CHANGING WHAT'S POSSIBLE

GRIDS Program Overview

This program seeks to develop grid-scale energy storage technologies capable of addressing emerging intermittency and ramping challenges for the transmission of renewable electric energy, through cost-effective storage. Such energy storage should provide full power within 10 minutes for durations over 60 minutes.[1] Ubiquitous, dispatchable and cost-effective grid-scale energy storage technologies are critical for accelerating adoption of renewable generation and reducing CO_2 emissions from the electricity generation sector.

B.1 BACKGROUND

With a U.S. generating capacity 1,100 GW delivering roughly 4.1 million-GWh per year, the electric grid is a critical resource that provides 30% of all energy consumed by American homes and businesses.[2,3] However, our current electric generation system is heavily dependent on fossil fuels. Today nearly 70% of US electricity is made from coal or natural gas, and electricity generation accounts for over 40% of US CO_2 emissions.[4] Addressing the problem of climate change and energy independence will require increased use of low-carbon emitting electric generation, including renewable generation from solar and wind, as well as enhancements in the efficiency and reliability of U.S. electric power distribution.[5]

A key characteristic of renewable energy generation sources is their variability. Figure 1 illustrates the strong variability of power output that occurs from intermittent renewable energy sources (both solar and wind) on the minutes to one hour time scale, with intermittent power changes of over 80%.[6,7] The grid power level deviation spectrum shows over/under variations between generation and transmission dispatch power levels.[8] The time scales for these deviations fall in three categories.

(a) Seconds-to-minutes of power for voltage and frequency support. For this application, power reserve capacity on the order of up to 5-7% of generation on the grid (about 20-50 GW nationally) is necessary, depending on time of day and season of the year.[9]
(b) Minutes-to-hours for smoothing and firming intermittent power from renewable generation. For this application, reserve power for up to one hour duration providing standby support at a power rating on the order of 20% of the power from renewable sources, currently at 25 GW nationally[10], yields a total storage capacity of 5 GWh needed today.
(c) Hours-to-days of power for daily energy peak shifting. For this application power capacity on the order of 200 GW and 1,000 GW-hr would necessary for up to 20% integration of renewables.[11]

[1] Corresponds to Independent System Operator and Federal Energy Regulatory Commission definition for 10-minute spinning reserves: http://www.caiso.com/2738/2738f17617750.pdf
[2] DOE U.S Energy Information Administration, http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html
[3] Lawrence Livermore National Labs, https://publicaffairs.llnl.gov/news/energy/energy.html#2008
[4] Lawrence Livermore National Labs, https://publicaffairs.llnl.gov/news/energy/carbon.html#2008
[5] Energy Independence and Security Act (EISA, 2007), Title XIII, http://www.ferc.gov/industries/electric/indus-act/smart-grid/eisa.pdf
[6] A. Curtright and J. Apt, *Carnegie Mellon Electricity Industry Center Working Paper* CEIC-07-05 (2007). www.cmu.edu/electricity
[7] DOE Bonneville Power Administration, Wind Generation & Balancing Authority Load Monitoring: http://www.transmission.bpa.gov/business/operations/Wind/default.aspx
[8] Ross Guttromson, "Renewables Integration" Pacific Northwest National Labs, January 29, 2010
[9] ARPA-E Calculation: Regulating reserves criteria following 5% for hydroelectric plus 7% for other generation sources rule, assuming for average to peak loads ranging from 400GW-750GW.
[10] DOE US Energy Information Administration, http://www.eia.doe.gov/cneaf/electricity/epa/epat1p2.html
[11] ARPA-E Calculation: Assumes 200GW generation from renewable resources meeting approximately 40% of average daily load, with 100% load shifting for 5 hours

