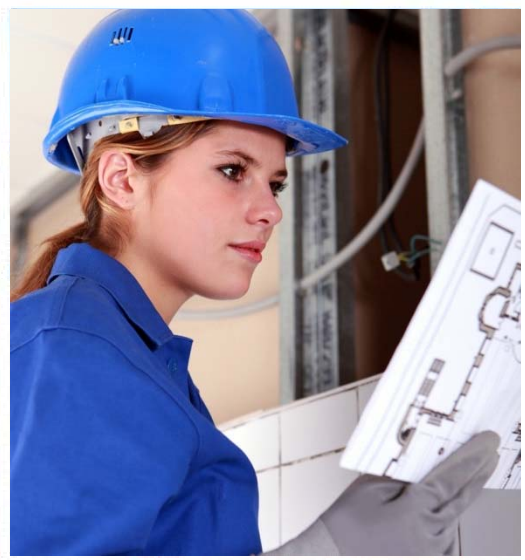
2014 Storage Plan Assessment Recommendations for the U.S. Department of Energy

A Report by:
The Electricity Advisory Committee
September 2014



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ELECTRICITY ADVISORY COMMITTEE

ELECTRICITY ADVISORY COMMITTEE MISSION

The mission of the Electricity Advisory Committee is to provide advice to the U.S. Department of Energy in implementing the Energy Policy Act of 2005, executing the Energy Independence and Security Act of 2007, and modernizing the nation's electricity delivery infrastructure.

ELECTRICITY ADVISORY COMMITTEE GOALS

The goals of the Electricity Advisory Committee are to provide advice on:

- **Electricity policy issues pertaining to the U.S. of Energy**
- **Recommendations concerning U.S. Department of Energy electricity programs and initiatives**
- **Issues related to current and future capacity of the electricity delivery system (generation, transmission, and distribution, regionally and nationally)**
- Coordination **between the U.S. Department of Energy, state, and regional officials and the private sector on matters affecting electricity supply, demand, and reliability**
- **Coordination between federal, state, and utility industry authorities that are required to cope with supply disruptions or other emergencies related to electricity generation, transmission, and distribution**

ENERGY INDEPENDENCE AND SECURITY ACT OF 2007

The Energy Storage Technologies Subcommittee of the Electricity Advisory Committee was established in March 2008 in response to Title VI, Section 641(e) of the Energy Independence and Security Act of 2007 (EISA).

Section 641(e)(4) stipulates that "No later than one year after the date of enactment of the EISA and every five years thereafter, the Council [i.e., the Energy Storage Technologies Subcommittee, through the Electricity Advisory Committee], in conjunction with the Secretary, shall develop a five-year plan for integrating basic and applied research so that the United States retains a globally competitive domestic energy storage industry for electric drive vehicles, stationary applications, and electricity transmission and distribution."

EISA Section 641(e)(5) states that "the Council shall (A) assess, every two years, the performance of the Department in meeting the goals of the plans developed under paragraph (4); and (B) make specific recommendations to the Secretary on programs or activities that should be established or terminated to meet those goals."

This report fulfills requirements of the biennial assessment outlined in EISA Title VI, Section 641(e)(5) above.

2014 Storage Plan Assessment

September 2014

More Information about the EAC in Available at:
http://energy.gov/oe/services/electricity-advisory-committee-eac

Letter from the Chair

September 2014

On behalf of the members of the Electricity Advisory Committee (EAC), I am pleased to provide the U.S. Department of Energy (DOE) with this report, "2014 Storage Plan Assessment." This report summarizes a review of DOE's energy storage program strategies and activities, and includes recommendations that the Electricity Advisory Committee (EAC) offers for the DOE's consideration as it continues to develop and implement its energy storage program, as authorized by the Energy Independence and Security Act of 2007.

These recommendations were developed through a systematic process undertaken in 2014 by the EAC. The members of the EAC represent a broad cross-section of experts in the electric power delivery arena, including representatives from industry, public interest groups, utilities, and state government. I want to especially thank Merwin Brown, Co-Director of Electric Grid Research at the California Institute for Energy and Environment at the University of California, for his leadership as Chair of the EAC Energy Storage Technologies Subcommittee and to the EAC members who served on the Subcommittee. Thanks also go to Patricia Hoffman, Assistant Secretary for Electricity Delivery and Energy Reliability, U.S. Department of Energy, Matthew Rosenbaum DOE Office of Electricity Delivery and Energy Reliability and Designated Federal Officer of the Electricity Advisory Committee, and to David Meyer, Senior Policy Advisor, DOE Office of Electricity Delivery and Energy Reliability.

The members of the EAC recognize the vital role that the DOE can play in modernizing the nation's electric grid. The EAC looks forward to continuing to support DOE as it develops and deploys energy storage technologies, policies, and programs to help ensure an effective, resilient, 21st century electric power system. This report fulfills the requirements in Section 641(e)(5) of the Energy Independence and Security Act of 2007.

Sincerely,

Richard Cowart, Chair
Electricity Advisory Committee

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Contents

Executive Summary

This report fulfills a requirement of the Energy Independence and Security Act of 2007 (EISA) Section 641(e)(5) that directs the Council, i.e., The Energy Storage Technologies Subcommittee, through the Electricity Advisory Committee, to prepare a report that does the following:

- Assess, every two years, the performance of the Department in meeting the goals of the five-year plan developed by the Committee in conjunction with the Secretary for integrating basic and applied research so that the United States retains a globally competitive domestic energy storage industry for electric drive vehicles, stationary applications, and electricity transmission and distribution.
- Make specific recommendations to the Secretary on programs or activities that should be established or terminated to meet those goals.

In 2012 the EAC conducted its previous review of DOE's energy storage program and activities.[1] The focus of that review was largely on the energy storage program and activities of the Office of Electricity Delivery and Energy Reliability (OE). For its 2014 review, the EAC continues to focus on the programs and initiatives of OE, but has expanded its scope to also include additional DOE offices, namely, Office of Science, Energy Efficiency and Renewable Energy (EERE), and Advanced Research Projects – Energy (ARPA-E), and also other federal agencies such as the Department of Defense (DOD). This expanded scope is in line with the scope of agencies included in the recent overall departmental strategy laid out in a DOE report entitled "Grid Energy Storage" in December 2013 (referred to hereafter as the "DOE 2013 Report").[2] The EAC applauds this broadening of agency and department inclusion. Accordingly the DOE 2013 Report also provided the documentation for the latest DOE energy storage overall strategy, as well as department-level strategies, on which this 2014 review is based. Note that, while the DOE 2013 Report contains many kinds of energy storage technologies, including thermal energy storage, the focus of this assessment was limited to electricity energy storage, which can be characterized as "electricity-in, electricity-out." Accordingly, the recommendations were formed to address electricity energy storage as described above, but might apply to other forms of energy storage technologies as well.

The EAC review of the federal energy storage program strategies and activities has found the program to be comprehensive and largely responsive to the needs of U.S. industry and public agencies. Despite these successes however, the EAC offers several areas where programs and initiatives could be amended, refocused, augmented or scaled back in order to better meet the objective of the Department and the strategic goals enumerated in the 2013 DOE Report. What follows below is a short synopsis of the Committee's recommendations.

The DOE strategic goals are very clearly tied to grid related applications. However, the portfolio of research funded through the Office of Science as well as through the National Science Foundation seems to be focused more on the basic sciences and component technologies rather than the integration with the grid. Given the scope of needs for meeting the goals set forth in the 2013 DOE Report, more grid-focused research support is needed through these or other venues. In a related manner, the EAC recommends that the goals of the storage program be broadened to include some additional issues energy storage might

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[1] Electricity Advisory Committee, 2012 Storage Report: Progress and Prospects. Recommendations for the U.S. Department of Energy," October 2012. Available at: http://energy.gov/oe/downloads/eac-2012-storage-report-progress-and-prospects-recommendations-department-energy

[2] U.S. Department of Energy, "Grid Energy Storage," December 2013. http://energy.gov/oe/downloads/grid-energy-storage-december-2013

address, e.g., increasing grid asset utilization and operations economic optimization.

Despite the success and importance of ARRA storage projects, it is not clear there is a capacity to continue funding such activities after the ARRA funds are expended. Yet the strategic goal of more storage is unlikely to be met without similar demonstration projects. The EAC recommends that similar demonstration projects continue with some level of continued funding from coordinated public (federal and state) and private sources. In a similar vein, several of the National Laboratories are very involved in storage research, and it would seem that more public-private partnerships could help leverage synergies across these research activities. In addition, the EAC recommends that the DOE conduct a parametric cost benefit analysis of the ARRA demonstration projects in order to enhance the value derived from these investments.

Although the different offices in DOE seem to collaborate and understand each other's projects, it is not clear how research is handed over from the successful basic research projects to the applications research projects to deployment/demonstration along the technology readiness path. The EAC recommends that inter-agency coordination around energy storage be made more transparent and that such coordination be augmented and strengthened.

In the years since the EAC's previous assessment and even since the period in which DOE developed the DOE 2013 Report, U.S. energy industry and policy expectations and strategies for the development and deployment of energy storage devices and systems have changed. The emergence of market transformations, public policy developments and technology trends related both to the U.S. energy storage industry specifically and global market trends more generally, have begun to shift the energy storage landscape. While many of these trends affect, or reflect, "utility-scale" energy storage development and deployment, perhaps the most recent and potentially significant trend is in the identification of emerging of applications for distributed energy storage. These shifts were especially evident in the presentations delivered to the EAC at its June 2014 meeting during an expert panel on distributed energy storage.[3] To the extent that the Department continues to fund research and analysis on storage applications and costs, the EAC recommends that applications for storage interconnecting at the distribution level should be an area of increased focus.

