The Secretary of Energy
Washington, DC 20585

July 30, 2010

The Honorable Ron Wyden
United States Senate
Washington, DC 20515

Dear Senator Wyden:

I want to thank you for your interest in grid-level storage, and to apologize for our delayed response to your request for a paper on this subject. When I heard from Deputy Secretary Poneman about your interest, I wanted to take the time to read it personally before we sent the document to you.

As you will see in the enclosed report, the Department "considers grid scale energy storage to be critical in enabling the transition to a future energy system that is more efficient, more reliable and can accommodate the novel technologies that will reduce the CO_2 intensity of our electricity and transportation sectors." Several of our offices and programs are sponsoring research, development, and deployment in this area: the Office of Science, the Office of Electricity Delivery and Reliability, the Office of Energy Efficiency and Renewable Energy, and ARPA-E. Their activities extend throughout the innovation chain, from basic research through prototypes to commercial deployment. As you well know, the success of their efforts will be critical to our ability to incorporate intermittent sources of renewable energy into the grid.

By their breadth, requests like yours help break down the stovepipes among various efforts and promote communication and coordination throughout the Department. I also want to assure you that the Deputy Secretary and I are fully committed to integrating the various parts of the Department of Energy into a coherent set of actions that nurture the entire innovation chain in energy. We will be using the enclosed report as a valuable tool in our own efforts to further improve our internal coordination of the Department.

As in all large organizations, the Department has barriers that inhibit improvement. It is my task to motivate the different stakeholders to invest the necessary time to look across disciplines and organizational structures, move out of their comfort zones, and share authority. The end result is that we will allocate our precious resources as effectively as possible.

I look forward to working with you on all of the Department missions that will enhance our economic competitiveness, nuclear and energy security, better our lives today and create a proud legacy for our children.

With best regards,

Sincerely,

Steven Chu

Enclosure

U.S. Department of
ENERGY

Grid Storage Report

Report to Congress
July 2010

United States Department of Energy
Washington, DC 20585

Message from the Under Secretary for Science

This report is provided in response to a request from Senator Wyden during my testimony before the United States Senate Committee on Energy and Natural Resources on December 10, 2009. The report addresses Departmental strategy for grid level storage projects through discussion of applications, DOE collaborative activity, and Office specific foci within the Department.

This report is being provided to the following Members of Congress:

- **The Honorable Jeff Bingaman**
  Chairman, Senate Committee on Energy and Natural Resources

- **The Honorable Lisa Murkowski**
  Ranking Member, Senate Committee on Energy and Natural Resources

- **The Honorable Ron Wyden**
  Member, Senate Committee on Energy and Natural Resources

If you have any questions or need additional information, please contact me or Jeffrey A. Lane, Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Steven Koonin

Executive Summary

The Department of Energy (DOE) considers grid scale energy storage to be critical in enabling the transition to a future energy system that is more efficient, more reliable and can accommodate the novel technologies that will reduce the CO_2 intensity of our electricity and transportation sectors. DOE is sponsoring research, development and deployment work across many parts of the Department.

Each DOE office has clearly defined roles in the development of electrical energy storage components and systems. The Office of Science (SC) conducts fundamental research into the scientific principles and physical processes underlying the material science and advanced electrochemistry that are necessary for the storage technologies of the future. Energy Efficiency and Renewable Energy (EERE) focuses on the development of storage technologies that enable integration of the office's renewable generation and efficiency technologies into the energy and transportation system. Given the responsibility to develop low-carbon technologies for transportation, EERE maintains a strong focus on developing battery storage technologies that meet the rigorous weight, volume and cost requirements needed to bring vehicle electrification into the mainstream market place. The Office of Electricity Delivery and Energy Reliability (OE) focuses on large-scale energy storage systems that will enhance the overall flexibility, reliability, and capability of the grid, and will enable transformation of the national electric generation and delivery system to meet the reliability and emissions goals of the 21st century. ARPA-E seeks high risk and high payoff projects which offer the possibility of significant and rapid developments in all energy technologies, not just energy storage.

Through these integrated efforts on scientific research, technology development and demonstration, and system analysis and simulation, the DOE is pursuing a coordinated agenda that will position the United States at the forefront of global activity in grid storage.

GRID STORAGE REPORT

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I. Grid Storage

Domestic use of electricity in the residential and commercial sectors is growing faster than for any other form of energy[1], and the reliable delivery of high quality electrical energy is now inextricably linked to the health of the U.S. economy[2]. Enhancing our national energy storage capability is an important tool to improve electric grid reliability and resiliency; adequate deployment of storage technologies can materially reduce power fluctuations, enhance system flexibility, and enable greater integration of variable generation renewable energy resources such as wind, solar and water power.

Aggregate electricity demand can double from early morning to late afternoon,[3] and local variations can be much larger. When considered in tandem with the perishable nature of flowing electricity in that unused current cannot easily be stored for later use, this demand variation has led to a severely underutilized system of grid assets which must be designed for a rarely achieved peak demand. Generators are successively turned on each day as demand increases and then idled again in the evening while maintaining costly and polluting "spinning reserve" to assure power quality. Indeed, additional resources continue to be required while grid assets generate at an average of less than half of full capacity.[4] Applications for grid scale energy storage have operational demands that cover a wide range for power, response time, and energy. Although generic in nature, the overlay of potential storage applications and functional characteristics shown in **Figure 1** is a useful guide to the storage opportunities in today's electricity grid. From fast reacting high power applications for frequency regulation and power conditioning which can prevent transient phenomena such as power spikes, to slow response high energy applications of peak shaving and diurnal shifting which can prevent persistent phenomena such as brownouts or even match renewable generation to load, the diversity of storage needs are significant.

The value provided by energy storage is not limited to the conventional grid. In fact, storage will also play an essential role in the nationwide efforts to create "Smart Grids." These electric networks, which will incorporate active monitoring and automatic control over operation, will have multiple options in responding to changing electric demands and events on the grid. Storage provides a buffer for active control of the system, smoothing transitions between operating states and leveling the constantly changing supply and demand.

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[1] EIA Energy Perspectives 2008 – Figure 8, http://www.eia.doe.gov/emeu/aer/ep/ep_frame.html

[2] Hamachi-LaCommare, Eto. *Understanding the Cost of Power Interruptions to U.S. Electricity Customers.* Lawrence Berkeley National Laboratory (2004)

[3] Rubinstein, Neils and Colak. *Daylighting, Dimming, and the Electricity Crisis in California*, Lawrence Berkeley National Laboratory (2001). *http://lighting.lbl.gov/pdfs/49971.pdf*

[4] Electric Advisory Committee report - Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid - December 2008.(*http://www.oe.energy.gov/DocumentsandMedia/final-energy-storage_12-16-08.pdf*)

