved transmission stability.
- Reduced transmission congestion.

Benefits for Customers

- Reduced time-of-use charges.
- Reduced demand charges.
- Reduced losses from poor power quality and unreliable service.

[4] Derived from a variety of sources including: Energy Storage Benefits and Market Analysis Handbook, Sandia National Laboratories SAND2004-6177, December 2004

[5] With storage the connection capacity in MW can equal the average output of the wind or solar power plant instead of its rated nameplate capacity.

2. Electric Power Storage Options and Renewable Energy Applications

Power storage can be located at several locations within the grid depending on the role it plays:

- At the generation site to provide the power generator with dispatchable high quality power and lower connection costs.
- Within the grid close to load centres to provide flexibility and ancillary services.
- At a customer's site where storage provides more options for demand response measures.

Storage facilities can be owned and operated by the generator, a separate storage entity or a customer — again depending on the role storage plays. There are many types of storage technologies that are suitable for different roles. These technologies are listed below and described in detail in Appendix B.

Storage Technology Options

The following is a summary of the options available for storing electrical power on a large enough scale to allow deployment of large proportions of renewable power sources into the grid:

Pumped Hydro Storage: water is pumped into a new or existing water reservoir and released as needed through a turbine generator.

Flow Batteries (Regenerative Fuel Cells): a reversible fuel cell stores and releases electricity by means of an electrochemical reaction, which occurs when the electrolyte flows across a membrane/cell stack.

Advanced Rechargeable Batteries: Sodium sulphur (NaS) batteries contain liquid sulphur and sodium separated by a solid ceramic electrolyte. Lithium-ion (Li-ion) batteries contain metal oxides and graphitic carbon separated by an electrolyte containing lithium salts.

Compressed Air Energy Storage (CAES): Air is compressed in underground caverns and then released as needed though a gas turbine, which can also be supplemented with natural gas.

Flywheels: A rotating cylinder enclosed within a low pressure or a vacuum environment connected to a motor/generator that draws electrical energy from a primary source. The motor driving the flywheel acts as a generator when power is needed.

Supercapacitors: Two electrodes (plates) of opposite polarity are separated by an electrolyte and store electric charges of equal and opposite magnitude on the surface of each electrode plate. During discharge, the built up charges on the plates create a current.

Hydrogen Storage: Water is electrolyzed into hydrogen (and oxygen), which is stored in compressed form. The hydrogen is used to generate power using a fuel cell or a reciprocating engine when needed.

Plug-in Hybrid Vehicles: Hybrid vehicles with additional batteries are used to store and release grid power when not in use.

Table 1 on the following page provides a summary of the advantages and disadvantages of storage technologies as well as the applications for which they are most suited.[6,7]

Storage capacity is measured in 1) power capacity (MW) — the maximum rate at which power can be stored and released, 2) energy capacity (MWh) — the amount of energy that can be stored equal to capacity times number of hours of storage, and 3) power density — the energy capacity per unit volume of storage.

Table 1: Characteristics of Energy Storage Options

Storage Option	Advantages	Disadvantages	Application	Efficiency
Pumped Storage	High power capacity Very high energy capacity Lower cost	Special site requirements Low efficiency	Spinning/standing reserve Arbitrage	70–85%
Flow Batteries	Medium power capacity High energy capacity	Low power density	Variability reduction Spinning/standing reserve	75–85%
Sodium-sulphur (NaS) Batteries	Medium power and energy capacity High power density High efficiency	Higher cost Production challenges	Variability reduction Uninterruptible power supply (UPS)	85–90%
Lithium ion (Li-ion) Batteries	Medium power and energy capacity High power density High efficiency	Higher cost Special circuitry	Variability reduction Uninterruptible power supply (UPS)	90–95%
Compressed Air	High power capacity Very high energy capacity Lower cost	Special site requirements Gas connection	Spinning/standing reserve. Arbitrage	70–80%
Flywheels	High power capacity	Low energy capacity Low power density	Power quality	90–95%
Capacitors	Long cycle life High efficiency	Low power density	Power quality	90–95%
Hydrogen Storage	High power and energy capacity	High cost Low efficiency	Variability reduction Spinning/standing reserve.	Low
Plug-in Hybrid	Widely distributed Low cost to power system	Difficult to manage	Variability reduction Spinning/standing reserve.	80–90%

[6] Electricity Storage Association http://electricitystorage.org/tech/technologies_comparisons.htm

[7] "*Detailed Cost Calculations for Battery Storage Systems.*" Dr. Dirk Uwe Sauer, Second International Renewable Energy Storage Conference, Bonn, Germany, November 19-21, 2007.

Energy Applications

The storage options most useful for integrating more renewable power into the grid are those that

- provide energy (MWh) and power (MW) storage at a reasonable price
- have reasonable "round-trip" efficiency (> 75%)
- can provide fast up and down response
- can be quickly deployed
- have low environmental impact
- can be located in either rural or urban areas
- can be located either at the renewable energy generating site or close to load centres.

As noted in the previous section, storage is most useful to wind and solar generators for

- firming production, frequency control and power quality of renewable power sources
- reducing connection and transmission capacity needed for renewable power sources by up to two-thirds
- allowing renewable power sources to take advantage of competitive power markets, for instance offering day-ahead guaranteed contracts.

Flow batteries, sodium-sulphur batteries, flywheels, and capacitors can meet all of these criteria. Pumped hydro storage and compressed air storage have specific site requirements but can meet most other criteria. Conventional hydro power plants with water storage and natural gas generators can be managed so that power outputs are coordinated with new renewable power plants.

Sizing Storage Systems for Renewable Energy Applications

A power storage system will normally be used to store power when a wind or solar generator is producing power above its mean power output, and to deliver power when the renewable energy production is lower than the mean. The power capacity of the storage must therefore be the greater of the maximum deviation above or below the mean. For example, if the output from a 100 MW wind farm with a capacity factor of 35% varies between 20 and 60 MW, then a 25 MW storage system will allow the generator to produce 35 MW most of the time.

The energy capacity of storage depends on the number of hours that the wind or solar system is below the mean and/or the coincidence of wind output with peak load. The less the coincidence, the more hours of storage are needed. If four hours of storage were needed for the 25 MW system described above, then a 100 MWh storage system would be required.

3. The Growing Power Storage Industry

Power storage is developing quickly into a major new industrial opportunity. At the Second International Energy Storage Conference (IRES II)[8] in 2007 and the Electricity Storage Association's (ESA) Annual Meeting[9] in 2008, several speakers spoke of the important role storage will play in the grid of the future, the numerous technologies that are near to commercial and cost-effective deployment[10] and the fact that some storage technologies are already being used for mainstream utility applications.[11]

As of 2007, there was 110 GW of pumped hydro storage in use globally, and about 850 MW of other types of storage — mostly compressed air and sodium-sulphur batteries. Sodium-sulphur and vanadium redox flow batteries are showing the highest market growth rates.[12]

In his keynote address to the IRES II conference, Hermann Scheer, Chairman of the World Council on Renewable Energy (WCRE), asserted that all modern energy systems require the storage of energy. While hydro, biomass energy, and conventional fuels can be stored before energy is generated, wind power and solar energy must be stored after they are converted into electrical form. [13]

At the same conference, Brad Roberts of the ESA described how the investment community is beginning to show interest in power storage. Several energy storage developers have received major venture capital investments increasing from $35 million in 2001 to $145 million in 2006. The investment community held a conference on opportunities in energy storage on Wall Street in 2007.[14] The American Electric Power (AEP) utility announced 1000 MWs of storage by 2020, and several other large U.S. utilities are involved in projects. The U.K. and Ireland have projects that combine wind power with storage.[15] In addition to firming up renewable power sources, storage technologies can help optimize power flow and potentially relieve congestion on transmission and distribution systems. A combination of smaller storage systems with renewable energy sources could significantly reduce dependence on diesel power in rural regions.[16]

While pumped storage is still the most used and effective method for long-term storage, new sites are difficult to find. Medium-term storage technologies such as compressed air are being

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[8] Held in Bonn, Germany, November 19–21, 2007.
[9] Held in Anaheim, California, May 19–22, 2008.
[10] http://www.eurosolar.de/en/index.php?option=com_content&task=view&id=290&Itemid=8
[11] Nourai, Ali. "AEP Energy Storage Projects and Financial Model for Selecting Sites." Electricity Storage Association's Annual Meeting, Anaheim, California, May 19-22 2008.
[12] *Electrical energy storage – state of the art technologies, fields of use and costs for large scale application.* Fraunhofer Institute. Electricity Storage Association 2008 Meeting May 20-22, 2008
[13] "*Decentralization and Modularization: The Techno-logic, eco-logic and socio-logic of new Renewable Energies.*" Hermann Scheer, Second International Renewable Energy Storage Conference, Bonn, Germany, November 19-21, 2007.
[14] *Investing in Energy Storage Technologies – Opportunities for Venture Capital, Private Equity and Hedge Funds.* October 11-12, 2007. Financial Research Associates, LLC.
[15] Tapbury Management Limited. "VRB ESS Energy Storage and the development of dispatchable wind turbine output: feasibility study for the implementation of an energy storage facility at Sorne Hill, Buncrana, Co. Donegal." http://www.vrbpower.com/docs/news/2007/Ireland%20Feasibility%20study%20for%20VRB-ESS%20March%202007.pdf
[16] Brad Roberts, United States Energy Storage Association, Second International Renewable Energy Storage Conference, Bonn, Germany, November 19-21, 2007.

adopted where sites are available. The most flexible technologies available are advanced batteries that can be placed either at a generation site or close to load centres, and effectively firm up variable supply sources. Flywheels can be used to provide fast-acting ancillary services as they can respond faster to frequency regulation.

At the ESA's Annual Meeting in 2008, Ed Cazalet of MegaWatt Storage Farms Inc. claimed that grid scale storage is ready today and storage must be deployed at the GW level now, where capacity, ancillary services and energy time shifting are needed. The best locations are often close to load, yet some storage technologies are modular and can be relocated, so optimization of initial location and size occurs over time with experience. Cazalet also claimed that the demand-pull from large-scale commercial deployment of storage projects would encourage manufacturing investment and lower costs through economies of scale. While research and development must continue, the time for commercial deployment is now.

The new U.S. Energy Independence and Security Act of 2007 defines "deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning" as a "Smart Grid" characteristic. It is therefore eligible for matching grants and other supportive measures under the Act.[17] The Energy Storage Technology Advancement Act of 2007 includes dedicated funding for research and development on storage technologies that focus on grid development and plug-in hybrids, with $50 million for each fiscal year from 2009 to 2014, and $80 million for each of the same years in the applied research program.[18] This Act represents the first time that storage technologies have been recognized as important as other clean technologies and also calls for the establishment of an Energy Storage Advisory Council.[19]

The California Independent System Operator (CaISO) recently published a report on integrating renewable energy into the grid and noted that storage would be of considerable benefit to this end.[20] Storage would help to shift peaks, provide regulation services and frequency control, and be ramped up and down quickly. Many storage technologies can be located anywhere in the grid. Others like pumped storage have very large capacity potential. The CaSIO report has already led to the development of a policy roadmap for power storage in California, including the need for energy and ancillary service markets to compensate storage services (see Policy Framework below).