A number of policy-driven events such as the American Recovery and Reinvestment Act (ARRA) and the AB 2514 legislation and subsequent regulatory decisions in California,[4] as well as commercial projects and ventures, have accelerated trends in deploying grid-connected energy storage demonstration at the utility- and distributed-scales. These experiences have revealed inadequacies in the availability of tools, especially those based on non-deterministic models that can, for example, account for the effects of market and system uncertainties. Such tools could lead to improved energy storage operation, resource assessment and decision making. Given that the evolution of the mix of generation resources is hard to predict and in particular, the proportion of renewable generation that is distributed at the low voltage levels versus that

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[3] Electricity Advisory Committee Meeting Presentations June 2014 - Tuesday, June 17, 2014
http://energy.gov/oe/downloads/electricity-advisory-committee-meeting-presentations-june-2014-tuesday-june-17-2014

[4] California Assembly Bill 2514 (2009-2010)
http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200920100AB2514

California Public Utilities Commission (2013) "Decision adopting energy storage procurement framework and design program" Rulemaking 10-12-007
http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M079/K533/79533378.PDF

concentrated at the high voltage transmission levels will vary temporally and regionally, the strategy for storage development, together with the tools mentioned above, must be broad enough to adequately cover any possible generation mix of the future.

These initiatives have also revealed the lack of validated reliability and safety codes and standards. The DOE's model for involvement in codes and standards is on the correct path. The Department should continue to convene planning activities and continue to provide technical support to standards and codes bodies. There is great value in DOE providing their impartial views of the energy storage industry and of proposals submitted to code bodies. DOE's role as neutral arbiter to make clear the rationale behind specific proposals has the potential of greatly increasing the likelihood of successful outcomes.

Pumped hydro (PHS) and compressed air (CAES) energy storage technologies are routinely projected to have high levels of deployment in studies of high renewable penetration scenarios. However, the true deployment potential for these technologies will depend on detailed information that determines whether such technologies can be sited on a widespread basis. New PHS and CAES resource and technology assessments need to be conducted to reflect changes in resource and technology characterization to improve the assumptions used in capacity expansion models used for scenario analysis.

The data, information and tools that DOE provides regarding energy storage technology, costs and systems is of critical importance and a vital resource for the research community and the industry alike. DOE should continue and expand the development of resources such as the 2013 EPRI/DOE Storage Handbook and the DOE Energy Storage Database. One key area where relevant information is lacking is on power electronics costs. A DOE-commissioned effort to produce a time series of power electronics costs and learning rates would greatly inform the work currently being undertaken in this area.

Today's restructured electricity systems rely on a mixture of competitive markets and traditional cost-of-service regulation markets. This hybrid regulatory design can create inefficiencies, however, for assets, such as storage, that can provide multiple services that straddle the two market classifications. Thus, there is a vital need for comprehensive study of and research on regulatory and market designs and their effects on storage to assist technology developers, device and system vendors, utilities, market managers and regulators.

Grid-connected renewable generation at both the transmission and distribution levels is another growing trend, especially in many states with some sort of public policy incentive mechanisms promoting renewable generation and in some competitive electricity markets as well, that affects energy storage deployment. The importance of renewable integration as a major value proposition for storage development calls for comprehensive study of the implications of different market and regulatory mechanisms on efficiently signaling the value of these services so that the full value of energy storage is considered.

Overview of DOE Programs on Energy Storage and Strategic Goals

The US Department of Energy has a vast array of programs on energy storage spread over its various offices. The technologies covered range from long-existing ones like pumped hydro to recently applied ones like batteries and flywheels to newer ones like capacitors and flow batteries. The research spans from basic sciences like new materials and processes to applied development of prototyping and demonstration of specific technologies. The research can be for short term or long term fruition, and is a mix of low-risk and high-risk.

The DOE overall research plan generally targets two major application areas: transportation and electric grid. Although these are two very large areas, they fall squarely within DOE's statutory authority and can be differentiated from storage research being targeted by say, the Department of Defense (DOD), whose area of interest is the security of their bases.

Of the two areas of transportation and electric grid, the Electricity Advisory Committee is more focused on the electric grid. However, there is significant overlap between the research, both basic and applied, on transportation storage technologies and grid technologies. For example, battery technologies are relevant to both areas but pumped hydro is not. (Similarly, there is overlap with the storage research in other agencies like DOD.)

Moreover, as transportation gets more electrified, which is dependent on the success of transportation storage research, there will be an enormous impact on the grid. The increase in electric load and the change in load pattern brought on by increasing penetration of electric vehicles will put further stress on the grid. Thus, the DOE should further promote coordination in order to better leverage the synergies available in the research taking place across these two application areas.

Given that each DOE Office has its own functions defined by its own goals and strategies, managing and coordinating the overlaps and the gaps in the overall storage research strategy becomes very important. This overall departmental strategy was laid out in a DOE report entitled "Grid Energy Storage" in December 2013 (referred to hereafter as the "DOE 2013 Report").[5] In the following sections, this report is summarized to provide a synopsis of the Department's approach with respect to grid storage.

DOE Energy Storage Strategic Goals

The DOE 2013 Report describes the Department's strategy around energy storage in the following way:

> *The future for energy storage in the U.S. should address the following issues: energy storage technologies should be cost competitive (unsubsidized) with other technologies providing similar services; energy storage should be recognized for its value in providing multiple benefits simultaneously; and ultimately, storage technology should seamlessly integrate with existing systems and sub-systems leading to its ubiquitous deployment.*

The Department's strategic goals for meeting this vision are that (1) energy storage should be a broadly deployable asset for enhancing renewable penetration –specifically to enable storage deployment at high levels of new renewable generation, (2)energy storage should be available to industry and regulators as an effective option to resolve issues of grid resiliency and reliability and (3) energy storage should be a well-accepted contributor to

[5] U.S. Department of Energy, "Grid Energy Storage," December 2013. Available here: http://energy.gov/oe/downloads/grid-energy-storage-december-2013

realization of smart-grid benefits – specifically enabling confident deployment of electric transportation and optimal utilization of demand-side assets. The DOE outlined four key challenges that must be addressed in order to meet these goals:

- **Cost competitive energy storage technology**
- **Validated reliability and safety**
- **Equitable regulatory environment**
- **Industry acceptance**

The Strategy for meeting these four challenges and ultimately reaching these three goals is summarized in the Table 1 below which reproduces the DOE Strategy Summary set forth in the DOE 2013 Report

Table 1 DOE Storage Strategy Summary

Challenge/Goal	Strategy Summary
Cost competitive energy storage technology	• Targeted scientific investigation of fundamental materials, transport processes, and phenomena enabling discovery of new or enhanced storage technologies with increased performance • Materials and systems engineering research to resolve key technology cost and performance challenges of known and emerging storage technologies (including manufacturing) • Seeded technology innovation of new storage concepts • Development of storage technology cost models to guide R&D and assist innovators • Resolution of grid benefits of energy storage to guide technology development and facilitate market penetration
Validated reliability and safety	• R&D programs focused on degradation and failure mechanisms and their mitigation, and accelerated life testing • Development of standard testing protocols and independent testing of prototypic storage devices under accepted utility use cases • Track, document, and make available performance of installed storage systems
Equitable Regulatory Environment	• Collaborative public-private sector characterization and evaluation of grid benefits of storage • Exploration of technology-neutral mechanisms for monetizing grid services provided by storage • Development of industry and regulatory agency-accepted standards for siting, grid integration, procurement, and performance evaluation
Industry acceptance	• Collaborative, co-funded field trials and demonstrations enabling accumulation of experience and evaluation of performance – especially for facilitating renewable integration and enhanced grid resilience • Adaptation of industry-accepted planning and operational tools to accommodate energy storage • Development of storage system design tools for multiple grid services

The Department has developed activities and initiatives to address each of these four challenges. These activities are the subject of much of the observations and recommendations presented in the subsequent sections of this report. A more exhaustive catalog of these activities was provided in Table 8 of the DOE 2013 Report; this table has been reproduced in Appendix A of this report.

The DOE has set both near term and long term targets for storage technologies that are based on both the needs of the industry and realistic for research planning. These include capital cost and levelized cost targets as well as system efficiency and cycle life targets for energy storage technology.

DOE Programs on Energy Storage

Each Office in the DOE performs a different function and thus has different objectives. Figure 1 shows that some offices support more fundamental research while others focus more on demonstration and deployment; some research focuses on high-risk, paradigm-shifting objectives while other work is lower-risk and aimed at more evolutionary goals.