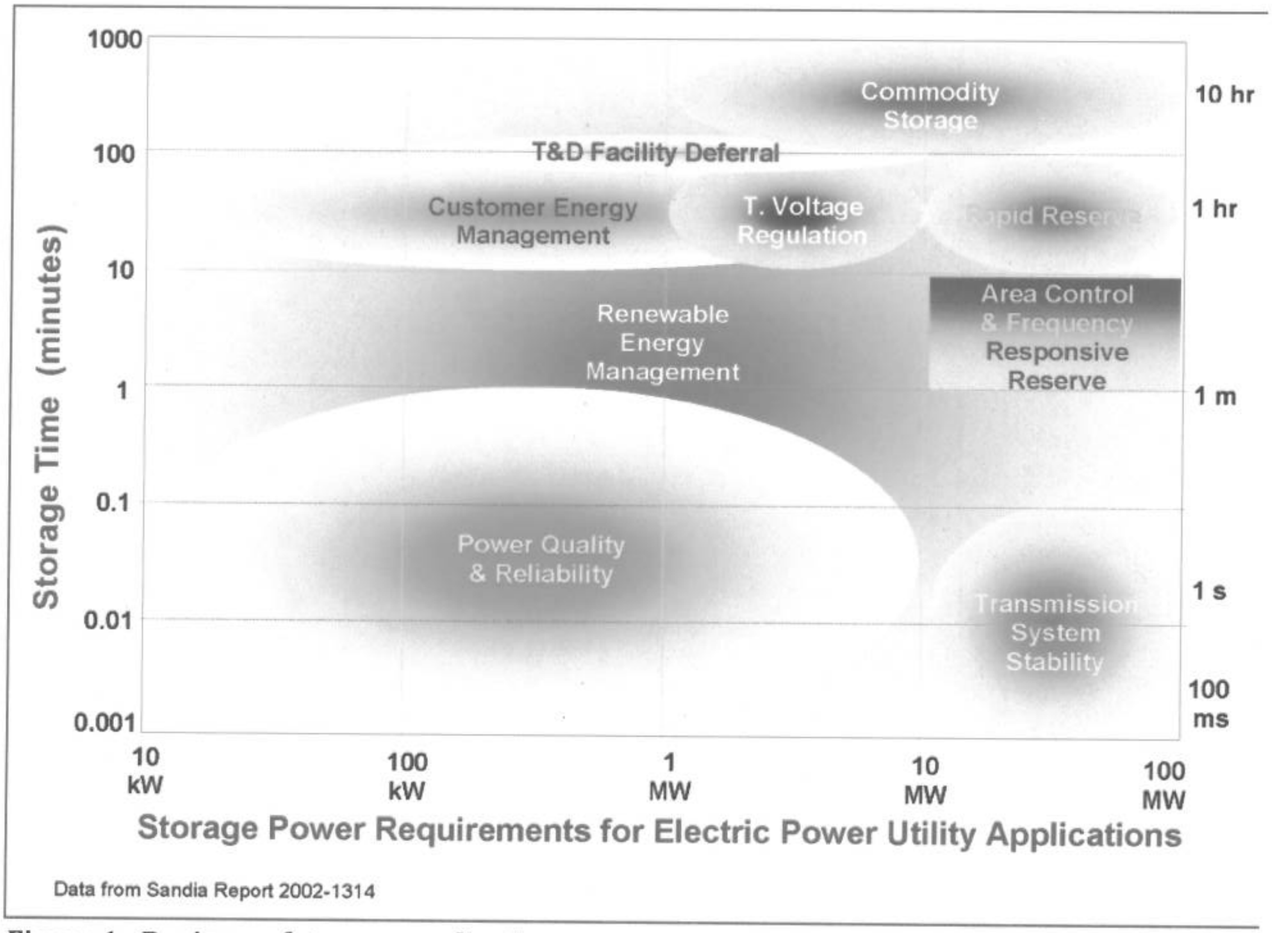

Figure 1 - Regimes of storage applications

Despite the large number of existing energy storage technologies and correspondingly wide array of storage applications, there are only a limited number of known fundamental phenomena that can be exploited to store energy. Currently these phenomena include lifting or spinning mass, compressing gas, electron movement and storage, chemical manipulation of materials, and thermal storage. The physics underlying the conversion processes between energy states that enable storage also define the characteristics for each storage technology, and the application space for which the technology is best suited. For applications such as load leveling where energy storage demands are large, mechanical storage via physical translation (gravity) or compression are typically employed. Conversely when high power and fast response is more important than energy duration, as is the case with frequency regulation and power quality applications, the phenomena employed tend to switch to electron (battery) or kinetic energy (flywheel) technologies.

For each class of storage technologies the performance characteristics of an individual technology is best suited to a subset of all potential applications. This is true even when technologies leverage similar fundamental storage phenomena and often leads to confusion in the discussion of generic storage technology classes, which is exemplified by the multitude of battery technologies and chemistries. Sodium-sulfur (Na-S) and lithium-ion (Li-ion) batteries, both of which store and transport electrons via electrochemical mechanisms, differ significantly enough in operational characteristics that one could not be used in place of the other. The chart in **Figure 2**, again generic in nature, includes an overlay of some current energy storage technologies on the operational and application characteristic space already presented in **Figure 1**. While not inclusive of all energy technologies, this overlay shows the diversity and uniqueness of applications even for technologies within a single class.

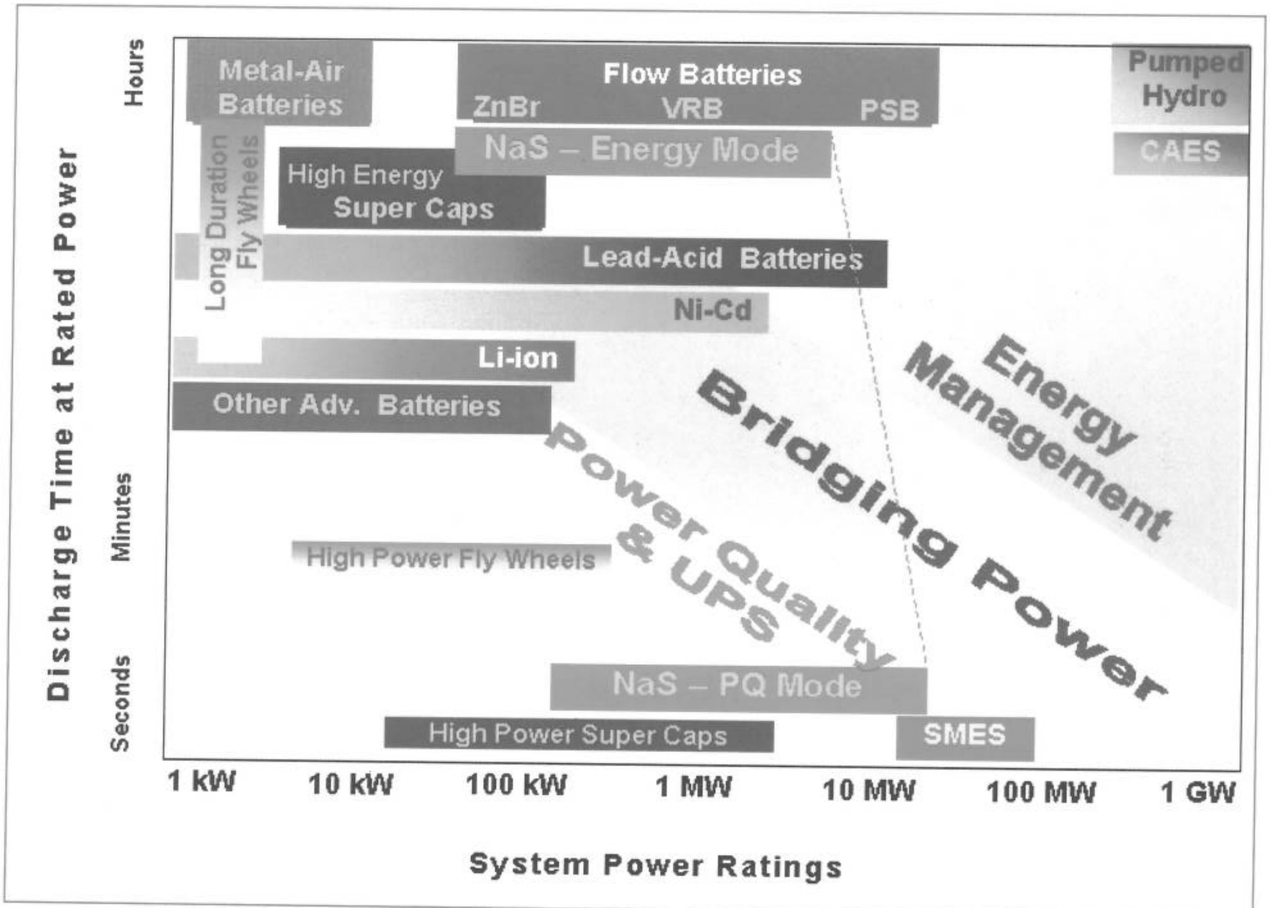

Figure 2 - Regimes of storage technologies [5]

[5] Graphical representation of the data contained in Sandia Report 2002-1314. http://prod.sandia.gov/techlib/access-control.cgi/2002/021314.pdf

II. Energy Storage at DOE

Because grid scale energy storage is actually a suite of technologies, with relevant applications governed by the operational characteristics of each, the DOE has historically grouped energy storage technologies by end-use sector. Li-ion chemistry batteries which are energy dense, relatively compact, and generally recognized as ideal mobile energy storage platforms fell under the auspices of the Office of Energy Efficiency and Renewable Energy's (EERE's) Vehicle Technologies Program (VTP). Conversely, Sodium-Sulfur batteries and other bulky storage mechanisms deemed suitable for stationary and grid applications were therefore the responsibility of the Office of Electricity Delivery and Reliability (OE) within DOE.

