House Committee on Science and Technology
Field Hearing: Options and Opportunities for Onsite Renewable Energy Integration

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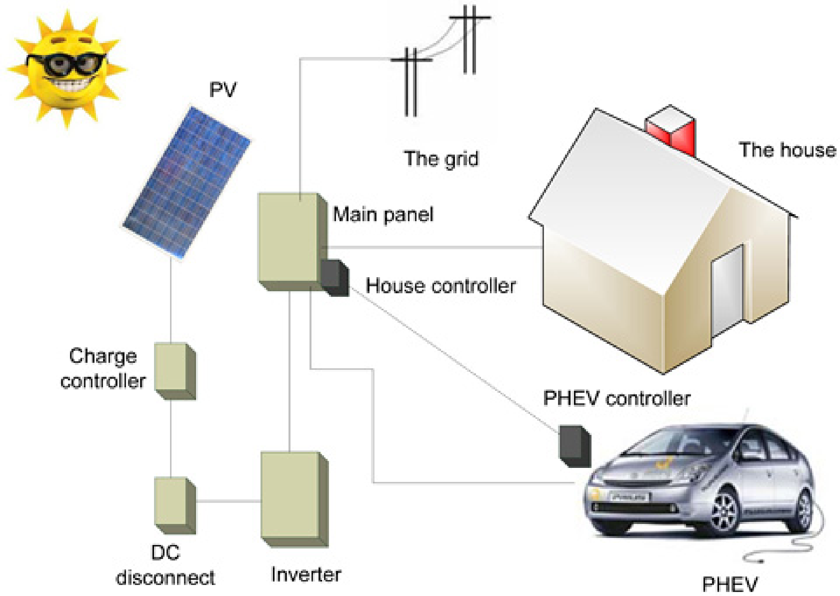
Testimony of Jeffrey P. Chamberlain, Ph.D.
Department Head, Electrochemical Energy Storage Research
Energy Storage Initiative Leader
Argonne National Laboratory

It is widely recognized that the continued and increasing reliance on fossil fuels by the citizens, businesses, and government organizations in the U.S. is not sustainable over the long term. One concept that is gaining popularity among scientists and engineers, businessmen, and policymakers is that of integrating renewable energy generation into a distributed use model, in which sun and wind energy is converted into electricity and used locally, at scales from individual buildings up to and including communities that include both buildings for residential and business or government use.

There are a wide variety of technologies and business models that are being considered to enable the adoption of an integrated, on-site energy generation and use model. Energy must be harnessed, either by solar cells and arrays, or by wind turbines, and then either inverted from DC to AC for immediate use, or stored for later inversion and use. "Smart grid" technologies are also capable of being used to ensure efficient use of energy, and the individual buildings and communities must still be integrated effectively into the larger regional grid. Although there are significant complexities regarding the integration of the various required technologies, the attractive prospect of reducing overall energy consumption as well as significantly reducing the consumption of fossil fuels is driving both policy makers and businesses around the world to carefully examine and develop both the technologies and the business models needed to make on-site renewable energy generation and use a reality.

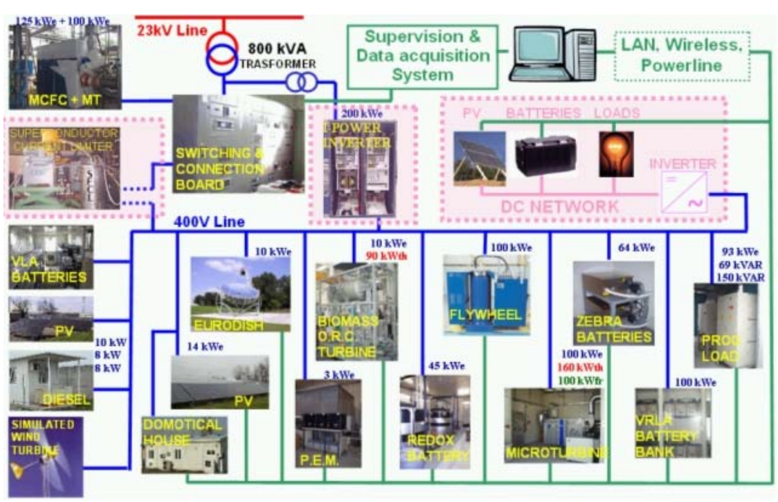
Below is a simple diagram (figure 1), illustrating the essence of a Cornell project, "CU Green," (http://www.news.cornell.edu/stories/May08/cugreen.hawaii.aj.html) developed for an experimental setup in Hawaii in June 2008. Even in this simplistic illustration, one can see the importance both for new technology development, as well as the importance of integrating the technologies across the system.