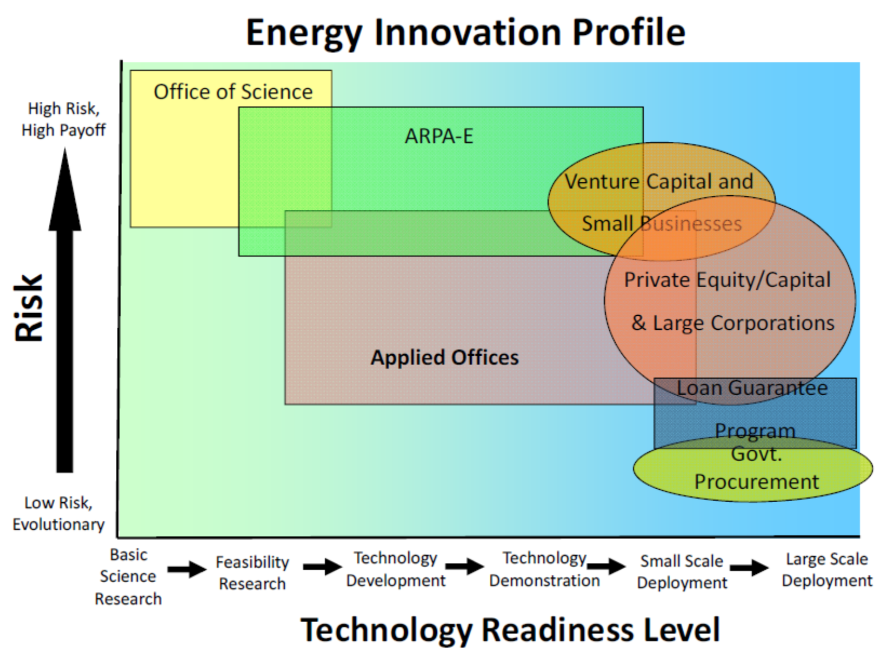

Figure 1 Role of DOE Offices in Technology Development, Maturation and Commercialization

The role of the different DOE offices in energy storage research is summarized in Table 2, which is reproduced from the 2013 DOE Report.

Table 2 Role of DOE Offices in Grid Energy Storage

OFFICE	Role
OE	Energy storage technology research, development, modeling, demonstration and control technologies that can increase the flexibility and resilience of the electrical grid), from the generator to the consumer, thereby allowing for grid integration of a greater diversity of technologies. This includes microgrids with storage, including for emergency preparedness.

EERE	R&D and demonstrations of on-site energy storage technologies that enable penetration of EERE technologies (generation, efficiency, or transportation) into the current system (grid). Additionally, removal of siting and permitting challenges faced by pumped storage deployment and the evaluation of how variable speed pumped storage can provide ancillary services and add to system flexibility.
ARPA-E	High risk R&D to prove & prototype disruptive new energy storage technologies.
SC-BES	Fundamental research to (i) design and develop novel materials and concepts and (ii) probe physical and chemical phenomena associated with electrical energy storage.
LPO	Debt financing of commercial energy projects which include innovative storage technologies.

Below is a brief overview of the current activities and initiatives being undertaken both within DOE and throughout other federal agencies in support of energy storage research, development, demonstration and deployment.

Office of Electricity Delivery and Energy Reliability (OE)

The OE Energy Storage Program is focused on accelerating the development, demonstration and deployment of new and advanced energy storage technologies. The program focuses on technologies that have the potential to improve the stability, reliability, resilience and economics of the future electric grid. This includes the management of intermittent renewable energy resources such as wind and solar power generation. The storage program seeks to improve the cost/benefit ratio of energy storage, provide field validation of first-of-a-kind systems and support modeling and analysis of storage systems and develop tools for utilities and users planning to introduce and us energy storage. It does this through support for work that is focused on storage system research and development, power conversation and grid integration, testing and field demonstrations as well as analytic studies.

Office of Science

The focus of the Office of Science is on basic research and activities including $7.5M/year of funding for small research teams dedicated to research related to material science and novel storage concepts[6] and Energy Frontier Research Centers[7] tackling issues related to battery storage, capacitors and the science underpinning potential storage breakthroughs. It also provides funding for the Joint Center for Energy Storage Research[8], a multidisciplinary research partnership with the goal of developing research prototypes for electrochemical energy storage systems beyond lithium-ion for the grid and transportation.

Energy Efficiency and Renewable Energy (EERE)

The Energy Efficiency and Renewable Energy Office is focused on storage technologies that can be used in buildings, electric vehicles, or to help integrate variable renewable technologies. Currently the work supported by EERE is focused on Sustainable Transportation and Renewable Power generation such as pumped hydro storage. This includes research and development support for battery storage and thermal energy storage as well as testing and field demonstrations and storage modeling and analysis.

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[6] http://science.energy.gov/~/media/bes/pdf/reports/files/ees_rpt.pdf

[7] http://science.energy.gov/bes/efrc

[8] http://www.jcesr.org/

Advanced Research Projects – Energy (ARPA-E)

ARPA-E has had several funding initiatives focused on energy storage and broader technology development around critical grid challenges. These include the Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS) program that focuses on development of low-cost storage technologies for the electric grid, the High Energy Advanced Thermal Storage (HEATS) program which seeks to develop revolutionary, cost-effective ways to store thermal energy and the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program that included four energy storage projects focused on developing low-cost energy storage devices for use on the customer side of the meter.

Department of Defense (DOD)

There are currently programs being run by each branch of the military, as well as jointly with other organizations (e.g., ESTCP/SERDP). Currently, the DOD is running several microgrid scale energy storage projects involving battery technology coupled with renewable and locally fired natural gas plants. These tests each focus on different technology aspects, battery types and chemistries, and battery size (large batteries versus distributed assets). Projects are focused on improving microgrid self-sufficiency (islanding) by improving load management and generation efficiency through the addition of energy storage.

Other Federal Agencies

The National Science Foundation (NSF) has several initiatives (e.g., FREEDM and CURENT Engineering Research Centers, the GOALI Program) in place to support the development of batteries and associated technologies. Other federal agencies involved in the support of energy storage research and development include NASA, EPA and NIST.

Assessment of DOE Goal Implementation

Cost Competitive Energy Storage Technology

Overview of DOE Program Goals

Today's relatively high cost of most storage technologies (compared to conventional alternatives) hinders their widespread use. This is because storage must ultimately compete with other assets (e.g., generation, transmission, and distribution) and policy mechanisms (e.g., demand response). This comparison between storage and other alternatives is sensitive to the upfront cost of building and installing storage systems and other characteristics such as cycle life and device efficiency. At the same time, storage economics are tied to understanding what value the assets can provide, since investments are ultimately made based on cost/benefit determinations. Storage benefits depend on having models that can capture value through optimal operational decisions and on having the analytical capability to translate short-run value capture into long-run cost/benefit assessments. The past few years have seen storage cost reductions and some technologies are moving past the laboratory stage to demonstration and pilot projects. Other, more established, technologies are seeing even greater use, and some commercial niches.

The Department has identified the following five goals to address these challenges to achieving cost competitive storage:

1. Targeted scientific investigation of fundamental materials, transport processes, and phenomena enabling discovery of new or enhanced storage technologies with increased performance;
2. Materials and systems engineering research to resolve key technology cost and performance challenges of known and emerging storage technologies (including manufacturing);
3. Seeded technology innovation of new storage concepts;
4. Development of storage technology cost models to guide R&D and assist innovators; and
5. Resolution of grid benefits of energy storage to guide technology development and facilitate market penetration.

Summary of Activities to Achieve Goals and Successes

To address the cost-parity challenge the Department has identified and focused its efforts on the following eleven specific activities:

1. Advanced redox-flow battery chemistry and component development to utilize lower cost membranes, electrodes, and bi-polar plates; increase energy and power density; develop non-aqueous redox-flow batteries; and bench scale test of potential $250/kW system;
2. Bench demonstration of low temperature sodium batteries with 90% efficiency;
3. Demonstration at relevant scale of secondary use of automotive of Li-ion batteries as safer and longer-lived stationary systems;
4. Bench demonstration of multi-cell Mg-ion batteries for stationary applications;
5. Develop and test high-performance nano-material-based flywheel components;
6. Advanced SiC, GaN, and AlN-based power converters for storage applications;
7. Develop and test new capacitor materials and structures
8. Benefit/cost analysis of storage for grid resilience, emergency response, renewable deployment, and improved asset utilization;
9. Storage cost models to guide R&D and for industry use;

10. Development of design tools for optimally serving multiple applications; and
11. Baseline techno-economic modeling of advanced research impacts; value-proposition development for emerging technology research results; first-market analysis for subsequent technology insertion; partnership formation for direct private sector or other governmental hand-offs.

The department has further focused on the following eight technology-specific research activities:

1. Flywheels: thick cross section carbon fiber composite structure formation; magnetically levitated system research, new nano-structured flywheel and magnet materials;
2. Compressed Air Energy Storage (CAES): proof-of-concept isothermal CAES research;
3. Electrochemical: novel low-cost high-cycle-life anode, cathode, electrolyte, and separator materials and structure research;
4. Flow-Batteries: high-current-density low-cost power modules, long-cycle-life low-cost electrodes, membranes, and catalysts; alkaline exchange membrane electrodes and multi-functional power/energy electrodes; semi-solid flow-able anolyte/catholytes; nanostructured electrode assemblies;
5. Superconductors: low-cost high-temperature superconducting materials; high-field coil configurations;
6. Capacitors: high-surface-area nanostructured ultracapacitors, low-cost, safe, and stable electrolytes and solvents;
7. Power electronics: novel inverter/converter topologies; integrated passive components; high-voltage wide bandgap semiconductor epitaxial materials; and
8. Batteries: low-cost high-energy-density batteries; rechargeable metal-air chemistries; in-situ sensors and control technologies; model predictive cell control algorithms; moldable energy storage structures; multi-functional storage chemistries.

The Department has made a concerted effort to achieve storage cost reduction through targeted research and development on novel materials, chemistries, systems, and engineering. As noted above, these research and development efforts are highly targeted to each storage technology, with ambitious system cost and performance goals set. The Department's efforts in achieving cost competitiveness are further buoyed by its recognition of the need to reduce total “system” costs. Indeed, actual “storage components” can represent only 30-40% of the total cost of a storage system. The Department's directed advanced research on developing novel and low-cost power electronics, power converters, and other components that constitute a large portion of storage system costs can translate into major system cost reductions.