Rigid separation across DOE offices of research, development and demonstration (RD&D) responsibilities for storage technologies was historically appropriate when delineation between grid and other technologies was obvious. However, the distinction between grid and non-grid applications is blurring as new storage technologies are introduced to the energy system and deployed in ever greater numbers. While grid storage technologies used to be limited to pumped hydro and compressed air energy storage (CAES), opportunity and need for additional storage technologies has grown along with regional limitations in pumped hydro capacity, an aging infrastructure, and the introduction of new and variable generation technologies. With potential for future electrification[6] of a substantial segment of the light-duty transportation fleet, the number of mobile-platform batteries transiently connected to the grid could become large, and at such time the distinction between grid and other storage technologies would nearly vanish.

Accordingly DOE has an integrated approach to the science, engineering, and technology of energy storage in which RD&D efforts are coordinated across offices based on technology maturity and the relevant spectrum of applications. When multiple potential applications exist for a technology, phases of the RD&D effort reside with programs as functions of the technology level and relevant primary application, but are also coordinated with other programs based on secondary applications (see case study). Technology-specific RD&D is therefore pursued in the office to which the potential applications best match the characteristics of the technology, while broad and fundamental research that can impact multiple technologies across multiple applications and offices is often funded by the Office of Science (SC).

[6] Electrification could occur via plug-in hybrid electric vehicles (PHEVs) or electric vehicles (EVs).

Case Study – Lithium-ion batteries

The principal drivers for improvement of Li-ion batteries have been mobile platform and transportation applications. This is because the volumetric (Wh/l) and gravimetric (Wh/kg) energy densities for Li-ion technologies are quite high, leading to size, weight, and maintenance benefits unique to this class of batteries. Conversely, many other technologies can match the high specific power and charge rate characteristics afforded by Li-ion batteries. Therefore the primary applications for Li-ion technologies are mobile platforms while other applications, such as frequency regulation for the grid, are considered secondary opportunities. This is supported by developments in industry where highly specialized Li-ion batteries are entering the vehicle market, and new grid scale demonstrations of Li-ion storage often consist of a large number of smaller mobile platform storage devices linked and controlled together.

Based on current technology characteristics and primary market application, the natural alignment for Li-ion R&D in DOE is the Vehicle Technologies Program (VTP) in EERE. This is reflected by $93 million for "Battery/Energy Storage R&D" in the 2011 VTP budget, much of which is specific to Li-ion technology via optimization research on the performance characteristics and cost of these batteries and chemistries while also supporting the development of next- generation mobile platform energy storage technologies.

A secondary application for current Li-ion batteries does exist in frequency regulation for the grid, and this is driving the development of control systems that will enhance grid integration capabilities. Therefore the DOE is supporting early demonstrations and grid-integration projects for Li-ion systems through Recovery Act and OE funding of Southern California Edison and Seeo demonstration projects in California. These two highlighted projects, which include nearly $35 million in industry cost-share, will generate significant knowledge and data on the benefits and value of grid-integrated storage that go well beyond the value of a single storage technology.

Pursuing higher risk endeavors, ARPA-E focuses on the development and demonstration of Li-ion storage mechanisms that are fundamentally different than current technologies. These include longer time-horizon technologies such as Li-air or alternative chemistries, which if successful could exceed the performance limits of current batteries at lower cost.

Finally, to include the full spectrum of Li-ion-relevant efforts at DOE one must also consider the storage related EFRCs funded through SC. From the Center for Electrical Energy Storage at Argonne National Laboratory to the Nanostructured Interfaces for Energy Generation, Conversion and Storage EFRC at Cornell University, a number of EFRCs will perform basic research that could impact the Li-ion batteries of the future. Importantly, the same EFRC research is just as likely impact the development of other electrochemical storage technologies, and so does not belong in a program dedicated to a single chemistry or application.

The coordination of the Li-ion relevant RD&D across the DOE occurs directly between offices, through a departmental working group, and via collaborative workshops and external advisory committees. Interagency coordination is ensured through the Interagency Advanced Power Group and the various MOUs for direct coordination between agencies, while industry coordination is ensured through the United States Advanced Battery Consortium and other means.

III. Grid Storage RD&D Activities by Office

The American Recovery and Reinvestment Act (Recovery Act) has enabled a significant expansion of grid storage related RD&D activities at DOE, which will keep the United States at the forefront of global storage efforts ranging from grid-integrated technology demonstrations to basic science. Descriptions of the efforts, organized by office, follow.

Office of Electricity Delivery and Reliability

With a focus on the larger system, OE efforts are aimed at enhancing the capabilities of the grid and enabling the system to incorporate new technologies ranging from generation to distribution to control. The OE Energy Storage Systems Program (ESSP) is developing new technologies, systems and analytical tools dedicated to the unique requirements of grid level storage, and in collaboration with other DOE offices, the storage industry, utilities and academia works to support market introduction of these technologies. ESSP activities include: advanced development and prototyping, bench and field testing, modeling and analysis, and smart grid.

The OE program develops prototype storage devices, power conversion systems, and control methodologies suitable for large scale grid systems. Additionally, ESSP provides neutral third-party testing for developers of energy storage components and systems. These bench, prototype and field testing capacities provide industry with critical feedback on technology and design throughout the development process and enable more effective integration of new storage technologies into the grid. ESSP development technologies include stationary batteries and electrochemical capacitors, flywheels, compressed air energy storage, and power electronic and control systems.

The OE Energy Storage Systems Program has the following long term goals:

- Develop stationary energy storage systems with installed capacity cost of $1300/kW (existing systems cost approx. $2500/kW).
- Develop stationary energy storage systems with installed stored energy cost of $150/kWh (existing systems range from $400/kWh to $1500/kWh).
- Develop energy storage systems to enable the US to cost effectively obtain >30% of its electrical energy supply from renewable generators.
- Develop tools to allow utility planners to seamlessly integrate energy storage into their systems.
- Collaborate with FERC (Federal Energy Regulatory Commission), regional and local utility regulatory commissions to create effective energy storage regulations for the U.S. grid.

OE works to ensure the office is addressing high priority needs and supports aggressive deployment of storage technologies. The program receives input on requirements, applications, and economic and regulatory conditions which affect the introduction of storage into the grid, thereby guiding program activities and ensuring relevance to commercial entities.

Through the Recovery Act, OE has funded 16 demonstrations of grid storage technologies. Leveraging $185 million in Federal funds, demonstration projects with a total value of over $770 million will begin construction in May of 2010. Each project will also include a demonstration period up to three years duration (see **Table 1**). The Recovery Act investment will therefore continue to generate new data on cost, construction, operation, performance, and value of grid storage systems through 2016. With OE support for demonstrations of technologies ranging from flywheels to flow batteries this investment will maintain domestic leadership in grid integration of storage technologies for several years to come, and the knowledge gained will be an invaluable asset as the next generation of grid models and planning tools are developed.