Figure 1. CU Green, by Cornell, in Hawaii



This testimony focuses on one aspect of the variety of technologies needed to enable the adoption of on-site renewable energy integration: **Energy Storage**. In figure 1, outside of the battery in the PHEV, there is a notable lack of energy storage listed as a requirement for this microgrid environment. Taken from the European Union Microgrid Project, figure 2, below, shows in great detail the complexity and variety of energy storage technologies that can be used in on-site renewable energy generation. Note the wind and solar indicators in the lower left-hand corner, and how the energy can flow into various storage devices for end use. Of course, no single system will have this great number of energy storage devices, but this particular European project was set up to test the various technologies available on the market today.

Figure 2. August 6, 2010, EU Microgrid Project
(http://www.microgrids.eu/index.php?page=index)



The role of Energy Storage in on-site renewable energy generation.

At its essence, the main role of energy storage in on-site renewable energy generation is to mitigate the intermittent nature of electricity generated by conversion of sun or wind energy. Power generated by coal-burning or nuclear plants is ramped up and down according to consumer demand. Such is not the case for either wind or solar energy conversion, and, in the case of on-site renewable energy generation without the ability to store energy, the consumer would be left only having useful electricity when there is either substantial wind or sun to convert to electricity. When an effective energy storage technology is integrated into the on-site generation system, electricity generated by the solar or wind conversion can be stored and used when the demands warrants its use.

As storage technologies are adopted for on-site renewable generation, they will be used for other applications as well, thereby increasing the total value of both the investment into the systems' development and the value of the systems themselves. Energy storage systems that will be of use to the microgrid application can also be used for grid load management and as back-up power supplies for communities. If integrated to the grid properly, utilities will be able to use battery systems to store electricity generated during off-peak periods to supplement demand during high-peak usage. Likewise, such energy storage systems can also be used during power outages or during natural disasters to supply electricity when grid operation is interrupted.

The table in figure 3, below, shows in detail the relative value of storage technologies in grid applications. This table is from an article by John Peterson, of Alt Energy Stocks, entitled "Grid-Based Energy Storage; a $200B Opportunity." Peterson's estimates are based in great part on the 2010 Sandia report, entitled "Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide; a Study for the DOE Energy Storage Systems Program," by Jim Eyer and Garth Corey, of Sandia.

Figure 3: projected capacity, benefit, and economic value of grid storage

		Discharge Duration*		Capacity (Power: kW, MW)		Benefit ($/kW)**		Potential (MW, 10 Years)		Economy ($Million)†	
#	Benefit Type	Low	High	Low	High	Low	High	CA	U.S.	CA	U.S.
1	Electric Energy Time-shift	2	8	1 MW	500 MW	400	700	1,445	18,417	795	10,129
2	Electric Supply Capacity	4	6	1 MW	500 MW	359	710	1,445	18,417	772	9,838
3	Load Following	2	4	1 MW	500 MW	600	1,000	2,889	36,834	2,312	29,467
4	Area Regulation	15 min.	30 min.	1 MW	40 MW	785	2,010	80	1,012	112	1,415
5	Electric Supply Reserve Capacity	1	2	1 MW	500 MW	57	225	636	5,986	90	844
6	Voltage Support	15 min.	1	1 MW	10 MW	400		722	9,209	433	5,525
7	Transmission Support	2 sec.	5 sec.	10 MW	100 MW	192		1,084	13,813	208	2,646
8	Transmission Congestion Relief	3	6	1 MW	100 MW	31	141	2,889	36,834	248	3,168
9.1	T&D Upgrade Deferral 50th percentile††	3	6	250 kW	5 MW	481	687	386	4,986	226	2,912
9.2	T&D Upgrade Deferral 90th percentile††	3	6	250 kW	2 MW	759	1,079	77	997	71	916
10	Substation On-site Power	8	16	1.5 kW	5 kW	1,800	3,000	20	250	47	600
11	Time-of-use Energy Cost Management	4	6	1 kW	1 MW	1,226		5,038	64,228	6,177	78,743
12	Demand Charge Management	5	11	50 kW	10 MW	582		2,519	32,111	1,466	18,695
13	Electric Service Reliability	5 min.	1	0.2 kW	10 MW	359	978	722	9,209	483	6,154
14	Electric Service Power Quality	10 sec.	1 min.	0.2 kW	10 MW	359	978	722	9,209	483	6,154
15	Renewables Energy Time-shift	3	5	1 kW	500 MW	233	389	2,889	36,834	899	11,455
16	Renewables Capacity Firming	2	4	1 kW	500 MW	709	915	2,889	36,834	2,346	29,909
17.1	Wind Generation Grid Integration, Short Duration	10 sec.	15 min.	0.2 kW	500 MW	500	1,000	181	2,302	135	1,727
17.2	Wind Generation Grid Integration, Long Duration	1	6	0.2 kW	500 MW	100	782	1,445	18,417	637	8,122