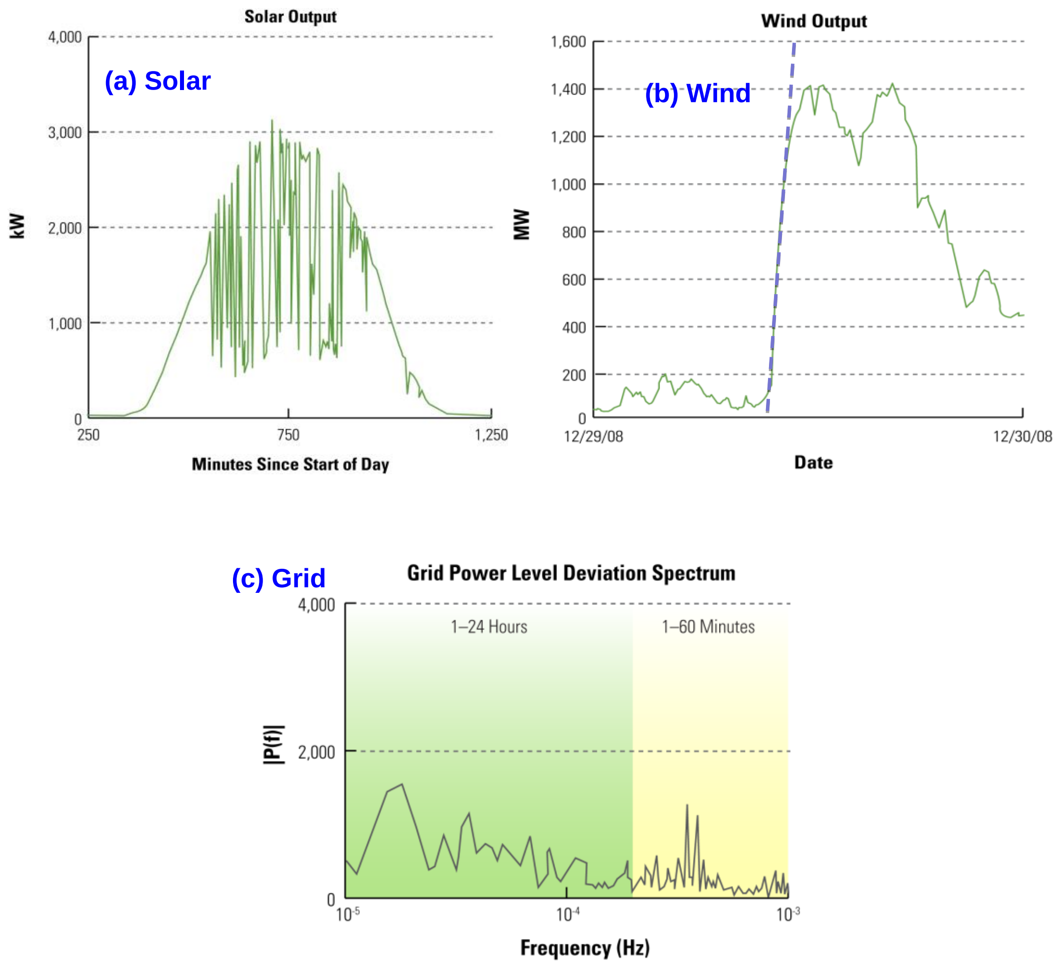

Figure 1: Intermittency within a day with durations of minutes to hours and variation of >80% in power output over these time scales limits the dispatchability of renewable generation due to weather related variations in (a) solar and (b) wind generation. Particularly for wind generation, the rate of change for power ('ramp') is a critical issue for balancing power systems, with high rates of change (MW/min), needing energy storage support for minutes-to-hours, shown as the dashed line on figure 1b. A power spectrum (c) shows the frequency of grid deviation between generation and load in the minutes-to-hours and hours-to-days timeframe on the grid. Added frequency and voltage regulation on the seconds-to-minutes timescale is done with grid ancillary services. Storage capabilities are needed to transform renewable resources into predictable and dispatchable firm power on the grid to enable a simultaneously low carbon and high reliability grid. In the absence of such storage, variations between generation and load are met through the purchase or sale of electricity at economically unfavorable prices, often from carbon emitting sources.[6,7,8]

Of the three categories, minutes-to-hours of electric storage for firming and smoothing of intermittent renewable power generation represents an urgent near-to-medium term application and technology need for our nation. The introduction of minutes-to-hours electricity storage can have two key impacts on CO_2 emissions as well as economics:

a) Enabling full utilization of renewable electricity generation;
b) Reducing the use of fossil fuels that are currently used for balancing the intermittency of renewables.

Utilization of Renewable Electricity: In the absence of widely available and cost-effective grid-scale energy storage, it may be difficult to reliably and cost effectively integrate large quantities of variable renewable generation into the grid. An example of the potential application of new storage technologies comes from the Pacific Northwest, where the Bonneville

Power Administration's (BPA) balancing authority control area has the nation's largest penetration of wind generation in the country at nearly 30% of peak load (2800MW of 10,500MW). BPA is facing the undesirable potential of frequent curtailments of wind generation or equally undesirable disruption of hydro operations in the absence of new grid balancing resources.[12,13] In parallel with renewable generation sources, grid-scale storage with the capacity to provide rated power for at least one hour would provide grid balancing and transform renewable generation resources into dispatchable and firm electric power. This would substantially increase the economic value and use of wind and solar power in the U.S. electric power generation sector.[14] New storage solutions would ultimately need to be scaled to tens of gigawatts of power with tens of gigawatt-hours of energy distributed across the grid, to address the minutes-to-hours power firming and smoothing need for renewable generation nationwide.