Table 1- Office of Electricity Energy Storage Demonstrations and Milestones

			Construction (Mo-Yr)		Demonstration (Mo-Yr)	
Recipient	Gov Amt	Total Cost	Begin	Complete	Begin	Complete
Duke Energy Business Services	$21,806,232	$43,612,464	Dec-10	Apr-11	May-11	May-13
Detroit Edison Company	$4,995,271	$10,877,258	Jan-11	Jun-11	Jul-11	Jun-14
Pacific Gas & Electric	$25,000,000	$355,938,600	Dec-11	Dec-14	Dec-14	Dec-16
Southern California Edison	$24,978,264	$53,510,209	Nov-10	Mar-11	Mar-12	Apr-14
Premium Power	$7,320,000	$16,080,554	Jul-10	Feb-11	Feb-11	Feb-13
Seeo Inc	$6,196,060	$12,392,120	Jan-12	Dec-12	Mar-13	Feb-14
44 Tech	$5,000,000	$10,000,000	Jun-11	Aug-12	Aug-12	Feb-13
Ktech Corp	$4,764,284	$9,528,567	Nov-11	May-12	May-12	Sep-12
East Penn Manufacturing	$2,245,523	$4,491,046	May-10	Feb-11	Mar-11	Dec-13
New York State Electric & Gas Corporation	$29,561,142	$125,006,103	Apr-11	Jan-13	Feb-13	Mar-15
Beacon Power Corporation	$24,063,978	$48,127,957	Jun-10	Jul-11	Nov-11	Nov-13
Primus Power Corporation	$14,000,000	$46,700,000	Apr-12	Dec-12	Jan-13	Jul-14
SustainX	$5,396,023	$10,792,045	Jun-11	Dec-11	Jan-12	Dec-13
Amber Kinetics	$4,000,000	$10,000,000	Jan-13	Jul-13	Jul-13	Jul-14
City of Painesville	$3,743,570	$7,487,153	Oct-10	Oct-11	Mar-12	Mar-14
Public Service Company of New Mexico	$1,755,931	$5,851,303	May-10	May-11	Jun-11	May-13

Advanced development and prototyping of new storage systems is another area of responsibility for the OE Energy Storage Systems program, and of the Recovery Act funded projects three are large scale (8-25 MW) battery based projects which are outgrowths of several smaller projects field-tested by OE. A fourth project is a 20 MW flywheel regulation project with is a direct descended of two OE projects collaboratively sponsored by DOE, CEC,[7]

[7] California Energy Commission

and NYSERDA,[8] and the office was instrumental in both the design of the system and in pursuing market rule changes that recognize the benefits of fast acting energy storage (a complete list of OE Recovery Act funded demonstration projects with descriptions can be found in **Appendix A**).

Further goals for advanced prototyping projects include:

- Life extension of lead acid batteries via carbon addition
- Flow battery electrolytes and membranes
- Materials and mechanisms to enable 30% increase in flywheel rotational velocity
- Improved siting technologies and methodologies for CAES and pumped hydro
- High temperature power conditioning systems controllers
- Bench and field lifecycle testing of grid storage technologies

In addition to technology prototyping and demonstration, modeling and analysis tools that study the technical operation of storage systems, their effect on electric grid, and the economic impact likely to result from the introduction of storage in various applications represent critical and still developing components for grid-scale storage. While this has been a focus of OE activities, the demonstration projects funded through the Recovery Act provide a significant and unprecedented opportunity to advance the relevant body of knowledge on these issues, and will enable OE to continue development of the improved system models and grid planning tools necessary to enable scale deployment of grid-storage technologies. OE will monitor the performance of Recovery Act contracts from project system manufacture and installation through project commissioning, and continue with performance data acquisition, analysis and reporting.

Furthermore, the OE program continues to pursue more specific goals in the modeling and analysis domain. The office is working to complete the development of a hybrid renewable energy storage modeling tool as well as initiate projects to write utility planning models which include energy storage.

The OE program is developing models and performing analysis to examine the role of stationary energy storage based on both technology function and grid location. Questions to be addressed via this effort include a) where one would place energy storage on the system; b) location and functional optimization of power and energy capacity; c) targets for application specific economic viability; and d) quantification of the application and location specific benefits of energy storage. One complication is the site specific nature of this type of analysis due to large regional diversity of rate structures, generation mixes, magnitude and mix of existing and

[8] New York State Energy Research and Development Authority

planned deployment of renewable generation technologies, construction costs and existing utility load factors.

The current set of grid storage analyses are evolving and expanding in scale; from village systems to microgrid systems to interconnected grids. Projects are ongoing with Bonneville Power Administration (BPA), planned for Hawaii, and will expand to a national assessment of the WECC[9] and ERCOT[10] interconnects. Additionally, OE is looking to leverage these new analytic tools to improve the sizing, placement and operation of energy storage systems and is working with vendors supplying utility planning software to develop energy storage modules for inclusion in commercial products. This will enable utility planning departments to examine energy storage as part of their normal planning activities. Finally, the Energy Storage Systems program is conducting a formal road mapping process in FY2010 to reassess program direction and activities. Representatives from academia, the storage industry, utilities, state energy agencies, and other DOE programs including EERE and ARPA-E participated in a planning workshop on July 19-23, 2010 to ensure a thorough and complete treatment of the most pressing issues facing the Department and the grid.

Advanced Research Projects Agency – Energy

ARPA-E is responsible for funding high-risk and high-payoff R&D projects to meet the nation's long-term energy challenges. ARPA-E received initial funding through the Recovery Act to fund transformational energy research that the private sector by itself cannot and will not support. The Agency's funding model is to identify technological and scalability gaps in the product deployment process stemming from science and technology challenges. Having identified the gaps, ARPA-E supports the most promising and potentially impactful of these products to a scale such that, if successful, they may be introduced to the marketplace.

In developing its funding opportunities, ARPA-E works closely with offices across DOE and the technical and investment communities to ensure relevance of its efforts. This coordination ensures that planned technology efforts are not duplicated, and facilitates future hand-offs for ARPA-E funded technologies at the conclusion of the funding cycle. With SC, ARPA-E works to identify emerging scientific phenomena and cutting edge materials that hold promise to be transformed into high impact new technologies. The Agency also works with DOE technology offices (EERE and OE) and other government agencies to identify emerging market needs and applications for follow-on programs. Furthermore, ARPA-E meets and communicates regularly with venture capitalists and other private investors to get a sense of emerging opportunities and investment risk profiles to assess the types of projects that are most suitable for subsequent translation to the private sector.

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[9] Western Electricity Coordinating Council
[10] Electric Reliability Council of Texas

ARPA-E invests in a range of technology areas with varying intensities across the energy spectrum. Within this, energy storage is viewed as an essential technology area and ARPA-E has initiated two programs for grid-scale and transportation energy storage. The Gridscale Intermittent Rampable Dispatchable Storage (GRIDS) program targets the disruptive development of stationary energy storage technologies which would be economically deployed on the grid to firm intermittent renewable generation. The Batteries for Efficient Energy Storage for Transportation (BEEST) program targets disruptive development of battery storage technologies with characteristics comparable to aggressive PHEV-100 electric vehicle transportation applications.

As a result of this intense focus on energy storage, approximately $49 million (12%) of ARPA-E's first $400 million in funding will be invested in R&D projects focused on grid-scale energy storage technologies, with a similar amount dedicated to mobile platform storage technologies.[11] This includes $19.2 million for 3 active grid level storage projects (see **Table 2**), and $34 million for projects selected in the GRIDS program (see **Appendix B**).