Key Gaps and Recommendations

Despite these successes, there are some key gaps in the Department's strategy toward achieving cost competitiveness between storage and conventional alternatives. We summarize these gaps and make recommendations for how the Department should focus its future efforts below.

Improved Storage Operation and Resource Assessment Tools

Efficient storage development and use are hampered by a lack of decision support tools for industry members. Utilities largely rely on commercial software products for resource assessment and operational planning. Many of these software tools are not well suited to modeling storage for novel applications beyond load leveling. Moreover, storage operators face the challenge of determining how those assets should be used. The flexibility of storage and its ability to provide many services complicates this problem.

For instance, if a storage asset is primarily used for voltage support, but the owner does not anticipate voltage problems on a given day, how should the otherwise-idle asset by used for other applications? This lack of decision support tools places storage at a disadvantage compared to conventional alternatives.

The Department has made some major contributions in providing tools to conduct these types of analyses. Two particular examples are the Energy Storage Computational Tool (available at https://smartgrid.gov/recovery_act/program_impacts/energy_storage_computational_tool) and GridLab-D (available at http://www.gridlabd.org/), which allow users to conduct storage valuations and simulations under a variety of use cases. These tools have some important limitations, however. One is that they are deterministic in nature, and do not account for the effects of market and system uncertainties. This may overstate storage value, since it assumes that the storage operator can optimize operations with perfect foresight of future conditions. On the other hand, system uncertainty can make storage's inherent flexibility more valuable to the system, which would not be captured by a deterministic model. Another limitation of these models is that they require the user to assume what combination of services the storage asset provides. Ideally, a storage asset should be used for whatever combination of services is value maximizing, and this may change diurnally, seasonally, or in a more dynamic manner.

The Department can address this need by supporting the development of advanced models that can better capture the full range of system dynamics and stochastics that may affect storage operations. As noted above, such models are useful for real-time, day-ahead, and medium-term operational planning. Moreover, good operational decisions that maximize value captured are needed to properly value storage assets for cost/benefit analysis and investment evaluation purposes.

PHS and CAES Resource and Technology Assessments

The Department recognizes their renewable-integration role as a key benefit of energy storage technologies. For instance, the Renewable Electricity Futures Study relied on massive storage deployments to economically and reliably serve load with extremely high renewable penetrations (NREL 2012). Given the high power and energy capacities required to temporally shift massive amounts of renewable generation and the costs and capabilities of today's storage technologies, these needs were modeled as largely being met by Pumped Hydroelectric Storage (PHS) and Compressed Air Energy Storage (CAES) systems.

The results and the mix of storage and other technologies built in the simulation were largely driven by assumptions regarding technology costs, capabilities, and availabilities. Specifically, the modeling assumed relatively (compared to other technologies) low PHS and CAES costs and suitable geology to support 35 GW of PHS and 120 GW of CAES. In some cases, these availability assumptions were based on old resource assessments. Given the reality that no new large PHS projects have been built in the United States recently and the only two recent attempts at building CAES plants in the United States (the Iowa Stored Energy Park and Norton Energy Storage) were unsuccessful, an important question is what the true PHS and CAES potential of the United States is.

We recommend that the Department conduct a comprehensive analysis of how much greenfield and brownfield PHS capacity exists in the United States and the cost of developing these resources. Along the same lines, a comprehensive study of how much CAES capacity could be developed in domal salt, bedded salt, porous rock, hard rock formations, and pipelines is equally vital. It would further be beneficial to use the failed development of the Norton Energy Storage project as a case study to understand what other issues (besides geology) are impediments to successful CAES development. Such an analysis was conducted for the Iowa Stored Energy Park (Schulte 2012). These assessments would help gauge whether the Department's assumptions regarding the potential for future PHS and CAES deployment are consistent with what is physically available. Similarly, a comprehensive analysis of why the Norton Energy Storage project failed would help the Department calibrate its assumptions regarding the ability of the market to deliver CAES resources. A detailed analysis of the Norton Energy Storage project may also reveal other (e.g., institutional, regulatory, or market) barriers to CAES development.

Validated Reliability and Safety

The 2013 DOE/EPRI Energy Storage Handbook names the lack of standards as one of the key challenges to adoption of energy storage systems. This point is further underscored in the 2013 DOE report which asserts that "the operational safety of large storage systems is a concern and will be a barrier in their deployment in urban areas or in proximity of other grid resources such as substations." The report goes on to conclude that "design practices that incorporate safety standards and safety testing procedures for the different storage technologies need to be developed and codified."

Standardization provides a solid foundation upon which to develop, demonstrate and deploy technologies as well as to provide a consistent pathway to enhance existing practices regarding the application and operation of technology. Standardized technologies are more apt to be safe, environmentally benign, secure and reliable. In the case of technologies potentially applied to the electric power system, like electric energy storage devices, they are more apt to be able to interoperate with other components of the system. Standardization also usually leads to better cost-effectiveness for a technology, through economies of scale, interoperability, and learning curve effects. Typically, some standardization is a key requirement for the widespread adoption of a technology. Model codes and standards are most typically developed in the voluntary sector, via established standards developing organizations (SDOs). Alternatively, widely accepted guidelines and recommended practices can be developed by ad-hoc groups of stakeholders. Yet, these documents are only useful to the extent they are adopted, cited, and specified. Adoption of model codes and standards by regulatory bodies or by stakeholders including utilities, insurers, financiers, and developers dictates compliance with the code or standard.

Codes and standards are effective provided there is common agreement on key issues such as (1) terminology; (2) areas of application; (3) common specifications; (4) performance criteria; (5) safety; (6) operational procedures; (7) test protocols; and (8) installation, commissioning, and interoperability with the power system.

The primary focus of energy storage standards has been in battery technology. While several standards exist for the battery (comprising the cell and module/pack interconnection) by itself, until relatively recently, there has not been much standardization at a storage system level (that is, system including the battery or other storage technology, the power electronics, and the balance of plant required for the product to function as a grid appliance). The absence of system standards is a significant obstacle to the widespread use of storage. Without generally accepted standards, it is difficult enough for users and vendors to agree on the critical technical parameters related to a single storage project, let along develop standard products through which cost reduction through volume manufacture can be actualized. At a minimum, it would be highly useful to the entire industry to agree on a common understanding of terminology, applications, specifications and performance criteria, dispatch algorithms, test and validation procedures, and safety.

Standards Development

While standardization is normally thought of as a formal (*de jure*) process through a standards body such as IEEE and IEC, standardization can also be achieved through an informal *de facto* process in which the energy storage community agrees on key issues. It should be noted that standards that are developed purely from a technology angle, without strong input from the application viewpoint, may not reflect the actual uses of storage, and may end up being wasted effort. For this reason, we suggest that a standards process is best done from an applications viewpoint, with storage owners and operators leading the way, and with input from technology vendors. The Department of Energy can facilitate this process by continuing to convene workshops of the relevant stakeholders. The DOE can also increase adoption of codes and standards favorable to energy storage adoption by sponsoring consultants on panels, including the NEC.

Recognizing the importance of standardization, several collaborative efforts are currently underway. A non-exhaustive list of these representative efforts are described below.

Table 3 lists US and International Organizations active in energy storage components and systems, or related products or protocols. Many other national and regional codes and standards bodies could be added if considering codes and standards bodies outside of the US, but this section is focused on the US.

Table 3 Organizations Active in Storage Component Systems or Protocols

US and International Organizations	Primary subject matter or document contributing to energy storage codes and standards
American Society of Heating Refrigeration & Air Conditioning Engineers (ASHRAE)	Building automation and building information models
Electric Power Research Institute (EPRI)	Energy Storage Integration Council (ESIC) Guidelines/tools
Electricity Storage Association (ESA)	Technical Committee (TC) contributes industry consensus opinions to other bodies
International Code Council (ICC)	International Building Code (IBC) International Energy Conservation Code (IECC)
Institute of Electrical & Electronics Engineers (IEEE)	Information and communications protocols; standards for power equipment (e.g. transformers) National Electrical Safety Code (NESC)
International Electrotechnology Commission (IEC)	TC 120: Electrical Energy Storage Systems TC 21: Secondary Cells TC22: Power Electronic Systems and Equipment TC 57: Power Systems Management and Associated Information Exchange
MESA Standards Alliance/Sunspec	Common communications protocols, component packaging and arrangement
National Electrical Manufacturers Association (NEMA)	Serves as secretariat or chair of other bodies to coordinate work; runs ANSI Accredited Standards Committee on Energy Storage Systems
National Fire Protection Association (NFPA)	NFPA 70, National Electric Code (NEC) Fire and safety model codes
National Institute for Building Science (NIBS)	Whole Building Design Guide (WBDG)
National Institute of Standards & Technology (NIST)	Convener of groups related to measurement science, reliability, cybersecurity, high voltage power conversion to provide technical support
Society of Automotive Engineers (SAE)	Battery safety, construction, and material standards
Smart Grid Interoperability Panel (SGIP)	Coordination of smart grid standards
U.S. Department of Energy (USDOE)	Technical support through Sandia National Laboratory (SNL) and Pacific Northwest National Laboratory (PNNL)
Underwriters Laboratory (UL)	Safety standards and guidelines

The intent of Table 3 is to provide a consolidated overview of the code and standards landscape surrounding the energy storage industry. A thorough report which outlines this landscape and provides a compendium of energy storage-related codes and standards is titled "Safety-Related Codes and Standards for Energy Storage Systems and Experiences Securing Energy Storage System Approval and Acceptance." The Report "Overview of the Process Associated with the Development and Deployment of Codes, Standards and Regulation in the United States Affecting Energy Storage System Safety" explains the value that a system of codes and standards brings to an industry and outlines how codes, standards, and regulations are written and adopted (PNNL 2014).