*Hours unless indicated otherwise. min. = minutes. sec. = seconds.
**Lifecycle, 10 years, 2.5% escalation, 10.0% discount rate.
†Based on potential (MW, 10 years) times average of low and high benefit ($/kW).
†† Benefit for one year. However, storage could be used at more than one location at different times for similar benefits.

The information presented in the table, and the extensive study by Eyer and Corey, show both the tremendous economic value of storage for the grid, and the wide array of valuable applications in the grid. The salient take-home points of the information in figure 3 are:

1) assuming adoption of energy storage technology onto the future grid, the economic value of such technology is over $200B
2) the value of storage technology for on-site renewable generation (contained in rows 15, 16, and 17) are relatively modest, but still in the billions of dollars
3) most research in the area of storage for the grid focuses on on-grid applications, not off-grid (or tangent-grid) applications as would be the case for storage for on-site renewable energy generation.

<u>Energy Storage R&D for transportation applications: useful for the grid?</u>

As the automotive industry moves from purely internal combustion propulsion to hybrid-electric, plug-in hybrid electric, and pure electric vehicles, businesses are commercializing new battery technologies that go beyond the standard lead-acid technology used by consumers today. OEMs have successfully integrated nickel-metal hydride (NiMH) battery systems into HEVs (e.g. Toyota Prius or Ford Escape Hybrid), and are beginning to integrate lithium ion batteries into some HEV applications as well (e.g. Johnson Controls-Saft lithium ion batteries for Mercedes' S400 hybrid). For PHEV and EV applications, OEMs are adopting a wide variety of lithium ion battery technologies. Notable and timely examples include the Chevy Volt and the Nissan Leaf, both of which are entering the market at the end of 2010. Both cars contain advanced lithium ion battery packs for propulsion.

Research at the DOE National Laboratories, and around the world, is ongoing in a race to develop the best performing lithium ion battery technology, to enable full penetration of PHEV and EV automobiles into the consumer market by decreasing cost and improving the performance of the battery systems, in terms of how much energy can be safely stored and retrieved in a given battery.

For over 40 years, Argonne has been a leader in performing research into electrochemical energy storage systems. Notably, this research has focused in the last 10 – 14 years on lithium ion battery systems, including basic materials research and development, systems and cost modeling, diagnostics of materials and systems, and performance testing of electrochemical cells and complete systems. Argonne also evaluates the performance of hybrid electric systems in vehicles as a complete system.

DOE's battery research programs managed by the Office of Vehicle Technologies in EERE span multiple national laboratories as well as universities and industry. Through DOE's programs, Argonne works in concert with Lawrence Berkeley National Laboratory, Sandia National Laboratory, Idaho National Laboratory, Brookhaven

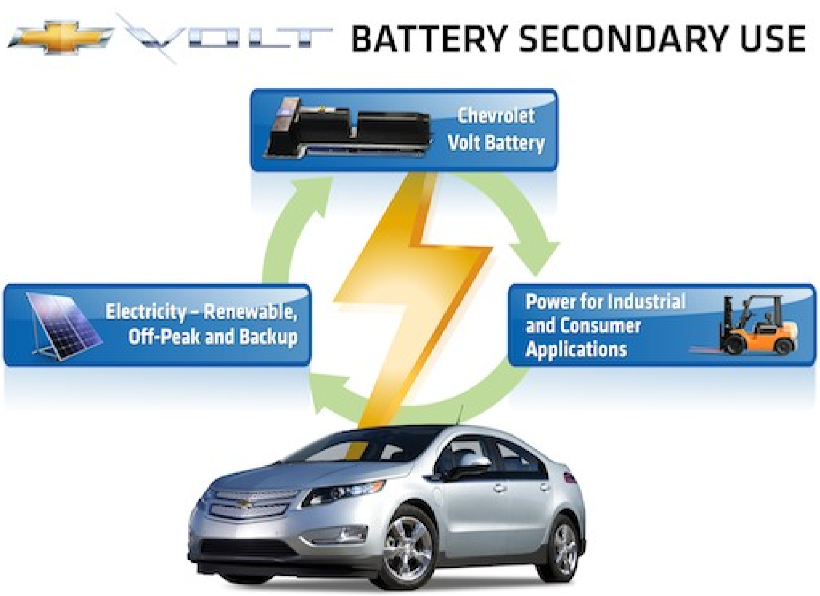
National Laboratory, the National Renewable Energy Laboratory, and Oak Ridge National Laboratory, as well as the Army Research Laboratory, NASA, and the Jet Propulsion Laboratory. Likewise, the National Laboratories involved in DOE's battery research programs interact directly with industry, from materials suppliers like Dow Chemical, DuPont, 3M and BASF, to battery manufacturers such as Johnson Controls, A123 and Ener1, to the OEMs (GM, Ford, Chrysler), through the U.S. Advanced Battery Consortium (USABC).