Table 2 - ARPA-E Grid-Level Storage Projects from FOA-1

Liquid Metal Battery [FOA-1]	$6.95M	A fundamentally new all-liquid battery concept completely eliminates the need for expensive and unreliable solid electrolytes and would provide highly scalable energy storage for the grid if successfully developed. Invented at MIT, this battery uses only domestically available materials, unlike lithium ion batteries designed for this application today. This battery has very low active materials cost (<$100/kWh) and could represent a complete game-changer for stationary energy storage if this high-risk R&D proves to be successful.
Planar Sodium-Beta Batteries [FOA-1]	$7.20M	A very high energy sodium battery that performs superior to existing large storage batteries produced today and at much lower cost through novel geometries and structures. A public-private alliance of scientists and engineers from Eagle Picher and the Pacific Northwest National Laboratory (PNNL) is developing this technology which will propel U.S. battery technology beyond international competitors. This project leverages fundamental discoveries made at PNNL in the solid oxide fuel cell area into the grid scale battery area and seeks to launch Eagle Picher, a leading manufacturer of batteries for the U.S. defense market, into the private sector battery market for the first time
Metal-Air- Ionic Liquid (MAIL) Batteries [FOA-1]	$5.13M	A breakthrough approach to metal-air battery concepts which if successful will achieve order of magnitude increase in energy density and reduction in cost for grid-level storage applications. A collaboration between Arizona State University and startup Fluidic, Inc to produce ultra-high energy, low cost (<$100/kWh) metal-air batteries that could finally overcome the power and recharging difficulties that have plagued this incredibly promising class of batteries in the past

[11] ARPA-E will invest nearly $46 million additional for transportation related storage projects, including $11.35 million for 3 active projects from FOA-1 and $34.6 million for ten projects in the BEEST program (FOA-2). A description of all BEEST projects can be found at http://arpa-e.energy.gov/ProgramsProjects/BEEST.aspx.

Office of Energy Efficiency and Renewable Energy

EERE is working on storage technologies that are components of EERE technologies for either generation or efficiency. With a focus on storage applications to enable market penetration of EERE vehicle, solar, hydrogen, and hydropower technologies, the office portfolio supports the push of individual technologies into the current energy system. This push may eventually contribute to the evolution of grid characteristics.

With an energy storage R&D budget of $76 million in FY 2010, the VTP has an ongoing focus on improving batteries for mobile applications to support electrification of the transportation sector. This includes research and development on battery abuse tolerance, low-temperature performance, lifetime, and cost. EERE battery RD&D efforts are focused on vehicle electrification, and a direct relationship to the grid does not exist at this time. However, because the potential for large-scale deployment of plug-in hybrid and electric vehicles exists, research into the effects and challenges of grid-connected vehicles is ongoing. VTP is also investigating potential "secondary uses" of vehicle batteries for grid-connected applications after the transportation-specific useful life of the battery has been consumed.

The Solar Energy Technology Program (SETP) is investing approximately $7.5 million in 2010 across a range of projects for grid-scale thermal storage including new molten salt materials, phase change materials, and thermochemical materials to improve thermal storage capacity for concentrating solar power (CSP) and other applications. As these thermal storage technologies advance the capacity factors and load following capabilities for CSP will improve, thereby enhancing operational control and easing grid integration.

Each EERE storage technology RD&D effort is informed by extensive analyses of the challenges, obstacles, and development needed for storage technologies to facilitate scale deployment of office technologies. SETP has ongoing work with Sandia National Laboratory on the SEGIS (Solar Energy Grid Integration Systems) initiative, which enables DOE to focus RD&D funding on technologies critical for solar photovoltaic systems and associated energy storage, including charge controllers, communication architecture, and advanced power inverters. Scientists at Lawrence Berkeley National Laboratory have been developing models to probe how plug-in electric vehicles might interact with the grid under different electricity pricing scenarios, work that will inform technology targets as battery usage patterns are illuminated under a variety of price structure scenarios.

With EERE support, the National Renewable Energy Laboratory has developed the Regional Energy Deployment System (ReEDS) analytic tool[12] which is used to model future expansion of electric generation and transmission capacity over the coming decades, and also includes the

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[12] http://www.nrel.gov/analysis/reeds/pdfs/reeds_full_report.pdf

use of targeted grid-scale storage to mitigate or delay costly infrastructure investments. EERE is also funding a study through the Electric Power Research Institute (EPRI) to quantify the value of existing ancillary services provided by hydropower and pumped storage facilities, including frequency regulation, load following, and spinning reserve.

EERE supports grid integration of storage technologies relevant to EERE applications through RD&D, analysis, and commercialization efforts. A list of select 2010 storage funding areas is provided in **Table 3**, while a more detailed description of the projects is provided in **Appendix C**.

Table 3 – Select 2010 EERE Storage Projects and Related Activities

Pumped Hydro Storage	$4.9M	• National Hydropower Assessment • Pumped Storage Resource Assessment • EPRI Grid Services Study
Batteries and Capacitors *(principally mobile)*	$87.8M	• Battery Development Contracts (9 cost shared contracts) • Industrial Material Supplier Contracts (9 cost shared contracts) • Battery Performance and Abuse Testing & Analysis • Laboratory & University Next Generation Battery Materials R&D • Small Business Innovative Research Grants for R&D of novel materials and integrated systems for batteries and capacitors • New Vehicle Technology abuse, tolerance, low-temperature performance, life, and cost Program Funding Solicitation • SEGIS (Solar Energy Grid Integration Systems)
Hydrogen Storage	$2.3M	• NREL Wind- and Solar-to-Hydrogen Demonstration • Lifecycle Cost Analysis of Hydrogen Versus Other Technologies for Energy Storage
Thermal Storage for Concentrating Solar Power (CSP)	$8.6M	• Phase Change Materials (high temperature) and integration with Stirling engine systems • Phase Change Materials (low temperature) • Solid Thermal Storage Media

Office of Science – Basic Energy Sciences

Significant advances in our scientific understanding of the physical and chemical phenomena underpinning the properties of batteries, fuel cells, and supercapacitors are needed to develop cost-competitive electrical storage solutions that have long lifetimes, high power and energy densities, short charge/discharge times, and appropriate physical characteristics to match the requirements of storage applications. The Basic Energy Sciences (BES) workshop on Basic Research Needs for Electrical Energy Storage in April 2007[13] identified key basic research areas requiring progress if advanced energy storage technologies are to be realized in the future,

[13] http://www.er.doe.gov/bes/reports/abstracts.html#EES

including: (1) Novel designs and strategies for chemical energy storage, (2) Solid-electrolyte interfaces and interphases, (3) Capacitive energy storage materials by design, (4) Electrolyte interactions in capacitive energy storage, (5) Multifunctional materials for pseudocapacitors and hybrid devices, and (6) Theory and modeling. A few of the potential research opportunities are:

- Many fundamental performance limitations of energy storage systems are rooted in the constituent materials of the storage system. Hence, novel approaches are needed to develop multifunctional materials that offer new self-healing, self-regulating, failure-tolerant, impurity-sequestering, and sustainable characteristics. For example, the discovery of novel nanoscale materials with tailored frameworks offers particularly exciting possibilities for the development of revolutionary three-dimensional architectures that simultaneously optimize ion and electron transport and capacity.
- New capabilities are also needed to "observe" dynamic composition and structure at an electrode surface, in real time, during charge transport and transfer processes. New *in situ* photon- and particle-based microscopic, spectroscopic and scattering techniques with time resolution down to the femtosecond range and spatial resolution spanning the atomic and mesoscopic scales are needed to meet this challenge.
- Predictive knowledge of structural and functional relationships formed from multiscale integration of theory-based methods at different time and length scales can effectively complement experimental efforts to provide insight into mechanisms, predict trends and identify new materials.

Through the Recovery Act, BES has significantly increased funding in these research areas with the initiation of six Energy Frontier Research Centers (EFRCs) directly related to energy storage. EFRCs are small groups of researchers focused on breakthroughs in science. They are mostly university-led teams working to solve the specific scientific problems that are blocking clean energy and storage technology development[14].

With a five year commitment and budget total of $90M for the six storage related EFRCs, the Centers represent a significant and sustained effort by BES to address the scientific needs identified in the Basic Research Needs report. Ongoing coordination activities with the DOE technology offices, ARPA-E, and the grid storage working group maintain awareness across DOE of the research outcomes. The six EFRCs most closely focused on energy storage issues are:

Center for Electrical Energy Storage: Tailored Interfaces

Argonne National Laboratory; Michael Thackeray, Director

Objective: To understand complex phenomena in electrochemical reactions critical to advanced electrical energy storage.

Science of Precision Multifunctional Nanostructures for Electrical Energy Storage

[14] A list of all 46 funded EFRCs can be found here: http://www.sc.doe.gov/bes/EFRC/index.html

University of Maryland; Gary Rubloff, Director
Objective: To understand and build nano-structured electrode components as the foundation for new electrical energy storage technologies.