Codes and Standards Categories

Codes and standards development to date has been largely reactionary, filling a gap when a problem or need arises. Expectations are that in the near to medium term future codes and standards development for energy storage systems and their components will be undertaken in a more progressive manner in which "gaps" in the codes and standards space are systematically filled. Efforts are underway in IEC TC120, EPRI ESIC, and the DOE-led Energy Storage Safety Workshop to inventory energy storage systems and provide a gap analysis and prioritization plan for the development of code and standards.

There are many ways to consider this whitespace, but a standards map will span multiple dimensions which may intersect including:

Component-to-system dimension (battery example given):

- Smallest component (Materials)
- (Cells)
- (Strings)
- (Power Converters)
- (Battery Management Systems)

  ….
- Largest component (Energy Storage Systems)

Content-area dimension:

- Terminology
- Unit parameters and testing methods
- Planning and installation (and commissioning)
- Environmental issues
- Safety considerations
- Communications and information exchange

Storage-medium-type dimension:

- Flow battery
- Pumped Hydro
- Compressed air, containerized
- Compressed air reservoir
- Flywheel
- Li-ion batteries

- Pb-acid batteries
- Sodium sulfur batteries
- Etc. (list not intended to be comprehensive)

DOE Support for Codes and Standards Development

The DOE Office of Electricity Delivery and Energy Reliability Energy Storage Systems Program assists in the development of standards in two primary ways: serving as the convener of committees spanning all stakeholders categories (user, manufacturer, integrator, testing lab, government, utility/customer, trade association/professional society, etc.) and providing technical support to third party standards and codes bodies. It accomplishes these tasks primarily by providing funding and staff from national labs, mainly Sandia National Laboratory and Pacific Northwest National Laboratory within the scope of codes and standards. Several projects evidence this engagement and these are summarized here.

In 2012, the Pacific Northwest National Lab (PNNL) published the first edition of PNNL-22010, The Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems. This document provides non-binding consensus opinions on how to measure the metrics the stakeholders deemed important in an energy storage system (e.g. round trip efficiency, ramp rate). This document is technology agnostic in that it is organized around representative duty cycles (e.g. peak shaving, frequency regulation) as opposed to differentiating tests based upon type of storage medium. This characteristic allows systems to be compared in an impartial manner. In 2014, this publication was republished in order to expand its content, add more duty cycles representing uses, and expand edit content based upon user feedback. Most importantly, the concepts and approaches to standardization in this work jumpstart and form the foundation to national and international standardization, especially for performance tests and performance reporting (PNNL 2014).

In early 2014, the DOE Office of Electricity Delivery and Energy Reliability Energy Storage Systems Program convened the first meeting of the energy storage safety workshop. The workshop brought together industry stakeholders to share knowledge on safety validation and safe operation of energy storage systems and to identify the gaps in understanding, analyzing, standardizing safety in energy storage systems. Safety is an immediate concern and the concept must be at the forefront of engineering, design, and installation. Three gaps were identified that need immediate attention: 1) the lack of standardized methods and the scientific basis necessary to validate system safety, 2) the need to update codes, standards and regulations relating to safety of energy storage systems, and 3) fuller development of incident preparedness. The result of these workshops led to the development of two reports from Pacific Northwest National Laboratory titled “Safety-Related Codes and Standards for Energy Storage Systems and Experiences Securing Energy Storage System Approval and Acceptance” and “Overview of the Process Associated with the Development and Deployment of Codes, Standards and Regulation in the United States Affecting Energy Storage System Safety” (PNNL 2014).

A further result of the DOE Energy Storage Safety Workshop was the funding of PNNL personnel to prepare a report of potential issues that could be submitted as public inputs to the 2017 revision of the NEC. This project will combine the ideas generated from multiple input groups including those at NEMA, IEEE, Solar ABC, and UL and more efficiently develop a single set of public inputs with supporting rationales. With a short three month timeline, this project was highly needed in order to develop new and edit existing NEC sections so that they are accepting of energy storage systems beginning with the 2017 model code. If coordination had not performed, the revisions may not have been made until the next revision, in 2020.

Finally, SNL and PNNL fund staff to serve on third party standards and code committees. This assists the development of documents within this group greatly by having technical staff available to perform the complex mathematical and design work on a non-biased basis. Without participation, calculations and the writing of sections of the documents would take much longer. One prominent example of this is PNNL personnel serving as the US Technical Advisor (TA, or in other committees, the Chair) of IEC TC 120, Electrical Energy Storage Systems (PNNL 2014).

Recommendations to DOE for future involvement in Codes and Standards Development

The DOE's model for involvement in codes and standards is on the correct path. The Department should continue to convene planning activities and continue to provide technical support to standards and codes bodies. DOE should expand their involvement in the efforts they already support and also engage in new activities as identified by the industry, particularly in code bodies such as those referenced in Table 3. There is great value in DOE providing their impartial views of the energy storage industry and of proposals submitted to code bodies. In light of the often highly politicized nature of code panels, DOE's role as neutral arbiter to make clear the rationale behind specific proposals has the potential of greatly increasing the likelihood of successful outcomes.

Equitable Regulatory Environment

Overview of DOE Program Goals

Today's restructured electricity systems rely on a mixture of competitive pricing markets and traditional cost-of-service regulation. This is because some services, such as generation, are best handled by the market, whereas designing markets for others, such as transmission and distribution, would be cumbersome or beyond our capabilities. Thus, cost recovery for many assets in restructured electricity systems is governed by which of these two classifications (competitive market-based or traditionally regulated) the services that it primarily provides fall under. This hybrid regulatory structure can create inefficiencies, however, for assets, such as storage, that can provide services that straddle the two classifications.

Storage technologies are capable of providing a wide range of valuable services to the grid. It is important that grid reliability services be properly specified, and that the value of reliability services be recognized and remunerated to asset owners providing those services, including owners of storage assets. In addition, there is a market design and regulatory conundrum that results from the disparate treatment of transmission assets (which are typically funded through cost-of-service rates) and market resources (that are funded through wholesale market tariffs where market resources are paid for reliability services through a competitive market clearing process, and cost-of-service is not guaranteed). A few examples illustrate the conundrum.

It is currently possible for a transmission owner/developer to invest in a cost-of-service storage asset to solve a narrow reliability problem (e.g. grid voltage support at a specified location) but in this instance, the FERC typically will not grant the storage asset owner the ability to capture market revenues, or allow the storage device to be dispatched as a market resource through the ISO's economic dispatch (because of the wholesale market pricing inefficiencies that would result). FERC has not allowed this dual use/recovery because they believe it will affect the price formation objective of wholesale markets.

However, this could lead to an outcome where the storage device is potentially not used to its maximum capability. It can be argued that, given the *ex-ante* decision to make the socialized investment in the storage asset, the under-utilization of the storage asset is leading to a sub-optimal outcome (from the perspective of maximizing social welfare). This conundrum would apply to any asset that is capable of providing market services, and which is given *ex-ante* cost of service treatment as a transmission asset (or similarly receives any form of out-of-market side payment). For example, let's assume that a gas generator (e.g. a combustion turbine or a combined cycle), a demand response resource, or a distributed generator, is granted cost-of-service treatment because it is deemed to be the most cost effective solution to a local reliability need (the so-called 'Non Transmission Alternative' option). An *ex-ante* cost-of-service investment would be made in an asset that could potentially provide a range of wholesale market services. Once the investment decision is made, the question then arises as to whether the device/technology should later be dispatched as an 'economic' resource and be allowed to collect market revenues? This is essentially the same problem as the above-mentioned storage example.

One answer to this conundrum is that the cost-of-service investment should not be made in the first instance, but this pre-supposes that the market design specifies the required reliability services with enough service and locational granularity, such that the market can fully address the identified reliability need. It also pre-supposes that out-of-market investments will not be made for other reasons by state regulators (such as the achievement of environmental goals). Such granularity is not attainable in today's market designs. Furthermore, the reality is that the industry operates in a bifurcated federal/state regulatory system, with the consequence that such cost-of-service investments will be made -- and hence the potential inefficiency is then established. How then is this conundrum resolved? And, if it isn't able to be fully resolved, how do we minimize the inefficiency that is created by the disparate regulatory treatment of transmission assets and market resources, and asset investments that are committed under differing federal and state regulatory systems? Finally, given this context, how should storage resources be treated relative to other classes of resources?

It would be valuable for the Department to study this problem, so as to provide the industry (including the FERC, state regulators, ISOs, RTOs, and market participants) with possible solutions and the trade-offs (both explicit and implicit) in each solution.

The Department has the following three goals to address these challenges by helping to spur a regulatory environment that is equitable to storage:

1. Collaborative public-private sector characterization and evaluation of grid benefits of storage
2. Exploration of technology-neutral mechanisms for monetizing grid services provided by storage
3. Development of industry- and regulatory agency-accepted standards for siting, grid integration, procurement, and performance evaluation.