The work performed by the group above has a primary focus on developing and testing new materials for advanced battery systems for use in transportation applications. Separately, DOE, though the Office of Electricity, has a variety of funded programs focused on enabling known technologies for use in a variety of stationary applications, mostly at megawatt scale.

Many businesses are now working to determine the technical and financial potential for aftermarket use of these large car batteries, particularly for grid storage. The concept is that, 1) at the end of useful life in an automobile, a lithium ion battery still has the capability of storing energy, but not in a useful way for automobile propulsion, and 2) by extracting further value from the expensive battery system (currently between $5000 and $15,000), the upfront cost of the battery system can be offset, and in a way subsidized by the extraction of value at the end of its useful life in a car.

A pertinent example (figure 4) of such an effort is being made by General Motors. GM has recently signed a Memorandum of Understanding with ABB Group, a Swiss-Swedish consortium, to investigate and quantify the value of a "used" Chevy Volt battery system for application on the grid (Energy Matters, September 22, 2010).

Figure 4: GM will work with ABB group to determine the most beneficial way to re-use battery systems from the GM Volt



This serves merely as one example of how the automotive and battery industries are rapidly moving to determine if their automotive batteries can cross over for effective use in grid applications. In the U.S., A123 Systems (an MIT startup), Johnson Controls (world's largest battery maker), and Ener1 (an Indianapolis battery maker) are all working quickly to adapt their battery technologies either for direct use on the grid, or for after-market use, when the effective life in an automobile ends. Outside the U.S., Panasonic-Sanyo, GS Yuasa, and NEC in Japan, and LG Chem, Samsung, and SK in Korea, as well as Lishen and ATL in China are all working quickly toward adapting their vehicle-use batteries for grid application.

In all likelihood, advanced batteries intended originally for use in automotive applications will have use and value in grid applications, including for individual buildings. However, this current focus by advance battery manufacturers and OEMs exposes the primary weakness in the U.S.'s R&D portfolio aimed at filling the energy storage need for on-site renewable electricity generation: the PHEV and EV battery systems were developed specifically for transportation applications, where a primary driver in the technology development is energy density, both gravimetric and volumetric. Batteries for electric cars must be as lightweight and small as possible. However, for on-site, stationary applications, the size and weight of the battery system is of significantly less importance. Instead, efficiency and cost are the primary drivers for stationary applications.

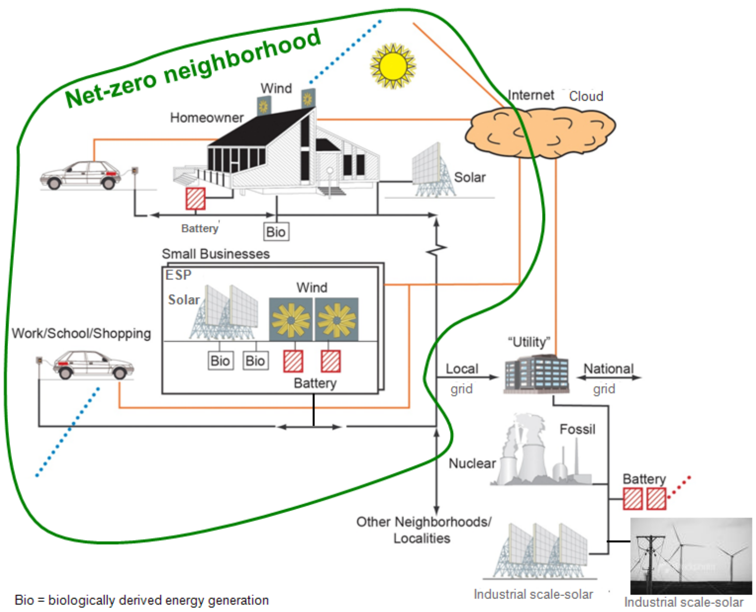
Energy Storage research for stationary applications is primarily focused on demonstration projects

As the U.S. endeavors toward net-zero communities, including on-site renewable energy generation and energy storage, the question arises: what is the best technology for storing energy locally, for individual buildings or small communities?