Nanostructured Interfaces for Energy Generation, Conversion, and Storage
Cornell University; Hector Abruna, Director
Objective: To understand and control the nature, structure, and dynamics of reactions at electrodes in fuel cells, batteries, solar photovolataics, and catalysts.

Center for Innovative Energy Storage
General Electric Global Research; Grigorii Soloveichik, Director
Objective: To explore the fundamental chemistry needed for an entirely new approach to energy storage that combines the best properties of a fuel cell and a flow battery.

Northeastern Chemical Energy Storage Center
State University of New York, Stony Brook; Clare P. Grey, Director
Objective: To understand how fundamental chemical reactions occur at electrodes and to use that knowledge to design new chemical energy storage systems.

Science Based Nano-Structure Design and Synthesis of Heterogeneous Functional Materials for Energy Systems
University of South Carolina; Kenneth Reifsnider, Director
Objective: To build a scientific basis for bridging the gap between making nano-structured materials and understanding how they function in a variety of energy applications.

In addition to EFRCs, the DOE has recently developed a complementary funding mechanism in Energy Innovation Hubs. Hubs are large, multi-disciplinary, highly-collaborative teams of scientists and engineers working over a longer time frame[15] to achieve a specific high priority goal. They are led by top researchers with the knowledge, resources, and authority to nimbly guide efforts, seizing new opportunities or closing off unproductive lines of research. In FY 2011 BES is proposing to lead the development of an Energy Innovation Hub on Batteries and Energy Storage. Key scientific questions to be addressed by the Hub include:

- *How can we approach theoretical energy densities?*
- *How do we increase safe storage capacity, power density and the rate of energy utilization?*
- *Cycle life: Can we create a perfectly reversible system?*

[15] If renewed, Hub funding can last for up to 10 years

Coordination of Department Activities

From fundamental research to technology demonstration and commercialization, the DOE is pursuing a comprehensive and diversified portfolio of grid storage related activities. Recent funding through the Recovery Act has provided an unprecedented opportunity to advance the breadth and depth of storage activity at the Department; in some areas funding and activities have increased more than 40-fold.

The increased activity is being coordinated by a new grid-storage working group, convened by the Under Secretary for Energy and consisting of a mix of senior leadership and technology experts from all programs and offices conducting storage-relevant work across the Department. SC, EERE, OE, Advanced Research Projects Agency – Energy (ARPA-E), and the offices of both the Under Secretaries for Energy and Science actively participate in this group, and for the first time an ongoing dialogue with a specific focus on storage has been established across all these groups. On a regular basis concerns ranging from electrode chemistry to systems analysis are shared, and as this working group matures collaboration across the Department is assured.

Energy storage also presents an opportunity to affect the reliability, quality, security, and economics of the grid, yet current grid models fail to capture the complete set of operational and financial implications for integrated storage technologies. A significant barrier to deployment of grid energy storage technologies continues to be uncertainty around the *in situ* performance characteristics and value[16] of the installations now and as the grid changes. Storage technology demonstration projects currently underway and funded by the Recovery Act will contribute significantly to the operational understanding of grid integrated storage, but grid models and planning tools must be developed to a point where the forthcoming wealth of operational data can be fully accommodated in grid planning, state estimation and contingency models. To address this OE is developing a plan to improve grid system models, and a workshop on the topic will be held in FY 2010.

[16] The Federal Energy Regulatory Commission classifies grid integrated storage as either a generation or transmission asset, but does not allow for revenue from both applications despite the capability of some storage technologies to serve both functions.

Appendix A

Office of Electricity Delivery and Reliability
Grid-Scale Storage Demonstration Project Descriptions

	Applicant	Demo State(s)	Storage Capacity	Storage Technology Provider		Gov Share ($M)	Total Project Cost ($M)	Description
2.1	**Battery Storage for Utility Load Shifting or for Wind Farm Diurnal Operations and Ramping Control**							
	Southern California Edison Company	CA	8MW	A123	Southern California Edison	25.0	53.5	Tehachapi Wind Energy Storage Project - Deploy and evaluate an 8 MW utility-scale lithium-ion battery technology to improve grid performance and aid in the integration of wind generation into the electric supply.
	Primus Power	CA	25MW	Primus Power	PG&E	14	46.7	Wind Firming EnergyFarm™- Deploy a 25 MW - 75 MWh EnergyFarm for the Modesto Irrigation District in California's Central Valley, replacing a planned $78M / 50 MW fossil fuel plant to compensate for the variable nature of wind energy providing the District with the ability to shift on-peak energy use to off-peak periods.
	Duke Energy Business Services, LLC	TX	20MW (5 plus 15)	TBD	Duke Energy	21.8	43.6	Notrees Wind Storage - Deploy a wind energy storage demonstration project at the Notrees Windpower Project in western Texas. The project will demonstrate how energy storage and power storage technologies can help wind power systems address intermittency issues by building a 20 megawatt (MW) hybrid-energy storage system capable of optimizing the flow of energy.
2.2	**Frequency Regulation Ancillary Services**							
	Beacon Power Corporation	IL	20MW	Beacon	PJM Interconnecti on	24.1	48.1	Beacon Power 20MW Flywheel Frequency Regulation Plant -- Chicago, IL - Design, build, test, commission, and operate a utility-scale 20 MW flywheel energy storage frequency regulation plant in Chicago, Illinois, and provide frequency regulation services to the grid operator, the PJM Interconnection. The project will also demonstrate the technical, cost and environmental advantages of fast response flywheel-based frequency regulation management.

	East Penn Manufacturing Co.	PA	3MW	East Penn	First Energy, PJM Interconnecti on	2.2	4.5	Grid-Scale Energy Storage Demonstration for Ancillary Services Using the UltraBattery Technology - Demonstrate the economic and technical viability of a 3MW grid-scale, advanced energy storage system using the lead-carbon UltraBattery technology to regulate frequency and manage energy demand.
	Public Service Company of New Mexico	NM	2.8MWh	Premium Power	Public Service Company of New Mexico	1.8	5.9	PV Plus Storage for Simultaneous Voltage Smoothing and Peak Shifting - Demonstrate how a 2.8MWh Zinc-Bromine flow battery along with a sophisticated control system turns a 500kW solar PV installation. into a reliable, dispatchable distributed generation resource. This hybrid resource will mitigate fluctuations in voltage normally caused by intermittent sources such as PV and wind and simultaneously store more energy for later use when customer demand peaks.
	The Detroit Edison Company	MI	1.5MW	A123	Detroit Edison	5.0	10.9	Detroit Edison's Advanced Implementation of A123s Community Energy Storage Systems for Grid Support - Demonstrate the use and benefits of Community Energy Storage (CES) systems for utilities and test the ability to integrate secondary-use electric vehicle batteries as part of the CES demonstration. This project will install 20 CES units, 25kW/2hr each, into a system that includes a 1 MW storage device integrated into a solar system.
	City of Painesville	OH	1MW	VRB	Painesville Municipal Power	3.7	7.5	Painesville Municipal Power Vanadium Redox Battery Demonstration Program - Demonstrate 1 MW vanadium redox battery (VRB) storage system at the 32 MW municipal coal fired power plant in Painesville. The project will provide operating data and experience to help the plant maintain its daily power output requirement more efficiently while reducing its carbon footprint.

