Advancing Electricity Storage Technologies

A Report from the APS Panel on Public Affairs Committee on Energy and Environment

Supplement for Policy Makers

MARCH 2007

PANEL ON PUBLIC AFFAIRS

Advancing Electricity Storage Technologies

A Report from the APS Panel on Public Affairs

Policy Supplement

Potential Impact of Advanced Energy Storage

Advanced electricity storage technologies have potential for significant environmental, economic and energy diversity benefits:

- *Reducing the Need for Reserve Power Plants:* Electricity storage technologies can provide an effective method of responding to daily fluctuations in demand. Electricity produced at off-peak hours can be stored and used later to meet demand spikes, thereby reducing the need for expensive, aging, and relatively dirty fossil-fired reserve generation plants.

- *Cutting the Cost of Power Failures:* As a result of the aging U.S. electricity grid, electricity outages cost the U.S. approximately $79 billion annually with 2/3 of that cost due to interruptions under 5 minutes. In particular, power fluctuations as short as tens of milliseconds cause computer-based systems to fail, crippling an economy that is increasingly reliant on digital technology. Electricity storage technologies can provide power to the grid to "bridge" gaps and smooth out short-term fluctuations until backup generation sources can be brought online.

- *Enabling Intermittent Renewable Energy:* The sun and wind are the two largest sustainable sources of carbon-free power, but both are intermittent, varying widely in the energy that they can provide at any one time during the day. Electricity storage technologies can smooth out this variability and allow unused electricity to be dispatched at a later time.

Current Status

There are currently six promising energy storage technologies: pumped hydropower, compressed air energy storage, batteries, flywheels, superconducting magnetic energy storage, and electrochemical capacitors. These technologies have basic research components that fall naturally with the DOE's Office of Basic Energy Sciences, and development and deployment components that are being advanced primarily through the DOE's Energy Storage Program. The Energy Storage Program has leveraged its modest funds (shown in Figure 2) with states, utilities, and industry to achieve limited penetration of some energy storage technologies.

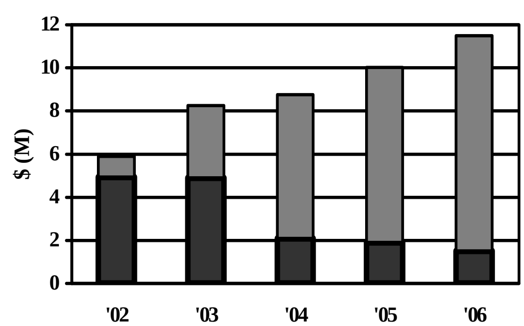

Figure 2. Funding levels of the Energy Storage Program of the Office of Electricity Distribution and Energy Reliability within the DOE over the last 5 years. Light regions indicate funds earmarked for specific projects.

- **Pumped Hydropower:** At a pumped hydro facility, water is pumped into a storage reservoir at high elevation during times when electricity is inexpensive and in low demand. Stored water is then released and used to power hydroelectric turbines when demand for power is high. Pumped storage hydropower is currently the most widely implemented storage technology in the U.S. and the world. In the United States, 38 plants provide 19 gigawatts of power. New developments in pumps and turbines allowing for adjustable water flow rates have increased the flexibility and efficiency of pumped storage hydroelectric power; however, some limitations, such as suitable geographic siting and facility size/capacity, still exist.
    - *R&D opportunities*: Power electronics and computer modeling/simulation

- **Compressed Air Energy Storage:** CAES uses high efficiency compressors to force air into underground reservoirs, such as mined caverns. When the commercial demand for power is high, the stored air is allowed to expand to atmospheric pressure through turbines connected to electric generators that provide power to the grid. Currently, there are 2 large-scale demonstration plants in operation, one in Germany and one in Alabama. In addition to these large-scale facilities, CAES can also be adapted for use in distributed, small-scale operations through the use of high-pressure tanks or pipes.
    - *R&D opportunities*: Demonstration projects and computer modeling.

- **Batteries:** Batteries have the potential to span a broad range of energy storage applications due in part to their portability, ease of use and variable storage capacity. In particular, they can stabilize electrical systems by rapidly providing extra power and by smoothing out ripples in voltage and frequency. Currently, numerous batteries including lead-acid, flow, sodium-sulfur, and lithium-ion all have commercial applications. However, many battery types have only limited market penetration, are expensive, or have short lifetimes.
    - *R&D opportunities:* Materials research, manufacturing techniques, demo projects.