Reduction of Fossil-Fuel Based Load Balancing: Since little energy storage exists on today's electricity grid, generation must be constantly adjusted to meet load. In the absence of grid-scale energy storage, the existing power grid is regulated with spinning reserves, commonly in the form of carbon emitting fossil fuel power plants, which are synchronized in stand-by mode, available for full power within 10 minutes, and run in parallel with renewable generating resources. Widespread grid-scale storage functioning as spinning reserves would have immediate impact on CO_2 emissions reductions by displacing fossil fuel powered spinning reserves.

The rate of change (also known as the "ramp") between power levels, shown in Figure 2b, is a major problem for integrating intermittent renewable resources. Ramps are short-term, unsupported losses or additions of power to the grid.[15] These rapid changes in power have a financial impact as replacement power is supported by reserves, which can be an order of magnitude more expensive than base electricity prices.[16] The uncertainty of intermittency is a cost associated with renewable generation.[17,18] For this reason, renewable generation from wind and solar is not considered firm dispatchable power by electric grid operators.

Current State of the Art for Grid-scale Energy Storage: The U.S. Department of Energy's Energy Storage Systems (ESS) Program has provided critical support for energy storage in testing, pilot scale demonstration, as well as authoring the handbook on grid deployment of existing storage technologies. More than 99% of existing grid-scale energy storage of electricity worldwide uses pumped hydroelectric storage.[19] Where suitable geographic and ecological conditions exist, pumped hydroelectric storage is well developed as an economically viable grid-scale storage solution.[20,21] However, many regions with energy storage needs do not have suitable conditions for widespread pumped hydroelectric. Even in regions with significant hydropower resources (such as the Columbia River basin), the widespread deployment of renewable generation resources is causing instability for the existing power grid which limits the continued rapid growth of intermittent renewable power sources such as wind and solar.[9] There is an urgent need for new storage technologies that

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[12] DOE Bonneville Power Administration, Wind Generation Capacity http://www.transmission.bpa.gov/business/operations/Wind/WIND_InstalledCapacity_current.xls

[13] E. Mainzer "Solving the Wind Integration Challenge" (Jan 2010) http://www.bpa.gov/corporate/WindPower/docs/2010-01-19_WIND-MainzerPresentation.pdf

[14] B. Lee and D. Gushee "*Massive Electricity Storage*" AIChE White Paper, AIChE/GRC (June 2008)

[15] R. Gramlisch and M. Goggin, "*The Ability of Current U.S. Electric Industry Structure and Transmission Rules to Accommodate High Wind Energy Penetration*" 7th International Workshop on Large Scale Integration of Wind Power and on Transmission Networks for Offshore Wind Farms (2008).

[16] B. Milligan, et.al. "*Impact of Electric Industry Structure on High Wind Penetration Potential*", NREL/TP-550-46273 (July 2009). http://www.nrel.gov/docs/fy09osti/46273.pdf

[17] B. Silverstein, "*Integrating Renewable Resources into the Electrical Grid*" FERC Technical Conference, (March 2, 2009) http://www.bpa.gov/Corporate/WindPower/docs/Silverstein_FERC_slides_March_2009.pdf

[18] Y.V. Makarov, et.al., "*Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the Bonneville Power Administation and California ISO Control Areas*," Pacific Northwest National Labs (PNNL-17574) 2008.

[19] B. Roberts, "Capturing Grid Power," *IEEE Power and Energy Magazine* (July/August 2009), p 32-41.

[20] EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications, (Final Report, 2003, Imre Gyuk, Project Manager) http://www.sandia.gov/ess/Publications/pubs.html

[21] *Energy Storage for Grid Connected Wind Generation Applications, EPRI-DOE Handbook Supplement* (Technical Update, 2004, Imre Gyuk, Project Manager) http://www.sandia.gov/ess/Publications/pubs.html

can provide the dispatchable power duration, low-cost, and life-cycle reliability of pumped hydroelectric, but provide scalability and siting for ubiquitous deployment across the grid.[22,23]

The next largest source of currently deployed grid-scale electric storage is sub-surface compressed air energy storage (CAES), with <500MW installed globally. The US Department of Energy is supporting several CAES pilot-projects through the Energy Storage Demonstration Program,[24] however the expansion of sub-surface CAES is challenged by the availability of sites with the requisite geology.