Hugo Chandler of the International Energy Agency (IEA) sees increasing use of renewable power as inevitable, and power storage as one way to introduce the required flexibility into the grid.[21] Storage can respond to large, rapid fluctuations in demand or supply. There is currently over 1 MWh of storage in operation.

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17 United States Bill H.R.6 Title XIII Smart Grids: http://thomas.loc.gov/cgi-bin/query/z?c110:H.R.6:

18 http://www.cbo.gov/ftpdocs/87xx/doc8728/hr3776.pdf

19 "USA Legislation Briefing Information: Energy Storage Technology Advancement Act of 2007." Electricity Storage Association's (ESA) Annual Meeting in Anaheim, California, May 19-22 2008

20 *Integration of Renewable Resources.* California Independent System Operator, November 2007.

21 Presentation at Side Event on Innovative Approaches to the Integration of Renewable Energy. Washington International Renewable Energy Conference. March 2008.

Full scale tests of many storage technologies are underway, including a multi-source facility at the Riso National Laboratory in Denmark where flow battery storage is used to store wind, solar and diesel generated power and to provide power to a load controlled office building.[22]

The cost of newer power storage options, like flow and sulphur batteries and flywheels, is likely to follow the same cost reduction patterns as other new technologies through the commercialization phase and mass production. A general guideline is a 12% reduction in costs for each doubling of market size. Several applications of power storage are already cost effective (see Section 4), so the prospects are good that renewable energy power storage systems will enjoy a prosperous future.

[22] *Vanadium redox-flow batteries – Installation at Risø for characterisation measurements* http://www.vrbpower.com/publications/casestudies.html

4. Power Storage Performance Case Studies

Examples of installations where each power storage technology has been installed are listed in Appendix B. In some cases, technical and financial analyses of existing or planned installations have been carried out for these projects. These range from situations where storage is used to firm up renewable energy production from variable sources such as wind to those designed to introduce more flexibility into the grid.

Effective technical and financial analyses of power storage projects take all of the co-benefits of storage into account as well as the increased value of power produced from renewable energy. As noted above, the flexible nature of storage provides many other ancillary services and allows the grid system operator to provide reliable power at lower cost.[23]

Technical Assessments

Several projects have demonstrated the effectiveness of advanced battery and compressed air storage:

- Full-scale tests of the vanadium redox flow battery in Utah, U.S. have shown that this technology can be cycled daily without loss of effectiveness. When used to improve the power factor, the reduced line losses were greater than the parasitic losses of the battery.[24] In Japan 4 MW of vanadium redox battery storage was used to smooth wind farm output from a 32 MW wind farm and operated successfully cycling up to 600 times per day.[25]
- At an existing grid-connected 11 MW wind farm with a 20 MW interconnect limit it was shown that use of vanadium redox battery storage would actually allow 12 MW of additional capacity. This increased total energy production by 16% and peak production by 78% compared with the simple addition of 9 MW more wind capacity. This was equivalent to raising the peak effectiveness of the wind farm up to its full capacity factor of 35%. The power factor was also significantly improved.[26]

From these studies it appears that about 20% of the wind farm's nameplate megawatt capacity in battery storage with six to eight hours of storage time is needed to firm up power from a wind farm so that it can deliver its average load (capacity factor) at any time.

- Simulation studies in California analyzed the addition of 750 MW of advanced battery storage close to the load centre in grid with high wind contribution. The results showed that batteries would make a substantial improvement in grid system frequency recovery.[27]

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[23] For a detailed discussion of the financial benefits of storage, refer to the *Energy Storage Benefits and Market Analysis Handbook*, Sandia National Laboratories SAND2004-6177, December 2004.

[24] *Electricity Storage for Capital Deferral.* Utah Power. http://www.vrbpower.com/publications/casestudies.html

[25] *The Multiple Benefits of Integrating the VRB-ESS with Wind Energy – Case Studies in MWH Applications*. http://www.vrbpower.com/publications/casestudies.html

[26] *Flow Battery Storage Application with Wind Power.* Mark T.Kuntz, VRB Power, California Energy Commission Staff Workshop: Meeting California's Electricity System Challenges through Electricity Energy Storage February 24, 2005

[27] *Energy Storage for Wind Integration, a Conceptual Roadmap for California.* Edward Cazalet et al, 4th Annual Carnegie Mellon Conference on the Electricity Industry, March 2008

- Studies at Princeton University have shown that the addition of compressed air storage[28] would allow wind farms to meet base load power demand with an 85–90% capacity factor. Further, the addition of storage would allow smaller turbines to be used to produce the same power output and lead to significantly lower emissions per kWh than wind/natural gas, natural gas combined cycle, and coal/carbon capture base load power plants.[29]
- The Princeton studies also showed that the use of compressed air or any cost-effective storage technology could also significantly boost the ultimate penetration level for wind energy on an electric grid to > 80%, compared to an upper limit of 40% that is determined by wind's low capacity factor. This higher penetration level is made possible by significantly increasing the wind park capacity relative to the capacity of the transmission line.[30]

Financial Assessments

Several studies have been carried out that illustrate the cost effectiveness of adding storage to renewable power systems:

- Several feasibility studies at actual wind farms have illustrated the financial cost effectiveness of vanadium redox advanced battery storage. In Ireland it was shown that if 2 MW/12 MWh of vanadium redox battery storage costing $9 million was added to the 10 MW Sorne Hill wind farm, which sells into a competitive market, the wind farm would be able to compete in day-ahead markets with 92% delivery.[31] In Australia, it was shown that vanadium redox battery storage reduced reliance on diesel generation in wind/diesel hybrid systems and at the same time firmed up wind frequency and voltage.[32]
- These studies showed that the cost of 200 kW (20% of wind nameplate capacity) vanadium redox batteries with a six to nine hour capacity to firm up power from each MW of installed wind capacity is about $800,000. This would increase the cost of a wind farm from the current $2 million per MW to about $2.8 million per MW, an increase in cost of 40%. This is easily recovered by the increased benefits of storage. For example, in the Sorne Hill case, the IRR for the addition of storage was estimated to be 10%. The payback for the Australia wind/diesel project was estimated to be 3.5 years.
- An analysis of adding 900 kW of advanced battery capacity with between one to eight hours of storage to an existing 9 MW wind farm in Ontario showed that 2.7 MW of firm power could be made available at all times. By using existing tariffs offered to peak

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[28] Compressed air storage has the added feature that in can utilize natural gas to supplement wind or other variable power outputs. Air compressed using wind or solar generated power is used to run a gas turbine generator. See Appendix for more details.

[29] *An Integrated Optimization of Large Scale Wind with Variable Rating Coupled to a Compressed Air Storage*. Samir Succar et al, American Wind Energy Association WindPower 2006, June 4-7, Pittsburg, PA

[30] *Baseload wind energy: modeling the competition between gas turbines and compressed air energy storage for supplemental generation*. Jeffery B. Greenblatt et al, Energy Policy 35 (2007) 1474–1492

[31] *Feasibility Study for the Implementation of an Energy Storage Facility at Sorne Hill, Buncrana, Co. Donegal, Ireland.* Tapbury Management Ltd., Sustainable Energy Ireland. www.vrbpower.com

[32] *Flow Battery Storage Application with Wind Power*. Mark T.Kuntz, VRB Power, California Energy Commission Staff Workshop: Meeting California's Electricity System Challenges through Electricity Energy Storage February 24, 2005

power distributed generation, the net present value of the wind farm would be increased threefold.[33] This study also showed that if the same peak premium were added to Ontario's standard offer premium for wind power, it would be even more financially attractive for distributed generators.

- A study using 1 MW of sodium-sulphur batteries in California to firm up wind power as an alternative to new transmission capacity showed that US $1 million in net benefits would be generated.[34]
- The studies of wind-compressed air storage systems at Princeton University (referred to above) showed that wind/storage is competitive with combined cycle natural gas when fuel costs exceed $9/GJ. In a competitive electricity market, with a GHG emissions cost of $35/tCequiv or greater, wind/storage has the lowest short-run marginal cost compared with straight natural gas or carbon capture and storage.[35,36]

As the cost of power storage comes down it will become even more attractive to use renewable energy as our primary source of base load and peak power.

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[33] *Ontario Wind Energy Storage Case Study.* Melanie Chamberland, Natural Resources Canada. Energy Storage Association Conference, Anaheim, USA, May 20, 2008

[34] *Economic Valuation of Energy Storage for Utility Scale Applications*. Dan Mears, Technology Insights. NRCan-CEATI Distributed Energy Cost-Benefit Analysis Workshop Toronto March 26, 2008

[35] *Comparing Coal IGCC with CCS and Wind-Compressed Air Storage Baseload Power Options on a Carbon Constrained World.* Samir Succar et al, Fifth Annual Conference on Carbon Capture and Sequestration – DOE/NETL, May 8-11, 2006

[36] *Baseload wind energy: modeling the competition between gas turbines and compressed air energy storage for supplemental generation*. Jeffery B. Greenblatt et al, Energy Policy 35 (2007) 1474–1492

5. A Policy Framework for Power Storage

The deployment of power storage to support high renewable energy grid integration will require appropriate policies to be put in place that value the role that storage plays, provide equitable means for cost recovery, encourage investment, and ensure that installations are safe and meet technical standards. No jurisdictions have yet implemented policies that specially address these requirements, although California is identifying the policies needed to integrate large amounts of renewable energy into the grid, including the deployment of power storage.[37,38] In Demark, where renewable energy has made the highest inroads into the grid, variability is handled through a combination of geographic distribution and power exchange with Norway.[39]

As shown in Section 4, in some jurisdictions current policies that provide higher prices for day-ahead power contracts are already sufficient to provide the valuation necessary to make storage a good financial investment. However, it is now possible to identify a suite of storage policies that would allow larger qualities of renewable energy to be integrated into the grid.

Power storage policies must be set so that they encourage investment in *any* type of storage, location and ownership structure. For example, polices should encourage the association of storage with a renewable energy project to firm up the renewable power, or within the grid to provide additional flexibility.

Market Incentives for Power Storage

Premium Tariffs

Feed-in tariffs or renewable energy payments are becoming the preferred option for accelerating the deployment of renewable power sources to establish renewable power industries and jobs and to reduce the cost through economies of scale.[40]

A special premium feed-in tariff for wind or solar storage facilities that provides firm power when needed would provide a reasonable rate of return for investors in storage as well as a stable investment environment. The premium or bonus payment could be provided for any renewable power facility eligible for a feed-in tariff that could provide dispatchable power or meet base load power demands. Alternatively a premium tariff could be offered during peak periods.