To answer this question, DOE's Office of Energy Efficiency and Renewable Energy and DOE's Office of Electricity have sponsored multiple projects across the laboratory complex and directly with industry. For example, as a result of Energy Independence and Security Act of 2007, DOE formed the National Laboratory Collaborative on Building Technologies, in which Argonne, Lawrence Berkeley, NREL, Oak Ridge, and Pacific Northwest National Laboratory are to work together on building efficiency improvements, including investigating energy storage as part of the answer. A more direct example is the case in which DOE has funded American Electric Power in Ohio, to install at test a 25-kW lithium ion "neighborhood" battery to reduce strain on the grid during peak load demands. Likewise NEDO in Japan has sponsored similar demonstration projects that utilize known lithium ion and flow battery technologies for microgrid applications. Separately, DOE's Office of Electricity actively participates in the international cooperation known as Energy Conservation through Energy Storage, or ECES. European, North American, and Asian governmental offices participate in the activity.

Figure 5 below (Gil Weigand, Oak Ridge, in Green Car Congress, May 5, 2010) illustrates how on-site renewables generation will fit into an overall net-zero neighborhood architecture. Note that there are several places and needs for energy storage technology. One technology alone will not fill each of these needs.

Figure 5: Net-zero neighborhood as part of a larger grid



In every example project described above, the primary objective seems to be to determine whether a known technology can be utilized for grid and microgrid applications. Technologies being tested and validated include lithium ion, lead acid, sodium sulfur thermal systems, pumped hydro, flywheel, ultra capacitor, sodium metal halide, and flow batteries. Until very recently, the primary focus around the world in energy storage for stationary applications has been an attempt to apply or adapt known energy storage technologies for these emerging applications. During the last several years, efforts have begun, to enable fundamental research on new materials and systems aimed specifically for use in stationary applications. These efforts are relatively small; this is where the largest gap exists that would prevent the most effective adoption of storage technology for on-site renewable energy generation.

DOE's Office of Electricity has begun to fund small materials research projects at Sandia National Laboratory and Pacific Northwest National Laboratory, and DOE's ARPA-E has funded over 10 new high-risk, high-reward materials-based projects aimed specifically at stationary storage applications. One example is 24M technologies, a spin-out from A123, with Professor Yet-Ming Chiang, MIT, as a founding partner. This project aims to develop entire new battery systems for both transportation and grid applications, starting from fundamentally new developments in materials physics and chemistry.

Coordinated Research and Development can address the existing gap

The opportunity before us today is to perform groundbreaking research to develop innovative, efficient, and low-cost energy storage technologies that will enable the most effective use of on-site renewables generation. The clear gap in our research in the U.S., and even across the globe, is that almost all materials research has been aimed either at transportation applications, or at megawatt-sized stationary applications.

State of research in U.S. for stationary storage for buildings and small communities:

- there are already multiple programs
- focus is on adapting automotive technologies, and integrating megawatt-scale technologies (e.g. pumped hydro)
- focus exists on integration technologies, modeling, “smart” grid creation
- Lacking: direct work on new energy storage technologies

Europe’s programs – same gap as U.S.
Asian programs – same gap as U.S.
In both Europe and Asia, though, it appears there is a more advanced strategy for coordinating the effort with respect to storage.

It is the opinion of the author that the best method for addressing the gaps described above is to combine a new strategic investment by DOE in research and development in the U.S. focused directly at the development of energy storage systems for buildings and small communities, and, importantly, to coordinate the research effort effectively with the resources already available to DOE. Specifically, the talent and skills needed to develop advanced energy storage technologies, from inception, to modeling and theory, through materials and systems development, and performance and full utilization testing, already reside in the DOE National Laboratory system. Also, there a both startups and large-cap businesses ready to commercialize any technology developed in the laboratories. If developed and managed properly, R&D funds could be utilized with great efficiency, if the various organizations worked in concert, collaborating toward a singular, well-defined mission. Further, a particular project on energy storage for on-site small-scale stationary applications could be incorporated into a larger, coordinated national effort at developing knowledge and technology for energy storage across a large variety of both stationary and portable applications.