Summary of Activities to Achieve Goals and Successes

To address the regulatory challenges that energy storage development faces and achieve its related goals, the Department has identified and focused its efforts on the following seven specific activities:

1. Documentation of federal, state, and local policies affecting storage deployment;
2. Review of IRP and similar regional, state, and community analytic processes affecting storage development and deployment;
3. Exploration of alternative policies that may affect technology attributes and deployment;
4. Supporting development of consensus-based codes and standards for performance, safety, packaging, cycle life, control, and grid integration of storage;
5. Maintenance of publicly available information on storage technology and attributes affecting its deployment;
6. Dissemination of comprehensive information on storage technology status, experience (e.g., ARRA projects), and realizable contributions to grid resilience, emergency response, renewable deployment, and asset utilization; and
7. Providing best practices for installation and use of energy storage to regulators, policy makers, and industry.

A major success in this area has been the development of the DOE Global Energy Storage Database, which is publicly available at http://www.energystorageexchange.org/. This database provides free up-to-date information regarding storage projects that have already been developed or are under development. In addition to basic characteristics (e.g., technology, power capacity, duration at rated power, projected lifetime, and performance), the database also reports the primary use case, ownership, value chain partners, and financing of each project. These data can be used to study how different ownership and contracting arrangements have helped or hindered storage project development.

The database further summarizes existing and proposed Federal and state-level legislation and regulatory decisions and rules related to storage. Cross referencing storage projects reported in the database with changes in the regulatory landscape within the United States can provide useful insights on the effects of policy, regulation, and legislation on storage development.

Key Gaps and Recommendations

Despite these successes, there are a number of key gaps in the Department's strategy toward developing an equitable regulatory environment for storage. Here we summarize these gaps and make recommendations for how the Department should focus its future efforts.

Comprehensive Study of Regulatory and Market Design and Impacts on Roles for Storage

Most restructured electricity systems rely on a mixture of markets and traditional cost-of-service regulation. This is because some services, such as energy, ancillary services, and generation capacity, are best handled by the market, whereas designing markets for others would be cumbersome or beyond current capabilities. These services, such as transmission, power quality, and distribution, are largely provided on a regulated basis. As such, cost recovery of an asset in a restructured electricity system is governed by which of these two classifications (market-based or regulated) the services that it primarily provides fall under. This hybrid design creates inefficiencies, however, if an asset can provide services that straddle the two classifications. This is especially true of energy storage, since it can provide a broad range of market-based and regulated services (EPRI-DOE 2003; Eyer and Corey 2010; Eyer et al. 2004; Masiello et al. 2014; Sioshansi et al. 2012).

As an illustrative example, consider the Western Grid case, recently decided by the FERC. This project consists of a set of batteries that were proposed to be built *solely* to provide voltage support, address thermal overloads, and provide other transmission-related services. The FERC issued a declaratory order designating the Western Grid batteries as transmission facilities and allowed rate-based cost recovery. One can contrast this with the Lake Elsinore Advanced Pumped Storage (LEAPS) case, also recently decided by the FERC. The LEAPS developer proposed building a 500 MW PHS plant along a new transmission corridor connecting the Southern California Edison and San Diego Gas and Electric service territories, intending to relieve transmission congestion into the San Diego basin. A major difference relative to the Western Grid case, however, is that the LEAPS plant would be operated and dispatched based on LMPs, which signal the cost of congestion along the newly built transmission corridor. Since LEAPS would be operated using market-based price information, the FERC did not allow rate-based cost recovery.

Taken together, these precedents suggest that storage developers must make a decision regarding what combination of services to propose providing, which determines cost recovery. This regulatory design *de facto* guarantees inefficient storage development and use. One option is to follow the Western Grid precedent, and propose a project that *only* provides regulated services, allowing rate-based cost recovery. However, projects built in this way will be inefficiently used since they are barred from providing valuable services priced in the market. From a social welfare-maximization perspective, the Western Grid batteries should be used for energy arbitrage or frequency regulation on days that they are not expected to be fully utilized providing transmission service. However, the developer explicitly barred itself from providing such services in its application to the FERC. Indeed, this was raised as a major objection in the case—that ratepayers would be made to recover the cost of batteries that would not be used to their full potential. The alternative option is to propose a project that provides services priced in the market, as done in the LEAPS case. In such an instance, the storage project would be subject to the risk of market-based (as opposed to rate-based) cost recovery. Moreover, the developer would not be remunerated for any services provided by the project that are not priced in the market. This option can, again, results in inefficient storage investment. For instance, even if LEAPS provided the most cost-effective means of relieving transmission congestion into San Diego, a developer may opt for a traditional transmission-only solution since its rate-based cost recovery is seen as being less risky.

Since today's hybrid regulatory paradigm creates these inefficiencies, it can stand as a barrier to efficient storage development and use. Thus, there is a vital need for comprehensive study of and research on regulatory and market designs and their effects on storage. More specifically, the fundamental question to be addressed is what combination of market and regulatory designs could be implemented to allow for most efficient asset investment and use. It should be noted that although this discussion is couched in the context of energy storage, this hybrid regulatory paradigm creates inefficiencies for other asset types as well. For instance, generators are remunerated for energy, ancillary services, and capacity that they provide. At the same time, they also provide reactive power and voltage support, which are not priced in the market. Rather, these services are provided based on ISO or RTO instructions and their costs are socialized, as opposed to being borne on a causation basis. Thus, the market and regulatory question that we pose here would stand not only to create a more equitable regulatory environment for storage, but would also address inefficiencies related to other asset types.

This research could be undertaken solely by the Department or in conjunction with other agencies that fund or conduct storage- or energy system-related research. For instance, the National Science Foundation operates a number of programs that fund energy-related research that span fundamental science, technology development, and system economics. Funding from programs of these types could be focused to study regulatory design as it relates to storage, in conjunction with more fundamental technology-related research.

It would, furthermore, be beneficial for the Department to host a collaborative discussion of regulatory models that could address the roles and economic opportunities for storage. This should ideally by hosted in conjunction with FERC, NARUC, and NCSL. Topics to be covered in the discussion could include using distributed storage (e.g., at data centers and other large commercial and industrial facilities) to provide ancillary services to the grid as well as more traditional micro-grid and renewable-integration services. This discussion could build off of recent successes that the FERC has had in spurring tariff changes that better signal the value of services that flexible resources, including storage, can provide (cf. FERC Orders 755 and 890). It is important to note that although storage was a major beneficiary of these tariff changes, these were not done solely to encourage storage development. Rather, these orders recognize that more flexible resources should command a market premium, with storage being a prime example of such a resource.

Regulatory Design to Capture Renewable-Integration Benefits of Storage

The Department has listed renewable integration as one of the primary benefits of storage. This is evident in numerous renewable-integration studies, which rely on massive storage deployments to economically reach high renewable penetrations (NREL 2012). These studies implicitly assume a central planning paradigm, with centralized optimization of renewable and conventional generation, transmission, and storage deployment. Moreover, storage operations are co-optimized with the use of conventional generation and other assets.

In practice, however, storage investments and operations are often determined by independent profit-driven entities. This raises some important regulatory issues to realize the full renewable-integration benefits of storage (as well as other sources of flexibility needed to accommodate variable renewables). The first is to determine the proper role of ISOs and RTOs in restructured electricity markets in co-optimizing storage operations with the commitment and dispatch of other resources. Many restructured markets in the United States hide and socialize the operational cost impacts of renewables, since renewable generators are at least partially protected from imbalance and related charges. For storage (and other sources of flexibility) to viably enter the market and provide renewable integration-related services, they must be properly remunerated. One approach to accomplishing this would be to change market rules to pass these costs directly to their sources (i.e., renewable generators). Doing so would provide renewable generators with strong incentives to either invest in assets or to contract with third parties (e.g., privately owned and operated storage facilities, demand response, etc.) that can reduce their exposure to these costs. An alternative approach, which seems to be more common in the United States, is to design new market products that capture the value of these services. One such example is the so-called flexiramp product that has been added to the California ISO markets (Wang and Hobbs 2014). A third option is to have the ISO or RTO co-optimize storage operations with the commitment and dispatch of other resource. None of the ISOs or RTOs in the United States are currently pursuing this approach, however, since it may jeopardize their independence.

As suggested above, the design of mechanisms to remunerate storage and other assets for providing renewable-integration services affects both their operations and development. From an operational perspective, market signals are needed to indicate how existing assets should be best utilized to address the variability challenges of renewables, and maximize their value. These signals and their impact on asset profitability would further affect investment. An important question raised by these alternative approaches to signaling the need for renewable-integration services is what types of inefficiencies they introduce relative to one another (or to other approaches not suggested above). A related question is what implications these different approaches would have for allocation of renewable-integration costs. As noted above, many markets in the United States socialize these costs to load, since renewable generators are at least partially protected from imbalance and related charges. If these costs are, for instance, to be directly levied on renewable generators, this would have important implications for the economic viability and development of the renewable industry. Depending on how these costs are passed on to renewable generators, they may also eliminate the benefits of geographical diversification. If each renewable generator is using a dedicated storage resource to balance its output, this results in excess energy being put through the storage cycle and associated efficiency losses. Similar inefficiencies would arise if conventional generation or demand response was being used to balance the output of individual renewable plants. This issue could be alleviated if renewable aggregation, that levies imbalance charges on the output of a set of aggregated renewable generators, is allowed.