A separate feed-in tariff could be provided for stand-alone storage that provides ancillary services to the grid operator. Once deployment of storage has reached the level needed for integration of large amounts of renewable energy into the grid, and costs have come down because of product development and economies of scale, these premiums could be reduced and phased out.

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[37] *Integration of Renewable Resources.* California Independent System Operator, November 2007.

[38] *Intermittency Analysis Report.* California Energy Commission Public Interest Energy Research Program. July 2007 CEC-500-2007-081

[39] *Wind power and its impact on the power system.* Hans Abildgaard, www.Energinet.dk Cross Cutting Session #5: Grid Integration: Integrating Renewables into Power Systems Operations. Washington International Renewable Energy Conference, March 2008

[40] Feed-in tariffs or Renewable Energy Payments provide guaranteed access to the grid for renewable energy power sources and provide a premium price sufficient for these sources to provide an adequate return for investors. In Ontario they are called standard offer contracts. For more information see Pembina's Fact Sheet and Primer "Feeding the Grid Renewably": http://re.pembina.org/pub/1598

Grid Services Performance Contract

Another innovative way of providing power storage with an appropriate compensation package that could be used to attract investors is to use a "grid services performance contract."[41] This would provide a long-term contract for all or some of the ancillary and other services provided by storage, setting out the payments that would be provided for each type of service. Part of these services could still be market based, but a long-term contract with some price stability would provide the opportunity to develop a local power storage industry and accelerate the deployment of storage to match wind and solar integration measures.

Other Incentive Measures

Other measures that should be used by governments to provide incentives for power storage include R&D and commercialization support, and accelerated capital cost allowance.

Pricing and Cost Recovery Policy in a Competitive Market

In a competitive market with fluctuating prices, storage operators (either renewable energy developers or independent storage companies) can buy electricity when prices are low and sell into the power market when they are high, or when ancillary services such as frequency regulation or load following are required. In markets where firm day-ahead contracts are provided with premium price, the addition of storage allows wind farms to compete with any other energy source for these contracts. In fact wind storage systems will always have the lowest marginal costs under these conditions.

However, care must be taken to ensure that market rules do not treat storage unfairly and thus should be modified accordingly.[42] Rules that could penalize storage include

- price caps that could reduce the revenue of storage facilities
- out-of-market purchases (imports) that deprive wind/storage facilities of opportunities
- start up and standby payments offered only to thermal generators

System operators should also allow storage to be eligible to provide ancillary services like load following, ramp up and ramp down, and frequency regulation with special tariffs. This would allow the operator to use storage for more than just peak shifting and increase the revenue for the storage operator. Storage systems should also be compensated for being able to respond immediately to forecast demand.

Wind or solar generators can also be provided with incentives to use storage by setting penalties for not delivering on forecasted power deliveries. If wind farms were required to provide day-ahead estimates of power output and face a penalty if they do not deliver, adding storage would eliminate the risk of these penalties. At the distribution system level, storage systems need to be compensated for the local capacity resources that they provide, allowing intentional islanding from the main grid if required.

Finally, energy storage should be allowed to benefit from carbon pricing schemes where a price is placed on GHG emissions. Storage allows a lower emissions generation mix to be used and

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[41] *Energy Storage for Wind Integration, a Conceptual Roadmap for California.* Edward Cazalet et al, 4th Annual Carnegie Mellon Conference on the Electricity Industry, March 2008

[42] *Ibid*

therefore should receive the additional revenue that this generates. If conventional gas combustion turbines are used to back up wind power, this can reduce the expected carbon and NOx savings from these renewable projects. If storage is added to firm up these wind projects and provide frequency regulation, then these backup resources are not required. Putting a price on carbon would provide an additional incentive to use storage.

Technical and Safety Specifications

All storage systems should be required to meet technical, safety and performance standards set by federal and provincial authorities.

6. Summary

Adding power storage to the grid will allow us to meet our future power needs primarily with renewable power sources, including those that have variable outputs like solar and wind power.

Storage provides renewable power generators with the ability to produce base load power or meet market demands whenever needed. Storage also provides grid operators with the flexibility to integrate large amounts of renewable energy into the grid and to manage a grid based on a wide variety of distributed sources.

Power storage can be installed at a power generation site, within the transmission or distribution parts of grid itself, or on a customer's premises.

Storage technologies suitable for the long or medium term include pumped hydro storage, flow and sodium-sulphur batteries, compressed air, hydrogen and plug-in hybrid vehicles. These technologies have many benefits to grid operators including integrating variable power sources into the grid, bringing stability to the grid, allowing better management of peak demands, reducing transmission capacity needed to connect renewable power sources, and improving power quality and frequency regulation.

Shorter term power storage technologies like flywheels and capacitors provide options for power consumers to manage their demand to minimize costs, and for grid operators to undertake more "demand response" measures to match demand to a varying supply at any time of day.

The power storage industry is evolving rapidly. Investment increased fivefold between 2001 and 2006 covering a wide range of applications from grid frequency regulation to wind farm base load generation. Grid operators in jurisdictions like California that need to integrate large amounts of renewable energy into the grid are turning to power storage to play an important role. Technical assessments and financial feasibility studies show that power storage is not only technically sound but also cost effective.

Policies that would accelerate deployment of power storage include higher feed-in tariffs for base load dispatchable renewable power sources with storage and storage performance contracts. Technical standards are needed to ensure effective and safe performance of power storage technologies.

In competitive electricity markets there is a financial incentive for power storage deployment as it allows renewable energy suppliers to successfully bid against conventional power generators. However, price caps and other market rules must be modified to ensure storage is not penalized. The services that storage provides must be properly compensated.

More feasibility studies and pilot projects are needed to demonstrate the technical and financial viability of power storage, and ways storage would be utilized in a smart grid based on renewable power sources.

Appendix A: California Renewable Energy Grid Integration Study Findings

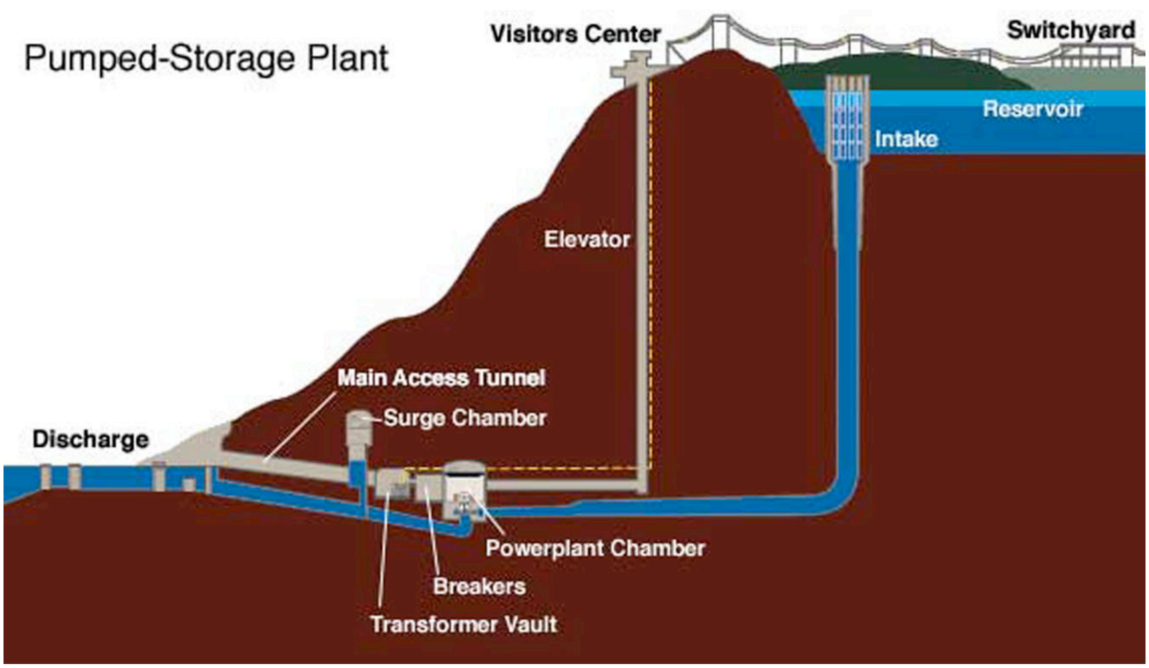
Detailed studies by the California Energy Commission and the California Independent System Operator have confirmed that it is possible to integrate a high level of variable renewable resources into the grid if the following policies and practices are in place. Many of these would support the introduction of power storage:

- Maintain a combination of local generating resources and power exchange agreements, or exchange capability with adjacent grids.
- Pursue generating resources with greater minimum turndown and diurnal start/stop capabilities, ensuring greater participation by loads.
- Optimize the use of pumped hydro and other power storage to aid in integrating variable renewable energy generation.
- Maintain or improve hydro flexibility and accessing generating resources with faster start and stop capabilities to aid with hourly scheduling flexibility.
- Require at least 10 MW/minute of upload following to incorporate high levels of renewable power sources, and 70 MW/minute of download following during light load periods.
- Provide other means of regulation besides conventional generation, such as flywheels or variable speed pumped hydro.
- Expand ancillary service markets, incentives, and requirements to limit costs and revenue reductions on generation providers.
- Maintain a verified catalogue of the flexibility characteristics of each individual generating resource.
- Implement policy, regulatory and contractual practices to maximize use of existing transmission, such as real-time line ratings, local short-term forecasting, and controls that manage output from multiple variable renewable energy resources.
- Develop protocols to curtail variable renewable energy generation under the rare circumstances of coincident minimum load, high wind generation and low conventional hydro flexibility,
- Implement regulatory and contractual arrangements for variable renewable sources designed to allow and compensate for the provision of ancillary services such as frequency regulation.
- Require high fidelity forecasting for all variable renewable (wind and solar) resources over multi-day, unit commitment, and short-term (hours and minutes) time frames.