Figure 2 shows a map of various existing grid-level storage solutions in terms of cost metrics, response time and duration of operation. Hydroelectric and CAES are below a $100/kWh cost as systems. However, these technologies face challenges limiting their potential for ubiquitous and widespread deployment. Existing installations of other advanced grid-scale modular energy storage technologies (batteries, flow batteries, etc) add up to less than 370MW globally. The widespread deployment of these technologies is primarily limited by the high capital cost of energy using existing modular energy storage technologies. Hence, alternative technical approaches providing equivalent energy and power are urgently needed to address the challenge of grid-scale energy storage.

Need for New Technologies: The development of new technologies for the widespread deployment of cost-effective grid-scale energy storage will be critical in enabling the drive toward low-carbon electric power generation. Cost-effective grid scale electrical storage will simultaneously increase grid reliability, reduce CO_2 emissions, and enable widespread penetration of intermittent renewable generation. The development of disruptive new low-cost grid-scale energy storage technologies will also allow the U.S. to assume global technology and manufacturing leadership in the emerging and potentially massive global market for grid-scale energy storage infrastructure.

In this program, ARPA-E seeks the development of revolutionary new technology approaches to grid-scale electrical energy storage which can provide the energy, cost, and cycle life of pumped hydropower (<$100/kWh and >5000 cycles) but which are modular and can be made available for widespread use at any location across the power grid. While many valuable applications for grid storage exist, this program focuses on developing revolutionary new grid-scale energy storage technologies to balance short-duration variability in renewable generation. The required grid-scale storage technology will be able to deliver full power within 10 minutes, provide at least 60 minutes of energy at rated power, and cycle between charge and discharge mode throughout the day with high round trip energy efficiency (>80%).

[22] E. Mainzer "Solving the Wind Integration Challenge" (Jan 2010) http://www.bpa.gov/corporate/WindPower/docs/2010-01-19_WIND-MainzerPresentation.pdf
[23] T. Moore and J. Douglas "Energy Storage: Big Opportunities on a Smaller Scale" *EPRI Journal* (Spring 2006) http://mydocs.epri.com/docs/CorporateDocuments/EPRI_Journal/2006-Spring/1013289_storage.pdf
[24] DOE Office of Energy, ARRA Smart-Grid Demonstration Grant Programs: http://www.energy.gov/news2009/documents2009/SG_Demo_Project_List_11.24.09.pdf

This program will focus on technology prototyping and proof-of-concept R&D efforts, not pilot demonstration projects. Ultimately, technologies developed in this program must be scalable to the GW and GW-hr levels of power and energy capacity, respectively. However, for this program, technology prototypes at a scale of ~20 kW or greater are expected; units of this size are scaled large enough to demonstrate the technical concept, yet are small enough to focus on technology development rather than pilot-scale development. The scientific and technical advances through this project