	Premium Power Corporation	CA/NY/MA		Premium Power	National Grid, SMUD	7.3	16.1	Premium Power Distributed Energy Storage System Demonstration for National Grid and Sacramento Municipal Utility District - Demonstrate competitively-priced, multi-megawatt, long-duration advanced flow batteries for utility grid applications. This three-year project incorporates engineering of fleet control, manufacturing and installation of seven 500-kW/6-hour TransFlow 2000 energy storage systems in California, Massachusetts, and New York to lower peak energy demand and reduce the costs of power interruptions.
2.4	**Compressed Air Energy Storage (CAES)**							
	New York State Electric & Gas Corporation	NY	150MW	CAES	New York State Electric & Gas (NYSEG)	29.6	125.0	Energy East Advanced CAES Demonstration Plant (150MW) Using an Existing Salt Storage Cavern - Demonstrate an advanced, less costly 150 MW Compressed Air Energy Storage (CAES) technology plant using an existing salt cavern. The project will be designed with an innovative smart grid control system to improve grid reliability and enable the intergration of wind and other intermittent renewable energy sources.
	Pacific Gas & Electric Company	CA	300MW	CAES	PG&E	25.0	356.0	Advanced Underground CAES Demonstration Project Using a Saline Porous Rock Formation as the Storage Reservoir - Build and validate the design, performance, and reliability of an advanced, underground 300 MW Compressed Air Energy Storage (CAES) plant using a saline porous rock formation located near Bakersfield, CA as the storage reservoir.

2.5	Demonstrations of Promising Energy Storage Technologies							
	Seeo, Inc	CA	<100kW	Seeos		6.2	12.4	Solid State Batteries for Grid-Scale Energy Storage - Develop and deploy a 25kWh prototype battery system based on Seeo's proprietary nanostructured polymer electrolytes. This new class of advanced lithium-ion rechargeable battery will demonstrate the substantial improvements offered by solid state lithium-ion technologies for energy density, battery life, safety, and cost. These batteries would be targeted for utility-scale operations, particularly Community Energy Storage projects.
	44 Tech Inc.	PA	10-100kWh	44 Tech Inc.		5.0	10.0	Demonstration of Sodium Ion Battery for Grid Level Applications - Partner with Carnegie Mellon University to demonstrate a new, low cost, long-life, highly efficient, environmentally friendly, stationary energy storage battery that uses a proven and fully novel cell chemistry. Specifically, an aqueous sodium-ion based electrolyte is used in conjunction with simple highly scalable electrode materials housed in low cost packaging.
	SustainX, Inc.	TBD	1MW	SustainX, Inc.		5.4	10.8	Demonstration of Isothermal Compressed Air Energy Storage to Support Renewable Energy Production - Design, build, and deploy a utility-scale, low-cost compressed air energy storage system to support the integration of renewable energy sources onto the grid. The 1 MW/4hr system will store potential energy in the form of compressed air in above-ground industrial pressure facilities. The technology utilizes isothermal gas cycling coupled with staged hydraulic compression and expansion to deliver an efficient and cost-effective energy storage solution.

	Amber Kinetics, Inc.	CA	5MW	Amber Kinetics, Inc.		4.0	10.0	Amber Kinetics Flywheel Energy Storage Demonstration - Develop and demonstrate an innovative flywheel technology for use in grid-connected, low-cost bulk energy storage applications. This demonstration effort, which partners with Lawrence Livermore NationalLaboratory, will improve on traditional flywheel systems, resulting in higher efficiency and cost reductions that will be competitive with pumped hydro technologies.
	Ktech Corporation	CA	250kW	EnerVault		4.8	9.5	Flow Battery Solution for Smart Grid Renewable Energy Applications - Demonstrate a prototype flow battery system that can be grid connected, charged and discharged, and scaled to utility power levels. The project will combine a proven redox flow battery chemistry with a unique, patented design to yield an energy storage system that meets the combined safety, reliability, and cost requirements for distributed energy storage.

Appendix B

Advanced Research Projects Agency – Energy
Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)

These projects have been selected for negotiation of awards under the ARPA-E GRIDS program; final award amounts may vary.

Lead Research Organization (Partner Organizations)	**Amount**	**Lead Organization Location** (City, State)	***Technology Focus – Application: Project Title*** **Project Description**
Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)			
ABB Inc (Brookhaven National Laboratory, Super Power Inc.)	$4,200,000	Raleigh, NC	*Superconducting Magnetic Energy Storage (SMES): Superconducting Magnet Energy Storage System with Direct Power Electronics Interface* ABB will lead a team developing an advanced superconducting magnetic energy storage (SMES) device. SMES is a novel technology that stores electricity from the grid in the magnetic field of a coiled wire with near-zero loss of energy. The proposed device will have instantaneous response and nearly infinite cycle life. If the high-risk breakthrough technologies in this project are successfully developed, the result will advance SMES from a high-cost solution for delivering short bursts of energy to a technology that is cost-competitive for delivering megawatt hours of stored electricity.
Beacon (Imlach Consulting Engineering, IONICORP)	$2,250,000	Wilmington, MA	*Flywheel: Development of a 100 kWh/100 kW Flywheel Energy Storage Module* Beacon Power will lead a team in developing a next generation flywheel energy-storage technology. In a flywheel system, electricity is stored as kinetic energy in a spinning wheel. The proposed flywheel could store four times more energy than current flywheels at 1/8th the cost. It employs a radically new "flying ring" design that is capable of accepting and delivering energy over 40,000 times during its 20-year lifetime. The proposed technology is ideal for simultaneously addressing both the renewable ramping challenge and other grid-storage applications.
Boeing	$2,264,136	Huntington Beach, CA	*Flywheel: Low-Cost, High-Energy Density Flywheel Storage Grid Demonstration* In this project, Boeing will develop a high-risk materials technology for low-cost, high energy-density flywheel energy-storage. In a flywheel, electricity is stored as kinetic energy in a spinning wheel. While flywheels are currently used for short-duration energy storage, this project will make possible a dramatic increase the energy density of the flywheel for longer-duration applications including renewable energy ramping. To increase energy density, Boeing will develop a

Lead Research Organization (Partner Organizations)	**Amount**	**Lead Organization Location** (City, State)	***Technology Focus – Application: Project Title*** **Project Description**
			new fiber material that allows the flywheel to spin at higher speeds without breaking. The resulting high energy density material will be enable subsequent scaling to utility-size and amenable to factory production at low cost.
CUNY Energy Institute (RBC, ULBI, CUNY)	$3,000,000	New York, NY	*Battery: Low-cost Grid-Scale Electrical Storage using a Flow-Assisted Rechargeable Zinc-Manganese Oxide Battery* In this project, the CUNY Energy Institute, in partnership with Rechargeable Battery Corporation (RBC) and the Ultralife Corporation, will develop a novel battery that radically transforms the chemistry and low-cost materials found in disposable consumer-grade alkaline batteries into a long-lasting, fully-rechargeable energy storage system. While CUNY has already demonstrated some of the basic scientific principles, work in this high-risk project will achieve a rechargeable battery system that lasts for over ten years, costs under $100/kWh, demonstrating potential for use on the electricity grid.
Fluidic Energy, Inc.	$3,000,000	Tempe, AZ	*Battery: Enhanced Metal-Air Energy Storage System with Advanced Grid-Interoperable Power Electronics Enabling Scalability and Ultra-Low Cost* Fluidic Energy will develop an advanced multi-functional energy storage (AMES) battery prototype. This is a high-risk technology which, if successful, will enable a highly scalable energy storage system well suited for supporting intermittent renewable resources (solar, wind) on the electric grid. The novel battery chemistry will overcome traditional electricity storage challenges of limited re-chargeability, low power density, and poor efficiency. This low-cost battery technology will be based exclusively on domestically-available, earth abundant active materials. A partnership with Satcon and Chevron Energy Solutions will ensure this project translates rapidly to products supporting renewable generation on the grid.
General Atomics (UC San Diego)	$1,986,308	San Diego, CA	*Flow Battery: GRIDS Soluble Lead Flow Battery Technology* General Atomics and the University of California San Diego will develop a novel flow battery technology, which pumps chemicals through the battery cell when electricity is needed. The proposed flow battery revolutionizes a century-old lead-acid battery technology to achieve low cost, high efficiency and reliability needed for use on the electric power grid. This high-risk technology development program will use novel materials that greatly increase power while resisting the corrosion that limits the cycle life of conventional lead acid batteries. These innovations will result in a battery that can be scaled for grid-scale energy storage, but which costs less and performs far longer than today's technologies.
General Compression	$750,000	Newton, MA	*Compressed Air Energy Storage (CAES): Fuel-Free, Ubiquitous, Compressed Air Energy Storage and Power Conditioning* General Compression will lead a team investigating a novel