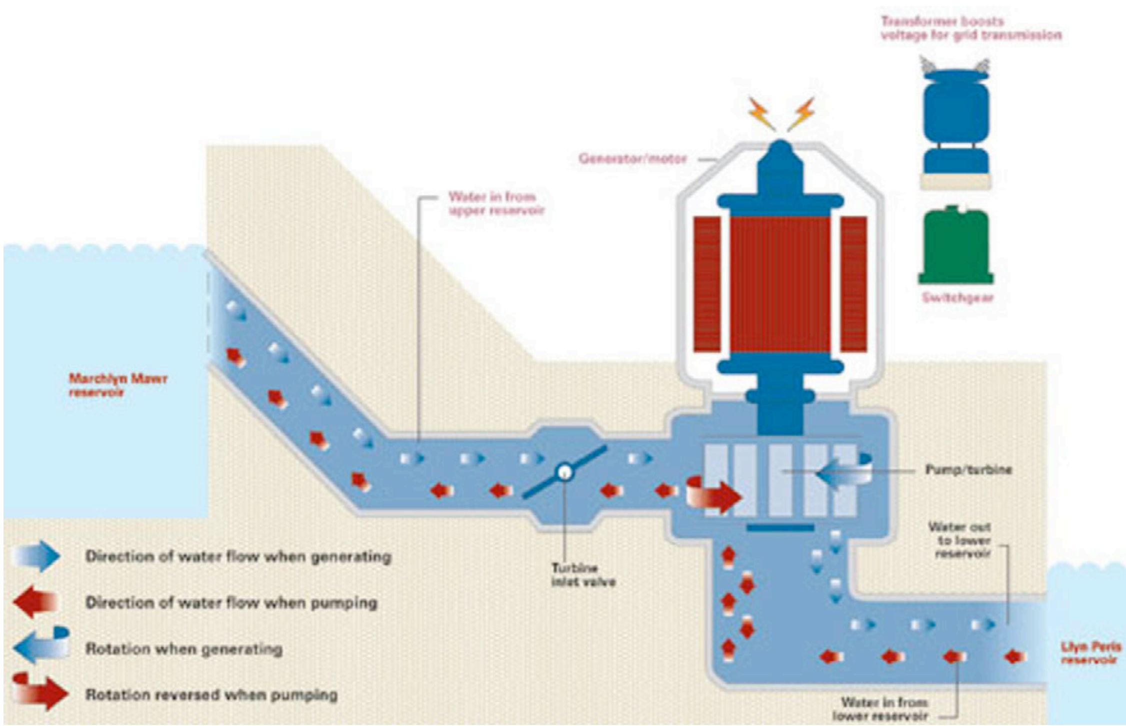
Appendix B: Power Storage Options

Pumped Hydro Storage

Pumped storage is the most widespread energy storage system in use within power networks today with over 90 GW or 3% in operation worldwide. Conventional pumped hydro uses two water reservoirs at different elevations. During off-peak hours water is pumped from the lower reservoir to the upper reservoir where it is held until it is released to flow through a turbine to generate electricity during peak hours. Feasibility depends upon geography, since a large body of water and/or a vertical separation between the storage and the discharge reservoirs is necessary. In some cases this vertical separation has been created or enhanced underground, where flooded mine shafts or other cavities can be used. Some high dam hydro plants have a storage capability and can be dispatched as pumped hydro. The open sea can also be used as the lower reservoir. In addition to natural and human-made lakes, anything that can hold water and is lower than the upper reservoir will serve as a lower reservoir, including natural or human-made underground cavities, and the ocean. The amount of water stored determines the discharge time. In existing installations this can be as much as 22 hours.



Source: http://upload.wikimedia.org/wikipedia/commons/9/9a/Pumpstor_racoon_mtn.jpg (accessed June 10, 2008)



Source: International Power "The Principles of Pumped Storage," web article.
http://www.fhc.co.uk/pumped_storage.htm (accessed June 10, 2008)

Advantages:

- A large-scale technology for bulk storage and the oldest storage technology available.
- A proven technology, making up more than 2.5% of the US energy market, and generating over 90 GW globally.[43]
- Long-time scale storage (can be used for seasonal fluctuations); no loss of energy due to long holding times.
- Of the energy used to pump, 70–85% can be recaptured.
- Fast response to changes in load demand, measured in seconds.
- Some high dams already include pumped storage capability.
- Suitable anywhere with a water supply and a vertical drop; water can be fresh or salt
- A salt-water plant can include desalinization.
- High capacity range (up to 1,000 MW and larger).
- Discharge times can range from hours to days.
- No waste or toxic materials.
- Main uses are frequency control, energy management and provision of reserve.[44]
- Can be used daily or even many times a day, and has a fast reaction if needed so can respond quickly to market conditions — generally takes less than 10 minutes to get to full capacity, and if run on standby can reach full capacity in 10 to 30 seconds.[45]

Disadvantages:

- Long construction times. Expensive and slow to build from scratch; this can be mitigated by using pre-existing structures or geographical features.
- Typically high capital costs, however can use hydro upgrades as an opportunity to reduce costs.
- Intensive technology with large land needs, tends to be far from load requiring transmission, water use impacts.
- If system uses underground caverns instead of rivers, may avoid ecosystem damage.

Applications of Interest

- The Okinawa Seawater Pumped Storage Power Plant in Yanbaru, Japan uses the open sea as its lower reservoir in its 30 MW system with an effective vertical drop of 136 m. Okinawa started operation in 1999 by Electric Power Development Co., Ltd. (J-POWER) [46]
- The Dinorwig plant in Wales, UK is one of the best-known pumped storage plants in the world. The plant was constructed between 1976 and 1982 in Europe's largest human-made cavern under the hills of North Wales. The six huge pump turbines can each deliver 317 MW, producing together up to 1,800 MW from the working volume of 6 million m^3 of water and a head of 600 m.
- The Bath County Pumped Storage Station in Virginia's Allegheny Mountains has a 2,100 MW pumped hydro system with six turbines that pump 11 million gallons per

[43] Electricity Storage Association, http://electricitystorage.org/index.html (accessed April 8, 2008).
[44] Ibid.
[45] Baxter, Richard. Storage: A nontechnical guide. 2006.
[46] www.ieahydro.org/01-Okinawa-Seawater-PSPP-lg.htm

minute. Generation uses 14.5 million gallons per minute. This system cost US $1.7 billion (1985 dollars). Operations began in 1985 and the station is owned by Dominion and Allegheny Power System.[47]

- The Ludington Pumped Storage system discharges into Lake Michigan, and with 1,872 MW can serve 1.4 million residential customers. This example is particularly relevant to Ontario, because of similar topography and climate.[48]

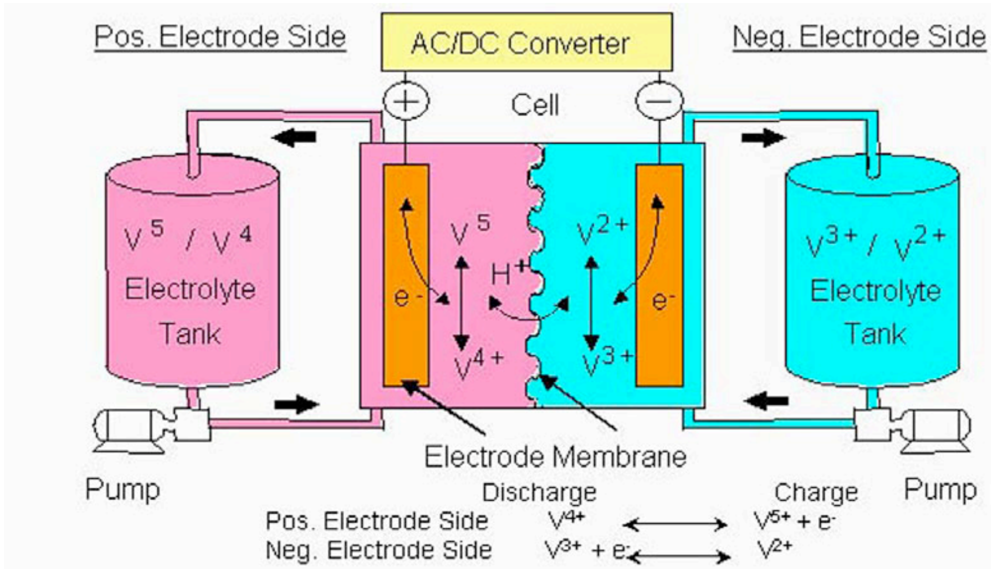
Flow Batteries (Regenerative Fuel Cells)

A flow battery (also referred to as a regenerative fuel cell) is an electrical energy storage system that converts chemical energy into electrical energy using different ionic forms of an electrolyte. In a reversible process, the electrolyte is pumped from two separate storage tanks containing conductive ion-rich substances, or electrolytes, into a fuel cell across an ion exchange membrane. Energy is stored and released by means of an electrochemical reaction, which occurs when the electrolyte flows across this membrane/cell stack. The migrating ions create a current that is collected by electrodes and made available to an external circuit. In crossing the membrane, the oxidation of one solution is reduced while that of the other is increased (this process is referred to as "redox," which stands for reduction/oxidation), creating a usable electric current. The reaction is reversible and almost indefinitely repeatable, allowing the battery to be charged, discharged and recharged. A redox flow battery is an energy storage technology that is charged like a battery, except that the energy is stored chemically in a "working fluid" rather than physically at an electrode as with conventional battery technologies.[49]

The choice of the electrolyte solution varies greatly and differentiates the technologies available on the market. The four leading flow battery technologies are polysulfide bromide (PSB), zinc bromine (ZnBr), hydrogen bromine (H-Br) and vanadium redox (VRB)

The flow battery getting the most attention is the VRB. It consists of two plastic tanks filled with different ionic forms of vanadium in a mild sulphuric acid solution, which serves as the electrolyte. Tests have confirmed that the VRB is capable of more than 10,000 charge/discharges without any deterioration in efficiency.

[47] www.dom.com/about/stations/hydro/bath.jsp
[48] www.consumersenergy.com/content/hiermenugrid.aspx?id=31
[49] Tapbury Management Limited. "VRB ESS Energy Storage and the development of dispatchable wind turbine output: feasibility study for the implementation of an energy storage facility at Sorne Hill, Buncrana, Co. Donegal." Accessed from http://www.vrbpower.com/docs/news/2007/Ireland%20Feasibility%20study%20for%20VRB-ESS%20March%202007.pdf on April 29, 2008.



Source: Sumitomo Electric Industries, Ltd. (http://electricitystorage.org/tech/technologies_technologies_liion.htm (accessed June 10, 2008).

Advantages:

- Output range of 50–10,000 kW with four to ten hours of storage.
- With a VRB the same solution is used on both sides of the membrane, so cross-contamination is not an issue. Mixing of the two sides (half-cells) causes no permanent damage. Solution can even be re-mixed to return it to its original state.
- Storage capacity is limited only by the size of the storage tanks.
- Can be left to discharge for long periods of time.
- Flexible, high-quality power output.
- Very fast response to change of load — a 100% change has been achieved in less than half a millisecond. Limiting factor is the electrical equipment, not the battery.
- Extremely large overload capacity — as much as 400% for ten seconds.
- Modular units allow for rapid design and construction including environmental management and permitting.
- Easy to upgrade at low incremental cost.
- No fuel inputs, hence immunity from fuel price fluctuations.
- Long life — newer VRBs are designed to last at least 12–15 years. Vanadium electrolyte solution lasts indefinitely (and can be easily recycled into a new battery)[50]; no disposal or contamination issues. Some flow battery systems last up to 30 years.[51]
- Very low maintenance costs.
- Efficiencies in the range of 65–96%.
- A theoretical charge/discharge window of 1:1, allowing off-peak charging for on-peak dispatch.

[50] Beck, Brian. VRB Power Systems: "Vanadium-Redox FlowCell Product." Electricity Storage Association's Annual Meeting, Anaheim, California, May 19-22, 2008.
[51] Baxter, Richard. *Storage: A nontechnical guide*. 2006.