The importance of renewable integration as a major value proposition for storage development calls for comprehensive study of the implications of different market and regulatory mechanisms on efficiently signaling the value of these services. Understanding the effects of these mechanisms on storage investment is also important. Moreover, the spillover effects of these different mechanisms on consumer energy costs, the role of ISOs and RTOs in determining market outcomes and any threats to their perceived independence, and the economic viability of the renewable industry need to be better understood. It should be stressed that although this discussion of regulatory design is couched around storage, the Department's ultimate goal should be consistent with the development of a regulatory and market paradigm that properly signals the value of flexibility in accommodating variable renewables, in a technology-agnostic manner. Doing so would allow all sources of flexibility, including storage, to more efficiently enter and participate in the market. As with the recommendation above, this research can be carried out solely by the Department or in concert with other agencies. The Department should make that research available to the ISO and RTO communities, state regulators, and FERC, in order to support stakeholders' assessments of market designs and regulatory improvements in this arena.

Industry and Stakeholder Acceptance

Industry and stakeholder acceptance has increased markedly in the United States over the last two years driven in large measure by American Recovery and Reinvestment (ARRA) funding administered by the U.S. DOE. The status of these projects range from deployed energy storage facilities to a new manufacturing facility to support future energy storage projects around the world. Early results of many of these efforts are now being disseminated: www.smartgrid.gov.

Table 4 ARRA Project Examples (Source U.S. DOE)

Title	Status	Technology	Location	Capacity (MW)
Beacon Power's 20 MW Flywheel Frequency Regulation Plant	Deployed	Flywheel	New York	20
Increased Turbine Efficiency with Ice Storage	Deployed	Thermal storage	Arizona	12 (as 3,500 tons of cooling capacity)
Compressed Air Energy Storage Facility	Under construction	CAES	California	300
Eagle Mountain Hydro-Electric Pumped Storage Project	Announced	Pumped hydro	California	1,300 initially (could exceed 4,000)
AES 400 MW Energy Storage Plant	Proposed	Battery	New York	400

In total, ARRA stimulus funding has supported 16 large-scale energy storage projects with a combined capacity of over 530 MW (see Table 5) ARRA funding for all 16 projects totaled $185 million, and this funding was leveraged at over 3 to 1 with $585 million of cost sharing (total project value of $772 million). ARRA funding is an example of the important role that DOE plays as a catalyst for funding large-scale storage development, while also showing strong support from manufacturers and utilities.

Table 5 ARRA Funded Energy Storage Projects (Source: Sandia National Lab)

Project Type	Number of Projects	Capacity (MW)	Comments
Battery Storage for Utility Load Shifting or Wind Farm Integration	3	57	3 battery projects ranging from 8 to 25 MW
Frequency Regulation Ancillary Services	1	20	one flywheel project
Distributed Storage for Grid Support	5	8	4 battery systems and 1 ultracapacitor
Compressed Air Energy Storage	2	450	300 and 150 MW projects
Demonstration of Promising Energy Storage Technologies	5	1	three battery systems, one flywheel and one CAES project
Total	16	536	---

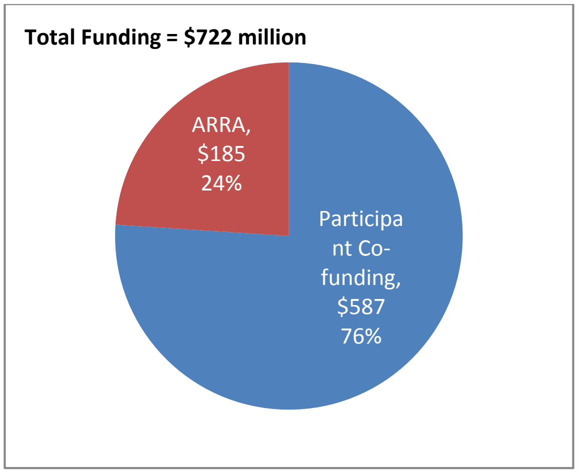

Figure 2 ARRA Funded Energy Storage Projects (Source: Sandia)

The California Energy Commission (CEC): A significant portion of CEC's energy storage program is currently aligned with projects that have received DOE ARRA awards. In fact, eight ARRA energy storage projects involve CEC Public Interest Energy Research (PIER) co-funding, as listed in Table Y. These eight projects represent $614 million, or 80%, of the total project funding allocated for ARRA energy storage projects ($772 million total). The CEC funding for these projects, as indicated in Figure 2, is highly leveraged against ARRA funding and participant co-funding. The CEC funding amount is $5.7 million compared to a total project cost of $614 million.

Table 6 ARRA Funded Energy Storage Projects with CEC PIER Funding, 2010-2011

Awardee	Project Title	Technology	Funding ($ Million)		
			PIER	DOE + Match	Total
Southern California Edison	Tehachapi Wind Energy Storage Project	Li-ion battery	1.0	52.5	53.5
Primus Power Corporation	Wind Firming Energy Farm	Zinc flow battery	1.0	45.7	46.7
Seeo Inc.	Solid State Batteries for Grid- Scale Energy Storage	Li-ion battery with nano-structured polymer electrolytes.	0.6	11.8	12.4
Sacramento Municipal Utility District	Premium Power Distributed Energy Storage Systems Demonstration	Zinc Bromine flow battery	0.2	5.2	5.4
Amber Kinetics, Inc	Utility-Scale Flywheel Energy Storage Demonstration	Advanced technology utility-scale flywheel energy storage	0.4	9.6	10.0
EnerVault Corporation	Flow Battery Solution to Smart Grid Renewable Energy Applications	Novel iron- chromium redox flow battery (BESS)	0.5	9.0	9.5
Los Angeles Department of Water and Power	Smart Grid Demonstration Project	Involves battery energy storage systems for electric vehicles	1.0	119.6	120.6
Pacific Gas and Electric Company	Advanced Underground Compressed Air Energy Storage Demonstration Project	"Second generation" compressed air energy storage (CAES)	1.0	354.9	355.9
Totals			5.7	608.3	614.0

Source: California Energy Commission

California Public Utility Commission (CPUC): Further evidence of stakeholder acceptance of electric energy storage is a recent mandate from the California Public Utilities Commission for an unprecedented 1.3 gigawatts of energy storage to support the state's power grid by decade's end. The order breaks new ground in seeking to establish a regulatory regime in which utilities, third-party storage providers, and customer-owned storage assets can play an integrated role. The order include rules that would limit utilities from owning more than 50 percent of the total amount of energy storage to be procured across the three "grid domains" of transmission, distribution, and customer-located storage.

The proposal also lays the groundwork for creating new ways for utilities and third-party storage owners to cooperate in paying for, and benefitting from, these assets. The proposal calls for utilities to "consider all forms of resource ownership (utility-owned, third-party owned, customer-owned, joint ownership), including entering into contracts with customer-sited storage resources," and further states that the utilities "may own storage assets in all three storage grid domains."

Conclusions

The DOE summarizes its strategic goals as follows:

1. Energy storage should be a broadly deployable asset for enhancing renewable penetration – specifically to enable storage deployment at high levels of new renewable generation
2. Energy storage should be available to industry and regulators as an effective option to resolve issues of grid resiliency and reliability
3. Energy storage should be a well-accepted contributor to realization of smart-grid benefits – specifically enabling confident deployment of electric transportation and optimal utilization of demand-side assets.

The EAC review of the federal energy storage program strategies and activities has found the program to be comprehensive and largely responsive to the needs of U.S. industry and public agencies. DOE's goals are well thought out - largely broad enough and timely to serve the needs of the electricity industry.

The EAC recommends that the goals of the storage program be broadened to include some additional issues energy storage might address. In particular, Goal #2 could be broadened to include the issues of increasing asset utilization and operations economic optimization.

Although the DOE strategic goals are very clearly tied to grid related application, the portfolio of research funded through the Office of Science (e.g. the Joint Center for Energy Storage Research[9] and the Energy Frontier Research Centers[10]) as well as the National Science Foundation (e.g. the Emerging Frontiers in Research and Innovation (EFRI) Renewable Energy Storage grants[11]) seem to be focused more on the basic sciences and component technologies rather than the integration with the grid. While some research endeavors are more grid-facing (e.g. the Future Renewable Electric Energy Delivery and Management Systems Center[12] and the Center for Ultra-wide Area Resilient Electric Energy Transmission Networks[13]), given the scope of needs for meeting the goals set forth in the 2013 DOE Report, much more grid- focused research support is needed through these or other venues. Furthermore, it is not clear if the current set of research expenditures are sufficiently targeted given that applications (prototyping, demonstrations, etc.) require proportionately more funds.

The Office of Electricity Delivery and Energy Reliability (OE) is the office tasked to spearhead the grid related research but many of their significant projects appear to have been funded through the ARRA. The impact and scope of these efforts was clear in the presentation the Imre Gyuk delivered to the EAC in March 2014.[14] Despite the success and importance of these projects, it is not clear if there is a capacity to continue funding such activities after the ARRA funds are expended. The strategic goal of more storage is unlikely to be met without similar demonstration projects. Although state mandates and private funds will help installation, the cost targets are unlikely to be met without DOE investments in these areas. The EAC recommends that efforts to continue similar demonstration projects continue with some level of continued

[9] http://www.jcesr.org/

[10] http://science.energy.gov/bes/efrc/

[11] http://www.nsf.gov/eng/efri/fy10awards_RESTOR.jsp

[12] http://www.freedm.ncsu.edu/

[13] http://curent.utk.edu/research/power-systems-research/

[14] http://energy.gov/oe/services/electricity-advisory-committee-eac/electricity-advisory-committee-2014-meetings/march-12

funding from both public and private sources. The EAC also recommends the DOE conduct a parametric cost benefit analysis of the ARRA demonstration projects in order to enhance the value derived from these investments.