- **Flywheels:** Flywheels store energy in a spinning disk on a metal shaft. Increases in the speed of rotation, the mass of the disk and locating more of the mass closer to the rim of the disk will increase the amount of energy stored. Two generations of flywheels have produced increases in storage capacity through increased disk mass (using steel) and increased rotation speeds (using light weight composite materials for the disk), but these have technical limitations. New prototypes utilize magnetic levitation to increase speed *and* mass while minimizing previous technical issues. This technology is best utilized for applications requiring short discharge time such as stabilizing voltage and frequency. A flywheel farm approach, where several devices are networked together, could allow for adaptation to large-scale energy management. Flywheels necessary for wider commercial energy storage applications are primarily limited by materials properties and cost.
    - *R&D opportunities*: Materials research

- **Superconducting Magnetic Energy Storage:** These devices are composed of superconducting windings that allow electric current to be stored indefinitely with little resistive energy losses. When the stored energy is needed, these devices can be discharged almost instantaneously with high power output over short time periods. Increasing the size of the windings can increase the amount of stored energy. However larger coils present a challenge because the associated increase in magnetic field becomes more difficult to contain. Further, the windings only exhibit the necessary superconducting property at low temperature; therefore, expensive coolants are needed to make the current devices operable.

  - *R&D opportunities:* Materials research and demonstration projects.

- **Electrochemical Capacitors:** Electrochemical capacitors store energy in the form of two oppositely charged electrodes separated by an ionic solution. They are suitable for fast-response, short-duration applications, such as backup power during brief outages. They are excellent for stabilizing voltage and frequency. By proper networking, these devices might be used for longer time-scale applications. Electrochemical capacitors have several advantages including a temperature-independent response, low maintenance and long projected lifetimes (up to 20 years), but they suffer from relatively high cost.
  - *R&D opportunities:* Materials research and manufacturing techniques.

- **Power Electronics:** While not a storage device explicitly, power conversion systems (PCS) are a vital part of any electricity storage system, because they serve as the interface between the storage system (typically running on DC current) and the electricity grid (delivering AC current). A PCS is able to make the necessary conversions so that the stored energy can be taken from or returned to the grid in the correct phase (AC/DC), frequency and level of demand. Systems using silicon carbide or diamond-based components exhibit superior performance. However, the high cost of these materials makes their widespread use undesirable since the cost of the PCS can range from 20-60% of the overall cost of the energy storage system.
  - *R&D opportunities:* Materials research, manufacturing techniques, and demonstration projects.

- **Additional Technologies**: Other technologies, such as reversible hydrogen fuel cells (RFC), may also provide breakthroughs in storage capacity. However, the current efficiency of commercial RFCs precludes their use in storage applications.

Broadening the Electricity Storage Program:

The APS Panel on Public Affairs explored the various components of a balanced program in a workshop with representatives from the national labs and the utility sector, along with an economist and university scientists. The Panel concluded that the six primary electricity storage technologies are at varying stages of maturity and that achieving the potential economic and environmental benefits of electricity storage will require a comprehensive and balanced strategy. Basic research, demonstration projects, incentives and regulation are all necessary elements that can be used to advance energy storage technologies. In fact, demonstration projects and regulatory incentives may have as much impact on technological penetration of electricity storage at this stage as basic research to bring down cost and raise efficiency.

Each of the program elements is considered below:

- **Basic Research:** The panel determined that there are five areas where fundamental research has a high potential for making electricity storage safe, practical and economical. These areas are materials research, power control systems, computer modeling, manufacturing techniques, and systems integration. Much of this research is of interest not only to the DOE but also to the DOD, NASA and the NSF.

- **Demonstration Projects:** Many electric utility companies consider cost-shared demonstration projects the single most important step the government can take to advance electricity storage technology. Demonstration projects would further encourage the utilities to deploy electricity storage systems by confirming that these systems can be integrated safely, seamlessly and reliably with existing systems. To this end, the utilities traditionally demand that a new technology, such as energy storage, be proven in the field by means of several installed plants operated successfully for at least a substantial fraction of their intended lifetime, typically on the order of ten or more years.

- **Regulatory Incentives:** Pricing and regulatory policies in the electricity industry create barriers to deployment of electricity storage technologies. Careful consideration of these barriers is critical to both long-term innovation and to the success of any DOE initiative in electricity storage. For example, some industrial electricity customers would be interested in storage technologies that smooth out the short-term electricity fluctuations that cripple their manufacturing plants. Residential customers would be uninterested in the service. A pricing policy allowing commercial customers to pay a premium for better service might cover the costs of deploying storage technologies. Another consideration is that many states retain restrictions on the specific roles that customers and industries can play in generating and distributing electricity. Electricity storage technologies cross traditional boundaries of generation, transmission and distribution; hence, easing ownership restrictions may encourage storage technology deployment.

Conclusions:

Given the potential environmental and economic benefits of electricity storage technologies, DOE should consider broadening the existing program. For a broader program to be successful, it must achieve a balance among basic research, demonstration projects, and regulatory incentives. To strike the appropriate balance among the various program elements, DOE should evaluate any larger initiative with significant input from the utility sector, state and regional utility regulators, and principal investigators from universities, national laboratories and industry. Regarding regulatory incentives in particular, since they can have a large impact on advancing electricity storage, DOE should convene a separate panel of experts to study regulatory, ownership and pricing policies that impact electricity storage.

In addition, DOE should include in these discussions representatives from other federal agencies whose portfolios include research that is needed for electricity storage technologies. The APS Panel determined that there would be substantial overlap with the interests of the Department of Defense, NASA and the National Science Foundation.