Disadvantages:

- High initial costs (25% more than a comparable lead acid battery), but can be mitigated by appropriate sizing (although Sorne Hill has a projected internal rate of return (IRR) of 17.5%).
- Bulky — quantity of power stored is determined by the amount of electrolyte available in the two half-cells.
- Membranes must be periodically replaced.
- Some choices of electrolyte fluid contain toxic elements and require replacement and disposal.
- High output systems require a large volume of electrolyte storage and a significant layout area of up to 2,000 m^2 within a two-storey building.

Environmental Aspects

- No routine contamination issues, since electrolyte can be used for the life of the battery.
- Some toxicity identified in vanadium, especially in its richly oxidized forms. Bio-accumulates in crabs and mussels. Negative effects in animals on neurological, reproductive and respiratory systems and on liver and kidneys have been noted. Lenntech, an air and water treatment company, claims flow cell components are not carcinogenic.[52]
- Vanadium is an element found combined in certain minerals, especially those containing carbon, such as crude oil, coal, oil shale and tar sands. By-product of other industrial processes; not mined or produced in isolation. Acquiring vanadium for batteries should not pose additional environmental stresses above those for which it is a by-product.
- Compared with lead-acid batteries, VRBs emit between 7% and 25% of CO_2, SO_2, CH_4 and NOx during their life cycles.

VRB Installations [53]

- Sorne Hill Wind Farm in County Donegal, Ireland; managed by Tapbury Management Ltd. — 2 MW x 6 hours (see box: "VRB Case Study") [54]
- Stellenbosch in South Africa — 520 kWh
- PacifiCorp in Southern Utah — 2 MWh (250 kW x 8 hours); substantially completed February 23, 2004
- Huxley Hill Wind Farm on King Island, Australia; operated by Hydro Tasmania — 1 MWh (200 kW x 4 hours); three-way system with wind and diesel[55]

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[52] Lenntech is a spin-off of the Technical University Delft and a water and air treatment company. It is a source of information on environmental/health effects of vanadium, www.lenntech.com .

[53] Beck, Brian. VRB Power Systems. "Vanadium-Redox FlowCell Product." Electricity Storage Association's Annual Meeting, Anaheim, California, May 19-22, 2008.

[54] Tapbury Management Limited. "VRB ESS Energy Storage and the development of dispatchable wind turbine output: feasibility study for the implementation of an energy storage facility at Sorne Hill, Buncrana, Co. Donegal." Accessed from http://www.vrbpower.com/docs/news/2007/Ireland%20Feasibility%20study%20for%20VRB-ESS%20March%202007.pdf on April 29, 2008.

- Sumitomo Electric Industries Ltd. Japan — several installations from 1996 to 2005, including utilities, office building, LCD factory, lab, golf course and university
- Test battery at Riso National Laboratory in Denmark, supplied by VRB Power of Vancouver
- California Energy Commission — 20 kW/180 kWh system for telecommunications application
- Progress Energy in Florida — 2 x 5 kW/25kWh for firming up solar application
- Winafrique in Kenya — 2 x 5 kW/25 kWh for telecommunications application
- Edison in Italy — 5kW/25 kWh for telecommunications application
- Denmark — 15 kW/125 kWh for wind firming application

Ireland Wind Farm with Storage Case Study

A VRB Energy Storage System (VRB-ESS) was connected to a 6 MW windfarm at Sorne Hill, Donegal, Ireland in a joint feasibility study by Sustainable Energy Ireland and Tapbury Management Limited. The purpose of the study was to determine the benefits and optimum size for such a system in providing dispatchability of wind power and ensuring grid reliability and stability under increased wind generation.

In the Irish example, there was no charge to electricity consumers from the Public Service Obligation Levy (Ireland's renewable energy support mechanism) because wind generation has previously reduced the cost of energy to Irish consumers.he Irish grid, in this case in terms of grid stability problems related to high wind penetration. It was concluded that if local active voltage control is possible (as provided by the VRB-ESS system that uses power conversion systems to connect wind to distribution networks), then additional wind capacity can be connected to the grid. Local voltage control services provided by a battery system like the VRB-ESS lift the constraints such as frency regulation and power quality common on a distribution network, which, according to the study, means that these grids need both active and reactive power to gain efficient voltage control — a feature that energy storage technologies (like VRB-ESS) are able to offer.

The study found that energy storage in this case reduced the financial risk in developing wind power and increased the value of wind in the electrical system as a whole. Energy storage technologies like the VRB-ESS enable wind power to be dispatchable in the same way as conventional energy.

VRB has identified an increase in demand for energy, and an increase in demand for clean energy from renewable sources such as wind. In the case of Ireland, it has been proposed that 20% of the electricity demand can be met with wind resources. In 2005, 5% of Ireland's electricity came from wind generation. The country has set a 15% renewables target for 2010, and a 20% target for 2020 (including projected increases in demand); to meet this target, wind power must be firmed up with storage technologies. The VRB case study returns for an equity investor the VRB-EES at 11.7% pre-tax, and 17.5% post-tax.

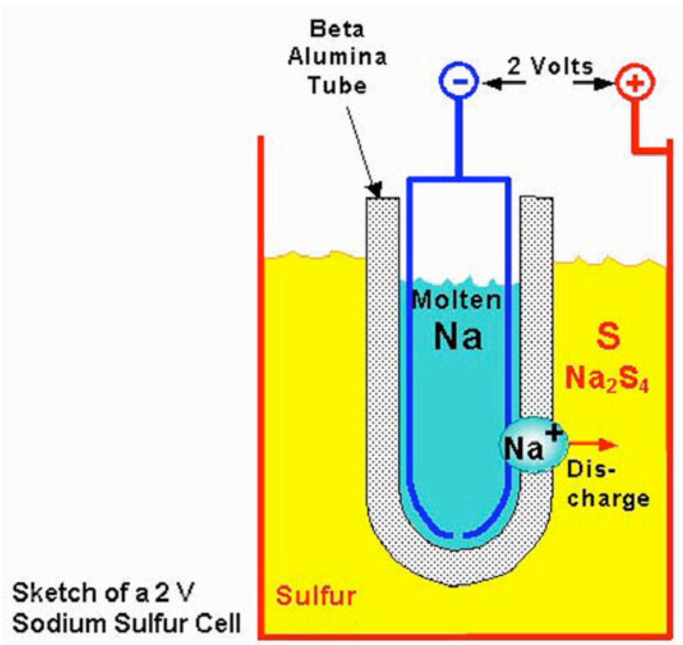
Source: Tapbury Management Limited. "VRB ESS Energy Storage and the development of dispatchable wind turbine output: feasibility study for the implementation of an energy storage facility at Sorne Hill, Buncrana, Co. Donegal." www.vrbpower.com/docs/news/2007/Ireland%20Feasibility%20study%20for%20VRB-ESS%20March%202007.pdf

[55] Hydro Tasmania. "Wind Power: Harnessing Tasmania's Wind Energy Resource." www.hydro.com.au/Documents/Renewables%20Development/5882Roaring40s.pdf

Advanced Rechargeable Batteries (NaS and Li-ion)

Sodium sulphur (NaS) batteries contain liquid sulfur and liquid sodium separated by a solid ceramic electrolyte. Lithium ion (Li-ion) batteries contain lithiated metal oxides and graphitic carbon separated by an electrolyte containing lithium salts.

During the discharge of either battery system, positive ions flow from the anode through the electrolyte to the cathode, which causes electrons to flow in the external circuit of the battery thus creating a voltage difference across the terminals. The process is reversed by applying a current to the cathode and driving the ions back through the electrolyte to the anode.



Source: Electricity Storage Association (ESA). 2003. *Technologies and Applications: NaS* (http://electricitystorage.org/tech/technologies_technologies_nas.htm, accessed June 10, 2008)

Advantages:

- Very high energy density (kWh/m^3).
- NaS efficiencies of 75–90%.
- Li-Ion efficiencies > 95%.
- Thermal energy loss in a NaS battery is recycled to keep battery at optimal operating temperature.

Disadvantages:

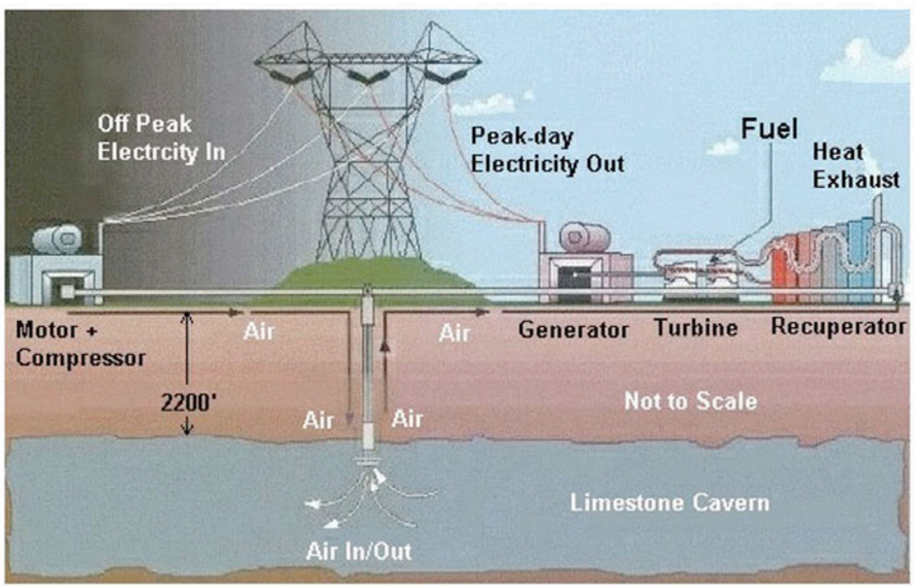
- Limited lifetime of fewer than 3,000 cycles.
- NaS battery cells must be kept at about 300 C.
- Li-Ion batteries lose large amounts of thermal energy and can dangerously overheat.
- Contain toxic components.
- Large-scale battery systems have very high initial costs ($600/kWh).

Compressed Air Energy Storage (CAES)

CAES uses off-peak energy to compress air into an underground cavern during off-peak hours (compression is accomplished with an electronically powered turbo-compressor). To generate electricity, the pressurized air is released through a turbine generator. More often, the compressed air is mixed with natural gas and they are burnt together, in the same fashion as in a conventional combustion-turbine plant, but without the usual need of a gas-powered compressor.. This bulk storage technology allows for three times more electricity to be produced from natural gas than in a conventional gas turbine power plant since about 66% of power produced in a gas turbine is used to compress air for combustion and high-temperature expansion, it is cost-effective to use off-peak base load sources (like wind) instead of expensive natural gas to compress it beforehand.[56] A plant with compressed air energy storage uses less than 40% of the natural gas used in gas generation without CAES.