Although the different offices in DOE seem to collaborate and have a good understanding of each other's projects, it is not clear whether there is an understanding of how research is handed over from the successful basic research projects to the applications research projects to deployment/demonstration along the technology readiness path. It seems ARPA-E has a well-defined operational path all the way from basic idea to commercialization within its own organization, but how this takes advantage of what is going on in the other offices is not clear. The EAC recommends that any existing inter-agency coordination around energy storage be made more transparent and that such coordination such be augmented and strengthened in order to provide more coherent priorities around storage research, development, demonstration and deployment and in order to better inform the development of national targets for energy storage on an ongoing basis.

From the list of projects, it seems that several of the National Laboratories are very involved in storage research. Given that the National Labs have a closer relationship to the DOE than say, private corporations or universities, it is not clear what strategic role they play in this area or how the DOE utilizes this resource. Along the same lines, it would seem that public-private partnerships could bring synergies to this research. A successful example of how industry has jointly collaborated with the National Labs for technology development is the National Renewable Energy Lab's National Wind Technology Center. The Sandia National Labs provide some level of industry engagement through their battery testing facility[15], but the scope of this engagement with the energy storage industry should be deepened and expanded.

The Department is making targeted investments in achieving storage technology cost reductions. In addition to this, the Department should focus its efforts on developing improved operational planning tools for storage devices, especially those that can be put to multiple applications. Such tools will help storage developers maximize the value of their investments and improve overall storage economics. The Department should also commission a comprehensive study of PHS and CAES resource availability. This is necessitated by previous studies that rely on massive storage deployments to achieve high renewable penetrations. Despite the Department's assumptions regarding PHS and CAES availability, no facilities have been recently developed. Such a study will help the Department reassess whether its assumptions on PHS and CAES availability are in line with what the market can reasonably deliver.

The DOE's model for involvement in codes and standards is on the correct path. The Department should continue to convene planning activities and continue to provide technical support to standards and codes bodies. DOE should expand their involvement in the efforts they already support and also engage in new activities as identified by the industry, particularly in code bodies such as those referenced in Table 3. There is great value in DOE providing their impartial views of the energy storage industry and of proposals submitted to code bodies. In light of the often highly politicized nature of code panels, DOE's role as neutral arbiter to make clear the rationale behind specific proposals has the potential of greatly increasing the likelihood of successful outcomes.

Today's hybrid regulatory environment, which consists of a mixture of competitive pricing markets and cost-of-service regulation, creates cost-recovery and valuation problems for assets that straddle the line between these two classifications. Energy storage is one such asset type, since it can provide services that would traditionally fall under the two cost recovery paradigms. Two recent FERC precedents suggest that storage and other assets that fall into these two categories may be built and operated inefficiently. The

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[15] http://www.sandia.gov/batterytesting/

http://www.sandia.gov/batterytesting/request.html

Department should support further research to understand how different regulatory or market designs may improve cost recovery and valuation of storage and similar assets.

The data, information and tools that DOE provides regarding energy storage technology, costs and systems is of critical importance and a vital resource for the research community and the industry alike. DOE should continue and expand the development of resources such as the 2013 EPRI/DOE Storage Handbook and the DOE Energy Storage Database. One key area where relevant information is lacking is on power electronics costs. A DOE-commissioned effort work to produce a time series of power electronics costs and learning rates would greatly inform the work currently being undertaken in this area.

Distributed Energy Storage (DES) is defined as energy storage located at or below the substation and is one of the fastest growing segments of the global energy storage market. This market includes behind the meter installations and thermal energy storage and is a key component to the development and deployment of smart grids. Studies conducted by both utilities and industry indicate that the largest payoff for energy storage maybe DES. Project sizes range from 5kW to over 5MW and span from residential to large industrial installations and substations. Market Drivers for DES include voltage stabilization, demand load management, UPS, line load balancing, renewable integration, and system inertia and ride thru capability for the distribution system. Key challenges or issues in this market are interconnect requirements, system cost, advancement of distributed resource markets, and system code and safety requirements for DES. It should be noted that DES is the market segment that also applies to micro-grids and has significant DOD applications. Accordingly, DES has many tools, codes and standards, regulatory equity, and cost and validation needs development similar to utility-scale energy storage. However, because some of the applications, value propositions, end users and grid integration requirements for DES are different from utility-scale energy storage, DOE needs to tailor additional strategies, goals and activities to meeting DES needs.

Industry and stakeholder acceptance has increased markedly in the United States over the last two years driven in large measure by American Recovery and Reinvestment (ARRA) funding administered by the U.S. DOE, and also due to state-level activities such in California. These efforts represent an incrementally large increase in experience with, and knowledge about, energy storage. The EAC recommends that DOE continue and perhaps even expand efforts to capture this learning and disseminate it to industry and stakeholders.

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Appendix A: Specific DOE Activities in Support of the Department's Energy Storage Strategy

Reproduced from: U.S. Department of Energy, "Grid Energy Storage," December 2013. Available here: http://energy.gov/oe/downloads/grid-energy-storage-december-2013

Cost Competitive Energy Storage Technology	• Advanced redox-flow battery chemistry and component development to utilize lower cost membranes, electrodes, bi-polar plates; increase energy (electrolyte composition) and power density (ion flux across the membrane); develop non-aqueous redox-flow – bench scale test of potential $250/kW system • Bench demonstration of low temperature sodium (Na) batteries with efficiency of 90%– metal halide, and Na-ion systems • Demonstration at relevant scale of 2nd use automotive, and safer, longer-lived stationary Li-ion systems • Bench demonstration of multi-cell Mg-ion batteries for stationary applications • Develop and test high performance nano-material-based flywheel components • Advanced SiC, GaN, and AlN-based power converters for storage applications • Develop and test new capacitor materials and structures Use directed advanced research for • Flywheels: Thick cross section carbon fiber composite structure formation; magnetically levitated system enabling technology research, new nano-structured flywheel and magnet materials • CAES: Proof-of-scientific- concept isothermal CAES research; • Electrochemical: novel low cost, high cycle life anode, cathode, electrolyte and separator materials and structure research • Flow-Batteries: High current density, low cost power modules, long cycle-life low-cost electrodes, membranes and catalysts; alkaline exchange membrane electrodes and multi- functional power/energy electrodes; semi-solid flow-able anolyte/catholytes; nanostructured electrode assemblies • Superconductors: low cost high-temperature superconducting materials; high-field coil configurations • Capacitors: High surface area, nanostructured ultracapacitors, low cost, safe, and stable electrolytes/solvents • Power electronics: Novel inverter/converter topologies; integrated passive components; high voltage wide bandgap semiconductor epitaxial materials • Batteries: Low-cost/high energy density batteries; rechargeable metal-air chemistries; in-situ sensors and control technologies; model predictive cell control algorithms; moldable energy storage structures; multi-functional storage chemistries • Benefit/cost analysis grid integration of storage for grid resilience, emergency response, renewable deployment, and improved asset utilization • Storage cost models (including manufacturing) to guide R&D and for industry use • Development of design tools for optimally serving multiple applications • Baseline techno-economic modeling of advanced research impacts; value-proposition development for emerging technology research results; first-market analysis for subsequent technology insertion; partnership formation for direct private sector or other governmental hand-offs

Validated Reliability & Safety	• Independent testing of prototype storage materials, components and devices in both lab and field systems • Forensic investigation of degraded storage from materials to systems • Degradation, failure, and safety processes/mechanisms characterization and models • Validation of accelerated life-cycle testing protocols • Documentation of field demonstrations regarding performance • Technology specific testing to support hand-offs to governmental and private sector partners, following initial de-risking of advanced research concepts • User facility for validation and testing of system performance
Equitable Regulatory Environment	• Documentation of federal, state and local policies affecting storage deployment • Review of IRP and similar regional, state and community analytic processes affecting storage development and deployment • Exploration of alternative policies that may affect technology attributes and deployment • Support development of consensus based codes and standards for performance, safety, packaging, cycle life, control and grid integration of storage • Maintenance of publicly available information on storage technology and attributes affecting its deployment • Dissemination of comprehensive information on storage technology status, experience (e.g., ARRA projects), and realizable contributions to grid resilience, emergency response, renewable deployment, and asset utilization • Provide best practices for installation and use of energy storage to regulators, policy makers, and industry
Industry/ Stakeholder Acceptance	• Conduct analyses and develop tools assessing the beneficial role of storage in cost-effectively achieving higher levels of renewable deployment Provide independent analytic support to public-private sector studies and field trials/demonstrations characterizing the benefits and costs of storage to facilitate renewable deployment • Collaborate with industry on enhancement of production cost models, transient event, and other grid simulation/analysis tools to accurately incorporate storage particularly to address enhanced resilience, emergency response, and renewable integration • Collaborate with industry on development of operations and control tools and algorithms that facilitate optimal utilization of storage • Researching mathematical models and algorithms for real-time optimal AC power-flow control and grid topology control optimization, including consideration of storage • Collaboratively address environmental uncertainties through partnered projects with the Dept. of Interior and the Army Corps of Engineers to improve water quality modeling and analysis tools for greater operational flexibility of pumped storage and hydropower projects • Collaborate with industry in prototype testing in controlled test bed(s) • Report results from ARRA projects incorporating storage. Collaborate with industry, States, DOD and other stakeholders on field trials and demonstrations of new or improved storage technologies, alternative deployment environments, enable evaluation of a range of grid applications/services or explore grid integration and operation/control approaches • Interface with private-sector financial institutions in the underwriting of innovative commercial energy storage projects applying to the DOE loan program.

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