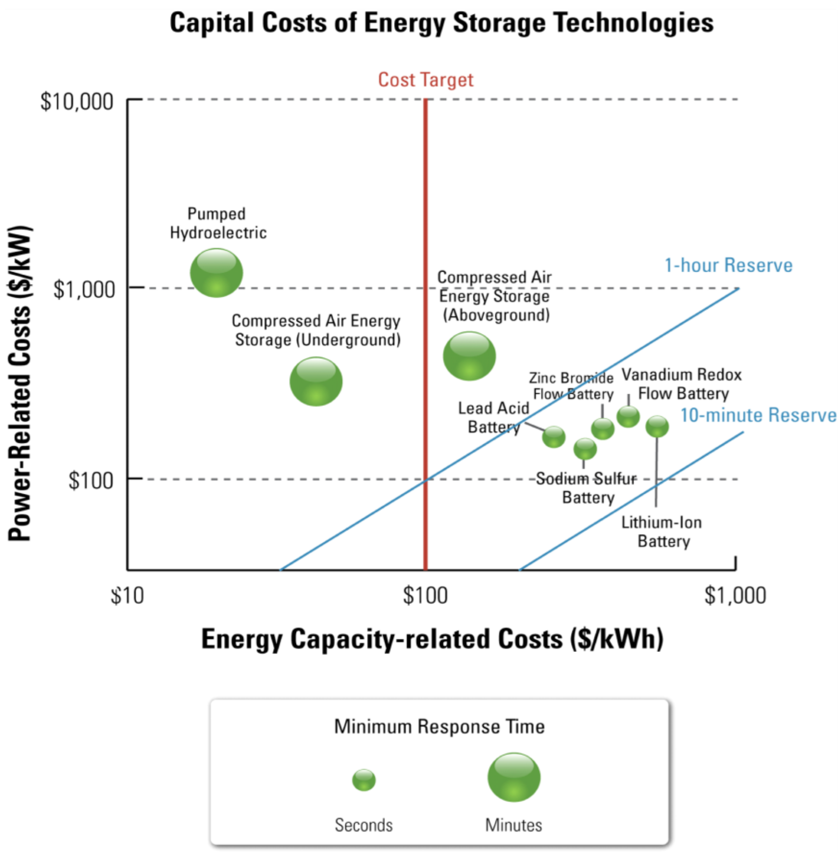

Figure 2: Energy and power costs bound a range of duration for various grid-scale electric storage technologies, with energy cost targets and minimum response time requirements for economically viable, dispatchable electric grid integration. Pumped hydroelectric and underground compressed air-energy storage are economically deployable in suitable locations. New storage technologies are needed to provide broader siting opportunities at economically favorable costs are needed for grid-scale deployment. With new development, such technologies might include advanced lead-acid batteries (PbA), Zinc-Bromide flow batteries (Zn-Br), Sodium-Sulfur (NaS) batteries, Lithium-ion (Li-ion) batteries and Vanadium Redox (VR) flow batteries.

are expected to have a transformational impact on grid-scale energy storage.

B.2 OBJECTIVES

The GRIDS program is focused on supporting high-risk, high-impact R&D efforts to develop proof-of-concept technologies and advanced system prototypes with high potential to revolutionize grid-scale electric energy storage. The developed technologies will have potential to achieve the economics of pumped hydroelectric storage yet may be deployed at any location on the grid. Projects must be capable of meeting technical criteria for energy, cost and reserve time of hydroelectric, as it is used for power regulation of large-scale intermittent generation as described below.

The technical requirements in this FOA are based on the economics of hydroelectric storage, which is currently used to provide large scale power firming for renewable intermittency at a capital cost for energy less than $100/ kWh at megawatts of power, with capacity of 100s of MW and 1,000's of MW-hr of power and energy, respectively in specific locations. But hydroelectric storage is not scalable or feasible in all geographic locations. This FOA seeks to support the development of grid-scale electrical energy storage technologies that show strong promise of subsequent scalability to GW of power, GW-hr of energy capacity cumulatively, can deliver for full power (100% of rated power) within 10 minutes, and are capable of operating for durations of at least 60 minutes at their rated power, and with an energy cost below $100/kWh.[25]

While hydropower can operate for up to 20,000 charge and discharge cycles before an overhaul is required, technologies demonstrated under this FOA must operate up to at least 5,000 charge and discharge cycles without degradation in power or storage capacity. This number of cycles represents a useful life of approximately 10 years, a minimum life required for initial use in a utility environment.[26] In order to operate on a cost competitive basis, the round-trip energy efficiency for stored electricity must exceed 80% per cycle, measured as energy from grid-to-grid, with all additional external energy inputs accounted for as electric energy equivalents. Measurement for a minimum of 60-minutes at rated power will be used for evaluation of round-trip efficiency and load duration. The electric energy costs ($/kWh) should be calculated on a total installed cost basis for energy capacity at rated power, not for de-rated operation.

Alternative approaches for grid-scale energy storage include, but are not limited to, those outlined in Figure 2.[27] For electric storage with a 5000 cycle lifetime, round trip efficiency of 80% and $100/kWh storage cost, the premium cost per storage cycle for storage would be $0.025 / KWh_e above the electricity cost, which is within the predicted cost range for technology adoption relative to the cost of alternative approaches to regulation power.[28,29]

B.3 AREAS OF INTEREST

Innovative technical approaches to grid-scale energy storage technologies able to approach, meet or exceed the "Primary Technical Requirements" and to approach, meet or exceed a majority of the "Secondary Technical Targets" stated below are of high interest. Areas of particular interest include, but are not limited to:

- Novel approaches to batteries, flow-batteries, fuel-cells, compressed air (non-traditional); superconducting-magnetic storage, ultra-high energy density flywheels, localized fluid pumping, high-scale ultracapacitors, or a combination of novel technologies to economically meet grid-scale storage energy and power requirements.