Lead Research Organization (Partner Organizations)	**Amount**	**Lead Organization Location** (City, State)	***Technology Focus – Application: Project Title*** **Project Description**
			compressed air energy storage process (GCAES™) that is highly efficient and requires no fossil fuel. In this project, a team of industry and academic researchers will show the potential for a near-isothermal CAES unit, which could result in an energy storage technology with high round-trip electrical efficiency and fast response times. Unlike conventional CAES installations, no fuel will be burned in the expansion stage of the process, dramatically reducing emissions and operating costs. Once successfully developed, the GCAES™ can accelerate the integration of renewable electricity generation, particularly wind, into the grid.
Lawrence Berkeley National Laboratory (DuPont, Bosch, 3M, and Proton Energy)	$1,592,730	Berkeley, CA	*Flow Battery: Hydrogen-Bromine Flow Batteries for Grid-Scale Energy Storage* Lawrence Berkeley National Laboratory and its team of industrial partners (DuPont, Bosch, 3M, and Proton Energy) will develop a novel flow-battery system for grid applications. Flow batteries pump reactive chemicals through the battery cell when electricity is needed; this project's battery will use hydrogen and bromine as its active materials. While this type of flow battery has existed for decades, it has been plagued by high costs, short lifetimes, and safety concerns. In this project, the LBNL team will apply unique technical approaches to address these challenges, and will deliver a proof-of-concept cell that will demonstrate the potential of this chemistry in grid-scale energy storage applications.
Primus Power	$2,000,000	Alameda, CA	*Flow Battery: Low-Cost, High Performance 50 Year Electrodes* Primus Power will develop new durable, inexpensive metal electrodes for flow batteries for energy storage on the electric grid. Electrodes are a key component of flow batteries, which pump reactive chemicals through the battery cell when electricity is needed. Flow batteries are potentially ideal for electric grid storage applications, but are often limited by the high cost and poor durability of the electrodes. In this project, Primus Power will leverage processes developed for other chemical industries to develop novel, low-cost metallic flow battery electrodes. If successful, the result will be a 5X decrease in costs while simultaneously doubling the power density of the energy storage system.
Proton Energy (Penn State University)	$2,148,719	Wallingford, CT	*Fuel Cell: Transformative Renewable Energy Storage Devices Based on Neutral Water* Proton Energy and Penn State University will develop an advanced energy storage device that incorporates a regenerative fuel cell. Like batteries, fuel cells use chemical reactions to produce electricity. Many fuel cells require expensive precious metals such as platinum to operate. In this novel design, a unique component will be developed that allows the fuel cell to operate without significant use of precious metals. This innovation will dramatically reduce cost, and enable the economical use of this fuel cell system for electricity

Lead Research Organization (Partner Organizations)	**Amount**	**Lead Organization Location** (City, State)	***Technology Focus – Application: Project Title*** **Project Description**
			storage on the grid.
United Technologies Research Center (University of Texas, Clipper Windpower, Pratt & Whitney, Sandia National Labs)	$3,000,000	Farmington, CT	*Flow Battery: Transformative Electrochemical Flow Storage System (TEFSS)* United Technologies Research Center (UTRC), in partnership with the University of Texas and Sandia National Laboratory, will develop a novel flow battery, a type of battery system that pumps reactive chemicals through the battery cell when electricity is needed. The proposed flow battery uses a unique design to deliver 10X more power than conventional flow batteries. This breakthrough will enable a dramatic reduction in the size and cost of the flow battery. The advanced prototype flow battery developed in this program will provide energy storage at 1/3 the cost of current flow battery systems, and will lay the technical foundation for commercially-available grid-scale energy storage solution.
University of Southern California (Jet Propulsion Laboratory (JPL))	$1,459,324	Los Angeles, CA	*Battery: A Robust and Inexpensive Iron-Air* *Rechargeable Battery for Grid-Scale Energy Storage* Researchers at the University of Southern California and NASA's Jet Propulsion Laboratory will team to develop a high-performance rechargeable battery for large-scale energy storage on the electricity grid. Iron air batteries have the potential to store large amounts of energy inexpensively since they rely on extremely low-cost materials: iron, which costs less than $.20/pound, and oxygen which is free in ambient air. Although, existing iron-air batteries have suffered from low energy efficiency and poor cycle life, in this high-risk technology development project, novel approaches will be tested, including new materials and structures to increase battery efficiency and cycle-life. This project will develop an iron-air proof of concept battery, the first step in the commercialization of this promising, low-cost battery chemistry.

Appendix C

Office of Energy Efficiency and Renewable Energy Storage Project Descriptions

Project Title and Description	Technology	FY 2010 Budget
National Hydropower Assessment Conducting geospatial, hydrologic, and environmental surveying and modeling, as part of the Program's National Hydropower Asset Assessment Program,	Pumped Hydro	$1.525M
Pumped Storage Resource Assessment Conducting Resource Assessments through ORNL and INL to estimate the potential for further deployment of pumped storage facilities in the US.	Pumped Hydro	$1M
EPRI Grid Services Study Funding a study through the Electric Power Research Institute (EPRI) to quantify the value of existing ancillary services provided by hydropower and pumped storage facilities, including frequency regulation, load following and spinning reserve.	Pumped Hydro	$2.4M
Battery Development Contracts (9 cost shared contracts) Research and development to address abuse tolerance, low-temperature performance, life, and cost	Batteries, capacitors *Mobile Platform*	$13.75M
Industrial Material Supplier Contracts (9 cost shared contracts) Research and development to improve battery materials	Batteries, capacitors	$11M
Battery Performance and Abuse Testing & Analysis Research tests hardware against manufacturers' specifications and the most applicable technical targets and benchmarks	Batteries, capacitors *Mobile Platform*	$8.25M
Laboratory & University Next Generation Battery Materials R&D (61 projects) Investigates new and promising materials, provides a better understanding of why systems fail, and develops models to predict system failure and enable system optimization	Batteries, capacitors *Mobile Platform*	$35.75M
Small Business Innovative Research Grants Research and development on novel materials and integrated systems for batteries and capacitors	Batteries, capacitors *Mobile Platform*	$2.25M
New Vehicle Technology Program Funding Solicitation Additional research and development to address abuse tolerance, low-temperature performance, life, and cost	Batteries, capacitors *Mobile Platform*	$5.0M
SEGIS (Solar Energy Grid Integration Systems) Research and development of critical enabling technologies for solar photovoltaic systems and associated energy storage, including charge controllers, communication architecture and "shared" multi-residence power inverters	Batteries, capacitors	$11.8M
Wind- and Solar-to-Hydrogen demonstration system to store energy generated by wind turbines and photovoltaics as hydrogen, using a combustion turbine or fuel cell to convert hydrogen back to electricity, assessing performance and improving energy capture	Hydrogen	$2.1M

Project Title and Description	Technology	FY 2010 Budget
Lifecycle Cost Analysis of Hydrogen Versus Other Technologies for Energy Storage DOE funded this study to compare costs of various storage technologies.	Hydrogen	$0.2M
Molten Salt R&D Materials research to find new molten salt formulations; Designing, construction, and testing of improved heat transfer fluids and system components that can withstand high temperatures	Thermal Storage for Concentrating Solar Power Plants	$3.1M
Phase Change Materials (high temperature) Research and devlopment of novel phase change materials; Integration of thermal energy storage with a stirling engine system to reduce susceptibility to transiet clouds and improve dispatchability after sunset	Thermal Storage for Concentrating Solar Power Plants	$2.6M
Solid Thermal Storage Media Research and development of solid thermal storage media with tailored heat-transfer fluids	Thermal Storage for Concentrating Solar Power Plants	$1.8M
Phase Change Materials (low temperature) Research and Development to improve performance and develop fire-resistive PCM to meet residential fire codes	Thermal Storage for Buildings	$1.1M