CAES has grid advantages beyond power supply and the integration of more wind power onto the grid. A CAES system can deliver upwards of 100 MW energy, and has a load-management role because it can respond well to fast changes in the grid and add power quickly to the grid (fast ramping rates). CAES also provides ancillary services like load following, frequency regulation and voltage control.[57]

CAES technology needs a cavern to store the compressed air, or can use aquifers, abandoned salt mines, or even human-made caverns. [58]



Source: Electricity Storage Association (http://electricitystorage.org/tech/technologies_technologies_caes.htm, accessed June 10, 2008).

[56] Baxter, Richard. 2006. *Storage Technology: A Nontechnical Guide*.
[57] Baxter, Richard. 2006. *Storage Technology: A Nontechnical Guide*.
[58] Succar, S. and Williams, R.H. April 2008. "Compressed Air Energy Storage: Theory, Resources, and Applications for Wind Power." Princeton University.

Advantages:

- High efficiency. More efficient than a conventional natural gas plant.[59]
- Stable heat rate at low capacity.
- High output in hot weather, since the air flowing into a CAES turbine is at a constant heat and pressure.
- Emissions are 30% lower than combined-cycle natural gas-fired plants, and 50% lower than simple cycle plants.
- Fast ramp rates because the air is already compressed: 0–100% in less than ten minutes; 50–100% in less than 15 seconds.
- Much less expensive than some other storage options, including pumped hydro, advanced batteries and superconductors.
- Can be built and made operational within three years of selecting equipment, completing preliminary engineering and obtaining permits.
- Uses significantly less fuel than a conventional combustion-turbine facility.
- Large capacity potential (~300 MW).
- Can withstand frequent starts and stops, and can easily switch between compressing or releasing or even both at same time.
- Can respond quickly to market demand — shorter ramp rates than natural gas turbine alone.

Disadvantages:

- Requires natural-gas combustion.
- Requires large airtight reservoir, which may be site specific.
- Temperature sensitive.

Installations

- Hundorf, Germany uses a dissolved salt cavern for its 290 MW unit that went online in 1978
- McIntosh, Alabama uses a dissolved salt cavern in its 110 MW CAES system with 26 hours of storage, and has been on-line since 1991
- Iowa Stored Energy Park, near Fort Dodge, Iowa, will use a pre-existing cavern for a 200 MW CAES application with 100 MW wind + off-peak coal and is projected to be on-line by 2011

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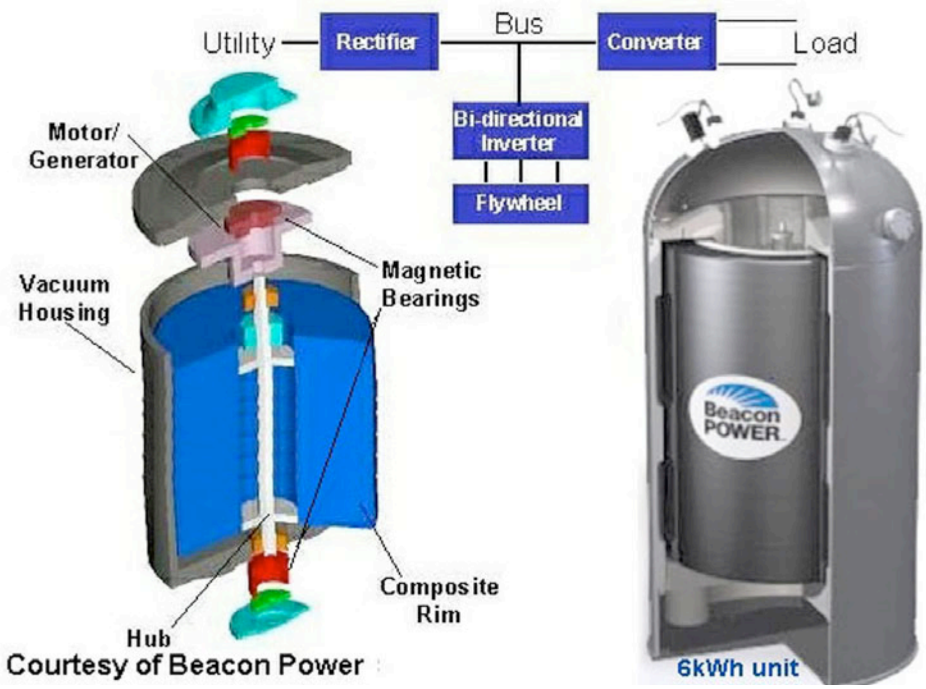
[59] Baxter, Richard. Storage: A nontechnical guide. 2006.

Flywheels

Flywheels serve to level power flow that comes in and out of a spinning mechanical device (a turbine). Flywheels are a storage device in that they store the energy as kinetic energy by accelerating a rotor very quickly.[60] Most modern flywheel energy storage systems consist of a massive rotating cylinder that is supported on a stator by magnetically levitated bearings within a low vacuum environment to reduce drag. The flywheel is connected to a motor/generator mounted onto the stator that draws electrical energy from a primary source and stores it by rotating the high-density flywheel at very high speeds (> 20,000 rpm). Energy is stored in the rotor in proportion to its momentum (at the square of surface speed).[61] The rotor slows down as the energy is released — a reversal of the charging process — and the motor driving the flywheel acts as a generator. Actual delivered energy depends on the speed range of the flywheel as it cannot deliver its rated power at very low speeds.[62]



Source: Electricity Storage Association. (http://electricitystorage.org/tech/technologies_technologies_flywheels.htm accessed June 10, 2008)

Advantages:

- Efficiencies ~ 90%.
- Ideal for applications that need frequent and deep discharges because energy is mechanically rather than chemically stored (less damage in discharging).
- Compact with few parts means less maintenance.
- Very short-term storage, more suited to smoothing. Not for bulk storage. Used to control frequency of output.
- Used for power quality, frequency regulation and regenerative energy services.

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[60] Baxter, Richard. Storage: A nontechnical guide. 2006.
[61] Baxter, Richard. Storage: A nontechnical guide. 2006.
[62] Beacon Power, http://www.beaconpower.com/products/EnergyStorageSystems/flywheels.htm#%23

- Can buffer time needed to get a backup generator online.
- Good at capturing wasted energy by storing it as kinetic energy in the rotor (good for repetitive motion applications, like light-rail trains that need short bursts of power and frequently stop).
- For frequency regulation smoothes moment-to-moment changes in power demand/supply; ideal for small or off-grid uses or for smoothing intermittent wind.
- Low toxicity in materials. No fuel stream, so no reliance on price fluctuations relating to a fuel source, nor the upstream and downstream environmental costs associated with fuels.
- Long life (20 years) with low maintenance, resulting in lower lifetime costs. While more expensive than batteries, long lifetime makes them less expensive overall.
- No temperature sensitivity.

Disadvantages:

- Individual units have capacities in the 25 kW range.
- Require a flywheel "farm" for multi-megawatt multi-hour storage (large area).
- High initial costs.

Supercapacitors

Supercapacitors (also called ultracapacitors or electric double layer capacitors (EDLCs)) store their energy in an electrostatic field and consist of two electrodes (plates) of opposite polarity separated by an electrolyte. When a voltage is applied to a capacitor during charging, electric charges of equal and opposite magnitude build up and are held on the surface of each electrode plate thus storing power within the capacitor. During discharge, the exterior circuit connecting the positive and negative terminals is closed and allows the built up charges on the plates to migrate through the circuit thus creating a current. Supercapacitors move electric charges between solid state materials instead of through chemical reactions (allowing for more cycles and fuller discharge without the same damage that would come with a chemical-based reaction).[63]

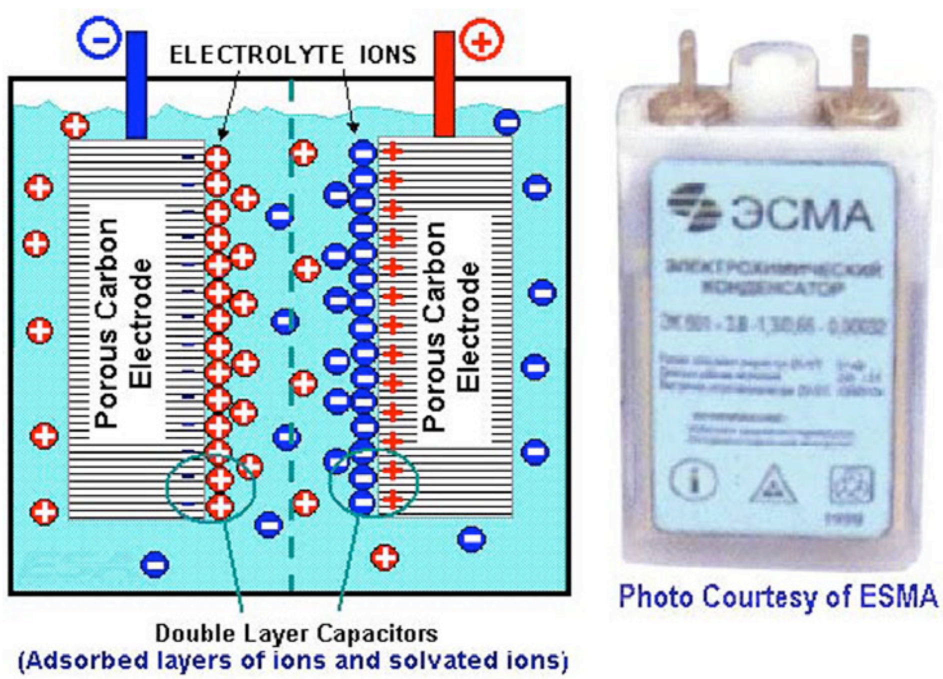
Unlike a battery, a capacitor stores energy using a static charge rather than a chemical reaction, and is composed of two electrodes (one positive and one negative) and a conducting medium or electrolyte.[64] A supercpacitor differs from a conventional capacitor in that it stores electricity not on two conductors separated by an insulator, but on the interface between a conductive surface and an electrolyte, forming an electric double layer. This allows it to store thousands of times the electricity of a conventional capacitor.

As a storage option for renewable energy, supercapacitors can even the power output of a wind or photovoltaic installation. They can absorb power quickly, and just as quickly discharge it, so

[63] Baxter, Richard. Storage: A nontechnical guide. 2006.

[64] A supercapacitor's electrodes are most often made of a rough carbon material, with an electrolyte that is either aqueous or carbon-based. The aqueous capacitors have a lower energy density, meaning they can store less energy relative to their size, but they operate over a wider range of temperatures, and are less expensive. Other possible, though more expensive, electrode materials are metal oxide and conducting polymers. Asymmetrical capacitors, which use metal for one of the electrodes, have a higher energy density than those which use the same material for both. (ESA, http://electricitystorage.org/tech/technologies_technologies_supercapacitor.htm).

they are far more powerful than batteries that rely on a slower chemical reaction. Supercapacitors effectively insulate the distribution system from fluctuations in supply. With their high-energy density, as compared to conventional capacitors, and low storage capacity, as compared to lead-acid batteries, they are best suited to applications of short duration, such as providing a boost in times of high demand, or acting as a bridging system for uninterrupted power supply. They are ideally suited for use in combination with fuel cells or electrochemical batteries that can supply power for deep energy discharges. Supercapacitors can reduce the required number of such batteries and extend their life.