- ARPA-E believes there are particular opportunities for advancing grid-scale storage technologies in areas including, but not limited to:
  - Electrochemical energy storage approaches based upon very low cost materials.
  - Novel approaches to compressed air energy storage (CAES), including systems with unique siting (including above ground and underwater) and systems that offer higher efficiencies and fast start-up times
  - Extremely high energy density, low cost flywheel technologies

[25] *Market Driven Distributed Energy Storage Requirements for Load Management Applications* (EPRI Report 1014668) D. Rastler, Project Manager (2007)
[26] *Electric Energy Storage, Primer on Applications, Costs and Benefits, (*EPRI Energy Storage Program, Draft 12/2009, D. Rastler Program Manager) [Report ID: 1020676]
[27] S. Schoenung and W. Hassenzahl "Long- vs. Short-Term Energy Storage Technologies Analysis: A Life-Cycle Cost Study" , Sandia Report: SAND2003-2783 (2003).
[28] ARPA-E calculation using:

$$Cost\ per Storage Cycle(\$/kWh_e) = \frac{Energy Storage Cost(\$/kWh)}{Cycles(\#) \times Round Trip\ Efficiency(\%)}$$

This calculation provides the "cost premium" for storage by allocating storage capital investment costs for energy at rated power ($/kWh) as a cost per storage cycle. This cost premium is in addition to the cost of stored electricity for storage. The cost premium considers only allocation of storage asset cost to the stored electricity, and does not include allocation of operation or maintenance expenses. http://www.electricitystorage.org/site/technologies/
[29] B. Milligan, "Analysis of Sub-Hourly Ramping Impacts of Wind Energy and Balancing Area Size" *Windpower 2009,* NREL/CP-500-43434 (June 2008) http://www.ornl.gov/sci/ees/pes/pubs/WindPower_2008_Analysis_of_Sub-hourly_Ramping.pdf (Premium for reserve power supporting ramp can be up to $0.90/kWh)

- New approaches to flow batteries that offer lower costs, higher power, and improved roundtrip efficiency through advanced power modules and novel storage chemistries
- Devices using higher critical current density superconducting storage materials
- Unique energy storage system designs that may have been unproven and deemed too technically risky for the prior Department of Energy's Office of Electricity Delivery and Energy Reliability led Energy Storage Demonstration Projects of the Smart-Grid Demonstration Grants Program [30].

- Energy storage systems that demonstrate a clear path to grid-scale deployment, providing 1MW - 10MW of power. Particularly for technologies such as flow-batteries for which energy and power costs may be scaled separately, ARPA-E is most interested in supporting technologies which address grid-scale challenges (MW), even though the solutions are being assessed in a downscaled (kW) advanced system prototype.

Areas of Supplemental or Secondary Interest

- Energy storage systems that may reliably operate on an unattended basis for extended periods of time (years) with low requirements for maintenance and low probability of irreparable damage due to conditions expected for grid assets.

- Energy storage systems deployable across a range of geographical (mountain/plains/coastal) or demographic (urban/rural) locations, including deployment which may be constrained by existing substation facilities size and location.

- Energy storage systems that are based on low-cost materials or have a low dependency on strategic/critical resources or materials, specifically such as alkali-metal or rare-earth metals of potentially limited domestic availability.

- Advanced power conditioning systems in "Advanced Systems Prototyping" category projects, based on novel low-loss power electronics which have the potential to significantly improve system functionality such as round trip efficiency or provide multiple mode operation.

- Energy storage solutions that are fault-tolerant to unscheduled disruptions including black-out.

Specifically Not of Interest

- Incremental improvements to, or combinations of, existing products or technologies with no additional advances in understanding or reduction in technical uncertainty.

- Pilot-plant demonstrations, which do not include a significant degree of technical risk or requirement for scientific research.

- Thermal storage, electricity demand response, or distributed generation, unless proposed as a part of an overall MW_e-in to MW_e -out electricity storage system.

[30] https://www.fedconnect.net/FedConnect/PublicPages/PublicSearch/Public_Opportunities.aspx, Reference # DE-FOA-0000036, (6/27/2009) "Smart Grid Demonstration Grant"

- Engineering of repurposed storage materials and devices (including used automotive batteries), unless proposed effort describes a specific high-risk technical challenge being addressed.

- Simulation and control studies of storage assets across the power grid that do not include a specific storage device.

It is assumed that any storage technology being considered by this program must show the capacity to operate unattended under typical environmental conditions and reliability requirements of power grid assets, including operation, maintenance, footprint, or safety considerations, as well as compliance with requirements of State and Federal regulatory organizations.[31] For the purpose of the proposed efforts, technologies relevant to the North American 60Hz AC grid will be assumed, unless otherwise explicitly stated and justified by the proposer.

B.4 TECHNICAL REQUIREMENTS

This FOA is focused around supporting grid-scale electric energy storage technology research and development projects that are able to address the specific quantitative performance targets and cost metrics described below. Proposed technical development plans must have well justified, realistic potential to credibly approach, meet or exceed the stated "Primary Technical Requirements" by the end of the period of performance for the proposed project in order to be considered for award. Proposed technologies will secondarily be evaluated against their potential to approach or meet the "Secondary Technical Targets" by the end of the period of performance for the proposed project. Proposed technologies will still be considered for award if they may fall short of one or more of the Technical Targets, but will be competitively evaluated and compared according to ability to address these targets.

The Primary Technical Requirements and Secondary Technical Targets for this FOA are clearly stated in the two tables below.

PRIMARY TECHNICAL REQUIREMENTS:

Requirement ID Number	***Requirement Category***	***Value (Units)***
1.1	System Capital Cost per Unit of Rated Energy Capacity (for measured capacity at Rated Power)	<$100/kWh
1.2	Minimum Operating Time at Rated Power (time at Rated Power for charge and discharge)	60 minutes
1.3	Maximum Response Time (time for system to go from 0% to 100% of rated power in discharge and in charge mode)	10 minutes

[31] Smart Grid Interoperability Panel,

http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/SGIPRecognizedStandards

1.4	Rated Power Capacity for Charge and Discharge in Advanced System Prototypes	≥20kW

SECONDARY TECHNICAL TARGETS:

Target ID Number	***Target Category***	***Description***
2.1	Cycle Life (cycled at rated power between charge and discharge)	5,000 cycle minimum, defined as number of cycles at which >20% reduction in total energy/power capability occurs relative to initial rated values
2.2	Round-Trip Efficiency	80% at rated power for of charge and discharge
2.3	Maximum Dwell Time	Maximum 10 minute response time for reversal between charge and discharge cycles
2.4	Scalability of Storage Technology for Grid-scale Application	Potential for subsequent scaling for grid-scale deployment (1-10MW). Scalability will be assessed at the power/energy ratio of the advanced systems prototype proposed.
2.5	Internal Losses	Less than 5% loss of energy in 24 hours from fully charged state.
2.6	Safety	Consistent with transmission and distribution grid deployment at unattended locations
2.7	Calendar Life	10 years minimum

ARPA-E will not consider selecting projects for award that do not clearly demonstrate realistic, well-justified potential to approach, meet or exceed the Primary Technical Requirements stated above by the end of the period of performance. With regard to Primary Technical Requirement 1.1, the system level cost requirement, ARPA-E understands that not all applicants will have access to sophisticated energy storage systems cost modeling. It is expected that all applicants will make a strong effort to justify how the technology holds promise to meet this FOA's $100/kWh cost target. The cost target is intended to be a forward looking consideration of energy storage system costs, including power conditioning system and balance of plant, assuming successful technology development as an advanced prototype, and subsequent scaling of manufacturing for grid-scale deployment.

ARPA-E expects that all novel energy storage approaches with the potential to achieve the aggressive cost and storage duration targets of the Primary Technical Requirements will likely have unique technology challenges in meeting the Secondary Technical Targets. ARPA-E will expect that each proposal will have strengths and weaknesses as it relates to Secondary Technical Targets. End of project performance target shortcomings relative to one or more Secondary Technical Targets will not preclude consideration for selection for award. However, it is expected that all proposed energy storage research and development plans will result in at least approaching the stated Secondary Technical

Targets by the end of the project period of performance and proposals will be evaluated against the proposed technology research and development plan's ability to do so.

ARPA-E will set aggressive intermediate "go-no go" metrics for each project selected for award under this FOA and will use independent external partners to validate the demonstrated performance of all proof of concept storage components / advanced system prototypes developed under this FOA, including standard tests of safety and reliability as well as accelerated testing to determine calendar life. For the purposes of this FOA, energy capacity (kWh) will be determined as the product of rated power (kW) and measured duration (hours) at rated power.

Other Technical Requirements:

In addition to the Primary Technical Requirements and the Secondary Technical Targets detailed above, applicants must address the following key technical requirements:

A.) Manufacturability of Proposed Technology at Scale

The applicant must describe the manufacturing approach(es) that will most likely be used to ultimately scale-up the proposed energy storage technology from the kW scale advanced prototype in the proposed effort to the MW scale for subsequent grid-scale deployment. This description must discuss the ability of this/these manufacturing approach(es) to scale at sufficiently low cost to address the $100/kWh Primary Technical Requirement. Applicants are also encourages to describe whether or not the proposed energy storage technology offers an opportunity for the U.S. to take a leadership role in grid-scale energy storage manufacturing and to provide a justification.

B.) Technical Strength of the Performance Team

The applicant should describe the unique elements/background/skills of the proposed technical team that makes the team uniquely suited to successfully execute the proposed energy storage research and development plan.