Source: Electricity Storage Association
(http://electricitystorage.org/tech/technologies_technologies_supercapacitor.htm, accessed June 10, 2008)

Advantages:

- Long lifetimes — supercapacitors can be cycled millions of times with virtually no loss of capacity. Can be expected to deteriorate to about 80% after ten years of normal use. Because of their expected long life (up to 20 years) and low maintenance, life cycle costs are minimized.
- Powerful — supercapacitors charge and discharge quickly.
- Charging is simple, as there is no danger of overcharge or "memory."
- Higher charging efficiency than lead-acid batteries; only 10% is lost in charging compared to 30% with lead-acid batteries.
- Not sensitive to temperature or rough environments; can save on climate control costs.
- Load handling is enhanced when supercapacitors are placed in parallel with a battery because they do not substantially resist alternating current.
- Supercapacitors are best suited to short-term applications, such as load levelling or bridging, in combination with another device such as a fuel cell that can supply longer-term storage.

- Efficiencies > 95%.
- Little degradation over hundreds of thousands of cycles.
- Low toxicity in materials.

Disadvantages:

- Not all of the energy stored in the supercapacitor is available for use.
- Low energy density — typically holds one-fifth to one-tenth the energy of an electrochemical battery. Asymmetrical capacitors with metal for one of the electrodes fare better in this regard than the symmetrical ones, and lose less to leakage.
- Cells have low voltages — serial connections are needed to obtain higher voltages. Voltage balancing is required if more than three capacitors are connected in series.
- High self-discharge — rate is considerably higher than that of an electrochemical battery.
- High per watt cost, though when seen as complementary to batteries rather that in competition with them, this is less of an issue.
- Not yet fully developed for applications of greater than 20 kWh/m^3. Maxwell Technologies has a capacitor that provides about 0.002 kWh.
- Very high rates of discharge per unit (in the range of seconds).
- Low energy density as compared to batteries.
- Higher ambient temperatures decrease the lifetime of the system and increase self-discharge. Good for cooler climates.

Installations

A European producer has ordered a US $3 million system from Maxwell Technologies, to be included in a wind power installation. A bank of 200–700 BOOSTCAP® cells will be installed on each turbine, and will provide backup power to ensure continuous operation in the event of a power failure.[65]

Hydrogen Storage Using Water Electrolysis and Fuel Cells

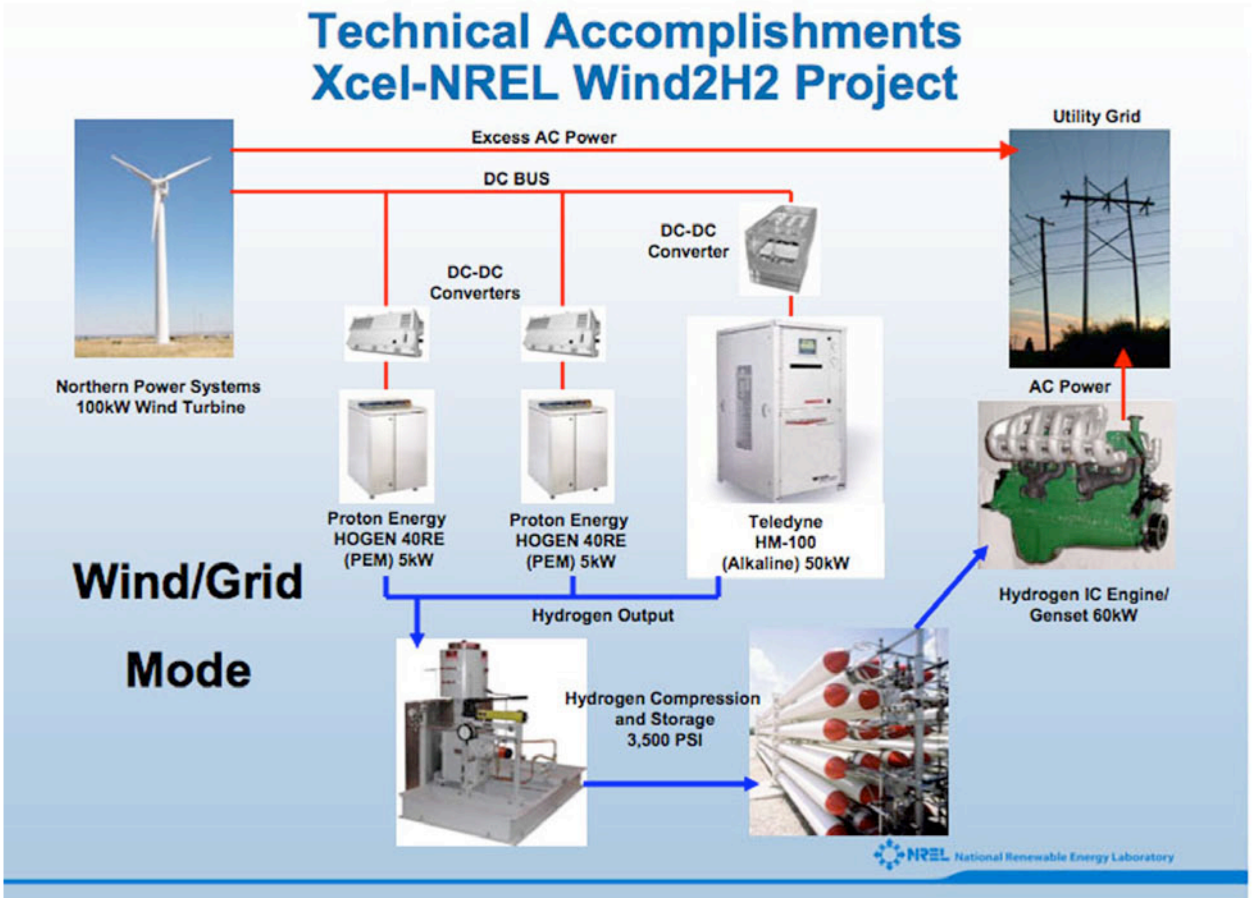
A hydrogen fuel cell is an electrochemical energy conversion device that produces electricity from the reaction of hydrogen fuel and oxygen combining in the presence of an electrolyte. Fuel cells differ from batteries in that they consume their reactants, which must be continuously replenished to sustain the reaction (see "Individual Fuel Cell" diagram, below).

In the creation and storage of the hydrogen energy can be "stored" during off-peak hours and used later to create energy through a fuel cell stack during peak demand. Water electrolysis is a preferred method to produce hydrogen and oxygen from renewable resources. It uses electricity to disassociate water into hydrogen and oxygen. The product gasses are then highly pressurized or liquefied for practical storage and use in the fuel cell.

The proton exchange membrane (PEM) is the most common form of fuel cell. In a PEM cell there are two electrolytes — an anode (with embedded platinum) and a cathode — that are separated by a solid polymer membrane. The platinum in the anode acts as a catalyst and encourages the hydrogen molecule to give up its only electron. The smaller proton is able to pass

[65] WindTech International, www.windtech-international.com

through the membrane while the electron is forced to go around, generating an electric current. At the cathode the proton and electron combine with oxygen to produce water and heat.



Source: Renewable Electrolysis Integrated System Development and Testing. National Renewable Energy Laboratory. (http://www.nrel.gov/hydrogen/pdfs/39803.pdf, accessed June 10, 2008).

Advantages:

- High energy density (Whr/kg).
- No generation of toxic emissions or products when paired with a non-combustion energy source (hydro, wind and so on). If hydrogen fuel is produced via hydrolysis of water using renewable electricity, the only emission is water vapour. Using natural gas in a fuel cell still involves carbon emissions (yet the fuel cell uses natural gas more efficiently than it burns it).
- Fuel cells are very reliable due to lack of moving parts or combustion.
- Individual fuel cell capacity ~ 500 kW.
- Can be plugged into the grid for the same purposes as a plug-in hybrid.

Disadvantages:

- Hydrogen fuel cell roundtrip efficiency ranges from 30–50% (electricity to hydrogen and back to electricity).
- Water electrolysis for utility scale hydrogen production requires a large and sophisticated processing plant.

- A fuel source is required. This fuel can be produced with water, but can also be produced with natural gas, both of which can be a limited resource.
- Requires multiple fuel cells or "stack" to achieve capacities > 200 kW.
- High cost (> $400/kW).
- Hydrogen needs a lot of storage, or must be compressed.

Installations

- The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) and Xcel Energy have teamed up to launch a US $2 million hydrogen-from-wind demonstration project. The project is located at NREL's Wind Technology Center near Denver, Colorado. The most significant problem researchers there hope to solve is how to efficiently and cheaply convert the high voltage generated by a large wind installation to the lower voltage required by electrolysis, and to do it on a large, megawatt scale.[66]

Plug-in Hybrid Vehicles

Electric or hybrid vehicles with additional batteries that can be charged from the grid can be both consumers and producers of energy. The batteries in these vehicles can store excess power from the grid during off-peak periods. Residual power remaining in a car's batteries when the vehicle is not being used can be fed into the grid when needed to meet peaks in electrical demand, to firm up production from renewable sources, and to address black out conditions. The vehicle user would be in control of this arrangement and be compensated accordingly for providing this service to the grid operator. Plug-in hybrid vehicles also provide more autonomy for buildings.

Using this vehicle-to-grid (V2G) concept, grid operators would be able to balance the power of energy generated at any given time to match demand. Millions of cars, each with several kilowatt hours of storage capacity, would act as a buffer, taking on charge when the grid generated too much power, and feeding some of it back when there were peaks in demand.

Advantages:

- Very large potential as number of hybrid vehicles grows.
- Provides flexibility to grid operators.
- Offers additional options for net zero energy buildings.

Disadvantages:

- Could increase peak demands if not managed effectively.
- Increases the demand for electricity, which can be an advantage if the electricity sources are renewable.

[66] U.S. Department of Energy National Renewable Energy Laboratory (NREL); www.nrel.gov; or from their Wind Technology Center www.nrel.gov/wind

German Case Study

At the November 2007 Second International Renewable Energy Storage Conference in Bonn, Germany, a number of speakers discussed the possibilities that exist for plug-in hybrids. There are about 46 million cars in Germany, which, if all were plug-in hybrids, would provide a combined power capacity of 3,200 GW compared to a combined capacity of 120 GW between all the power plants in the country. Combining renewable energy sources with mobility is a win–win situation. Using 90% electric and 10% fuel mix in vehicles would balance and buffer energy from renewable sources. In this concept, energy from wind and solar sources could exceed 20% of the energy mix with storage. Plug-in hybrids integrate wind and solar energy with industry and households. Integration can be achieved through smart grids. When approximately 20% of the entire load consists of plug-ins, the cost of energy supply for all will be reduced.

Sources:

"The multifunctional power plant car." Wolfgang Palz, Second International Renewable Energy Storage Conference, Bonn, Germany, November 19-21, 2007.

From hybrid systems towards sector-spanning integration: concepts for the use of wind energy for individual transport. Roger Kohlmann, Federal Association of the German Gas and Water Industries. Second International Renewable Energy Storage Conference, Bonn, Germany, November 19-21, 2007.

Appendix C: Sources

Pumped Hydro Storage

- A PowerPoint including pumped storage figures and CAES http://electricitystorage.org/pubs/2000/summer2000/PHS-CAES.pdf
- www.consumersenergy.com/content/hiermenugrid.aspx?id=31
- Summary of an Electric Power Research Institute (EPRI) study of a wind farm/pumped storage proposal for Hawaii: http://www.epri.com/OrderableitemDesc.asp?product_id=000000000001011993
- See also sources cited above in Applications of Interest section.
- http://electricitystorage.org/tech/technologies_technologies.htm
- www.dom.com/about/stations/hydro/bath.jsp

Flow Batteries or Regenerative Fuel Cells

- VRB Power Systems, a manufacturer based in Vancouver, has a contract to supply Ireland's Sorne Hill Wind Farm; easiest access to Sorne Hill study; www.vrbpower.com
- Sustainable Energy Ireland, an Irish government agency whose mandate is to promote and assist in the development of sustainable energy in Ireland; involved in Sorne Hill Wind farm, among others; www.sei.ie
- Electricity Storage Association (ESA), a trade association made up of electricity suppliers, technology developers and researchers formed to promote the development and commercialization of energy storage delivery systems; site contains descriptions of some storage technologies, papers are quite old (mostly from 2001, one from 2004); www.electricitystorage.org
- Lenntech, "a spin-off of the Technical University Delft," a water and air treatment company; source of information on environmental/health effects of vanadium; www.lenntech.com
- University of New South Wales, Chemical Sciences and Engineering, information on vanadium-bromide redox battery; www.vrb.unsw.edu.au
- Wireless Energy Chile is evaluating the Latin American market for VRB, if you can read Spanish (I can't) there may be something of interest at www.wireless-energy.cl
- California Energy Commission, Distributed Energy Resource Guide http://www.energy.ca.gov/distgen/equipment/energy_storage/energy_storage.html
- mpower; battery supplier having mostly to do with small batteries, but has a fairly good overview of storage technologies on their site www.mpoweruk.com/flow.htm
- U.S. government Federal Energy Management site; info about Tennessee Valley Authority PRB project: www1.eere.energy.gov/femp/newsevents/fempfocus_article.cfm/news_id=7235
- http://electricitystorage.org/tech/technologies_technologies.htm
- http://www.vrbpower.com/technology/index.html

Advanced Rechargeable Batteries - NaS/Li-ion Batteries:

- http://electricitystorage.org/tech/technologies_technologies.htm
- http://www.ngk.co.jp/english/index.html

Compressed Air Energy Storage:

- U.S. Department of Energy (DOE) Energy Efficiency and Renewable Energy, general description compressed air technology; http://www.eere.energy.gov/de/compressed_air.html
- DOE description of compressed air project in Iowa: http://www.eere.energy.gov/state_energy_program/project_brief_detail.cfm/pb_id=1099
- Iowa project site, no new information beyond what is in: DOE: www.isepa.com
- CAES Development Co. L.L.C. site about the McIntosh compressed air facility, lots of information specific to this facility: http://www.caes.net/mcintosh.html
- Power Engineering, the journal of Power Engineering International; a good article describing CAES in general and the proposed Norton Ohio plant in particular: http://pepei.pennnet.com/Articles/Article_Display.cfm?Section=Archives&Subsection=Display&ARTICLE_ID=98019&KEYWORD=%22Norton%20Energy%20Storage%22
- Ridge Energy Storage & Grid Services, developer of CAES projects; "The Economic Impact of CAES on Wind in TX, OK, and NM, June 27, 2005"; Report of a study with lots of good economic analysis, some of which can be extrapolated to other locations: http://www.seco.cpa.state.tx.us/zzz_re/re_wind_projects-compressed2005.pdf
- ELECTRIC POWER CONFERENCE, BALTIMORE MD. 30 MAR - APR 1 2004 "Toward optimization of a wind/compressed air energy storage (CAES) power system" by Greenblatt, Succar, Denkenberger and Williams, Princeton University http://www.princeton.edu/~cmi/research/Capture/Presentations/CAES.ppt
- http://www.eere.energy.gov/de/compressed_air.html
- http://www.doc.ic.ac.uk/~matti/ise2grp/energystorage_report/node7.html

Flywheels:

- http://electricitystorage.org/tech/technologies_technologies.htm
- http://www.beaconpower.com/products/EnergyStorageSystems/flywheels.htm

Capacitors:

- Electricity Storage Association (ESA), a trade association made up of electricity suppliers, technology developers and researchers formed to "promote the development and commercialization of … energy storage delivery systems"; site contains descriptions of some storage technologies, papers are quite old (mostly from 2001, one from 2004); www.electricitystorage.org
- Power Systems Co., Ltd., a Japanese developer and supplier of supercapacitors, an excellent site; www.powersystems.co.jp/english
- ECaSS Forum, a group composed of academics and industry interested in disseminating information about supercapacitors. An informative site; www.ecass-forum.org
- SCAP-Group, a newly founded network for "the support of SCAP-technology and applications as an ecological contribution in Switzerland as well as on a global level." www.supercapacitor.org
- Maxwell Technologies, seems to be the most prominent manufacturer of ultracapacitors, with a good website: www.maxwell.com
- Paul Scherrer Institute in Switzerland is studying various kinds of supercapacitors for various applications in their electrochemistry laboratory. http://ecl.web.psi.ch/supercap/index.html

- Namisnyk, Adam Marcus, "A Survey of Electrochemical Supercapacitor Technology", Thesis for B.A. in Electrical Engineering, University of Technology, Sydney Australia, 23 June 2003; description of supercapacitors, their components and applications. http://services.eng.uts.edu.au/cempe/subjects_JGZ/eet/Capstone%20thesis_AN.pdf
- Windtech International, a magazine of wind energy www.windtech-international.com

Hydrogen Storage:

- U.S. Department of Energy National Renewable Energy Laboratory (NREL); www.nrel.gov; or from their Wind Technology Center www.nrel.gov/wind
- Xcel Energy, a private company supplying electricity through all kinds of generation, including 78 MW from wind; www.xcelenergy.com
- Aspen Institute, a NGO think tank which addresses many issues of interest to US policy makers, including energy and environment; www.aspeninstitute.org
- Northern Power Systems, supplier of the 100 kW wind turbine to be used in the project; www.northernpower.com
- Bergey Windpower Co., supplier of the 10 kW wind turbine used in the project; www.bergey.com
- Hydrogen Utility Group, sponsored by the Department of Energy, the National Hydrogen Association, and the Electric Power Research Institute, and includes 13 North American and 1 So. Korean utilities; www.nrel.gov/hydrogen/pdfs/doe_hug_briefing.pdf ; www.nrel.gov/hydrogen/pdfs/utility_hug_briefing.pdf
- The Bellona Foundation, a multi-disciplinary environmental NGO based in Norway and supported by industry, business, individuals and the Norwegian government; lists 2 hydrogen/wind projects for remote installations on the Norwegian islands of Utsira and Rost; http://www.bellona.org/english_import_area/energy/hydrogen/18283
- http://gltrs.grc.nasa.gov/reports/2006/TM-2006-214054.pdf

Plug-in Hybrid Vehicles:

- *How Plug-in Hybrids Will Save the Grid - The use of vehicles that run on electricity could be a boon to the ailing electrical grid* http://www.technologyreview.com/Energy/17930/?a=f
- Wolfgang Palz, "*The multifunctional power plant car.*" Second International Renewable Energy Storage Conference, Bonn, Germany, November 19–21, 2007.
- *From hybrid systems towards sector-spanning integration: concepts for the use of wind energy for individual transport.* Roger Kohlmann, Federal Association of the German Gas and Water Industries. Second International Renewable Energy Storage Conference, Bonn, Germany, November 19-21, 2007.
- Grid management control systems for Vehicle to Grid systems http://www.gridpoint.com/smartgrid/capabilities/phev.integration.aspx
- National Renewable Energy Laboratory Research http://www.nrel.gov/vehiclesandfuels/hev

Appendix D: Other Links

Energy Storage Technology Advancement Act of 2007:

http://science.house.gov/legislation/leg_highlights_detail.aspx?NewsID=1983
http://science.house.gov/press/PRArticle.aspx?NewsID=1972http://www.cbo.gov/ftpdocs/87xx/doc8728/hr3776.pdf
http://www.cbo.gov/ftpdocs/87xx/doc8728/hr3776.pdf

United States Energy Storage Association:

http://www.electricitystorage.org/pubs/2007/Newsletter_Dec_07.pdf
http://www.usatoday.com/money/industries/energy/2007-07-04-sodium-battery_N.htm

Australian Commonwealth Scientific and Research Organization (CSIRO) Wind Energy:

http://www.csiro.au/science/WindEnergy.html
http://www.csiro.au/org/pse.html
http://www.csiro.au/news/SmarterEnergyStorage.html

Thermal Storage:

Cool Thermal Storage, BC Hydro:

http://www.bchydro.com/business/investigate/investigate795.html

PCM: Phase change material for latent thermal storage:

http://epb.lbl.gov/thermal/pcm.html
http://www.pcm-solutions.com/thermalstorage.html

International Energy Agency Task 32 on Advanced Thermal Storage:

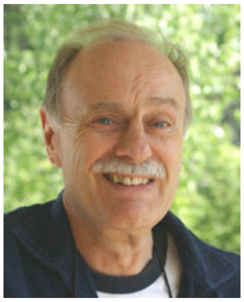
http://www.iea-shc.org/task32/index.html

Policies for heat storage:

http://www.preheat.org/fileadmin/preheat/documents/reports/PREHEAT_WP4_report.pdf

About the Authors

Roger Peters, P.Eng.



Roger Peters is a Senior Policy Advisor to the Pembina Institute, a Canadian policy research and advocacy organization specializing in sustainable energy solutions. Roger has 30 years experience in energy efficiency and renewable energy as a consultant, researcher, writer, policy advisor, and advocate. In 2005, Roger helped to create the Canadian Renewable Energy Alliance, a joint initiative of Canadian NGOs who support a global transition to renewable energy. The Alliance published a model Canadian Renewable Energy Strategy in 2006 and is actively engaged in prompting more Canadian support for renewable energy. Roger has significant international experience in Asia, Latin America and Africa on energy efficiency and rural energy projects.

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Lynda O'Malley is a Masters Degree Candidate at the School of Environmental Studies at York University, where she is studying renewable energy solutions and policy options. Lynda is also working with the Toronto Region Conservation Authority and York University on the TRCA's Renewable Energy Road Map project.

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