B.5 CONCEPT PAPER STRUCTURE

Applicants are required to first submit a Concept Paper describing the essence and novelty of their new technology concept in order to be considered for award under this FOA. The purpose of the Concept Paper phase of this FOA is to allow applicants to communicate their grid-scale energy storage technology concept to ARPA-E, with a minimal level of investment in time and resources, and receive feedback on ARPA-E's level of interest in the concept before ARPA-E requests the submission of a more time and resource intensive Full Application.

General Concept Paper requirements can be found in Section IV.B.2 of this FOA. Specific requirements and key elements that each Concept Paper must address are found in this section (Section I.B.5) and in the rest of Section I.B.

As stated in Section IV.B.2, Concept Paper will consist of a body not exceeding five (5) pages in length containing the following sections: 1.) Abstract and 2.) Technical Section. The Concept Paper will also include a one page "Cost Summary" (described in Section IV.B.2) and a one page completed "End of Project Targets" table that should be included in a single Concept Paper file, but will not count toward the five (5) page Concept Paper body limit. The End of Project Targets table will include the end of project target for the scale and form factor of the prototype device deliverable, as well as the end of project targets for all Primary Technical Requirements and Secondary Technical Targets. The "End of Project Targets" template can be found in Appendix 1 in Section X.

TECHNICAL SECTION

Specific issues/questions that should be considered and addressed in the Technical Section include the following:

- Identification of whether the applicant is applying for an award under the "Proof of Concept Seedling" category or the "Advanced Systems Prototyping" category.
- A detailed description of the novel technology approach to be developed in the proposed project, including a description of its basic operating principles and how the proposed approach is unique and innovative. To the degree possible, preliminary data supporting any novel technology claims should be included.
- A description of the current state-of-the-art in the proposed technology area, including key shortcomings/limitations/challenges, and how the proposed project will seek to significantly improve upon the current state-of-the-art performance and overcome current key shortcomings/limitations.
- The applicant should provide a brief paragraph addressing the following issues for each of the Primary Technical Requirements (1.1-1.4) and Secondary Technical Targets (2.1-2.7)
  - What is the current state-of-the-art performance level for the proposed technology area for the specified requirement/target?
  - What level of performance will the project proposed target for the specified requirement/target? What are the specific technical issues that have limited performance of this technology to date for the specified requirement or target?
  - How does the project proposed address these specific technical issues to provide enhanced performance relative to the specified requirement or target? The applicant should provide technical justification and preferably preliminary data for why this proposed target can credibly be met.
  - What are the key technical risks/issues associated with the technology development plan related to the specified requirement or target?
- A brief description of the subsequent manufacturing or pilot-design approach by which the proposed energy storage technology would be scaled to grid-scale integration and the scalability/cost issues related to this approach.
- A brief description of how the project, if successful, would impact U.S. leadership in grid-scale energy storage technology development and manufacturing.
- A brief description of the project team and why they are uniquely suited to successfully execute the proposed battery research and development plan.
- A brief description of the impact ARPA-E funding on the proposed project relative to other previous or existing funding sources the project team has secured.

B.6 CONCEPT PAPER EVALUATION CRITERIA

General Concept Paper Evaluation Criteria are found in Section V.A. of this FOA. More specific Concept Paper Evaluation Criteria are described in this section.

Concept Papers will be evaluated against the following evaluation criteria in decreasing order of importance:

- To what degree does the Concept Paper present a grid-scale energy storage technology development plan that demonstrates credible and well-justified technical potential to approach, meet or exceed each of the Primary Technical Requirements of this FOA. Technology approaches will be evaluated in a quantitative fashion, with technology approaches rated according to the degree to which they fall short of, meet, or exceed each Primary Technical Requirement.

- To what degree does the Concept Paper present a grid-scale energy storage technology development plan that demonstrates credible and well-justified technical potential to approach, meet or exceed each of the Secondary Technical Targets of this FOA. Technology approaches will be evaluated in a quantitative fashion, with technology approaches rated according to the degree to which they fall short of, meet, or exceed each Secondary Technical Target.

- To what degree does the Concept Paper present a unique and innovative technical approach to significantly improve grid-scale energy storage performance over the current state-of-the-art.

- To what degree does the Concept Paper present a clearly demonstrated understanding of the current state-of-the-art and technical limitations of the current state-of-the-art in the relevant technology area.

- To what degree does the grid-scale energy storage technology proposed in the Concept Paper hold potential to enable U.S. technology, manufacturing, and deployment leadership in grid-scale energy storage systems markets.

- To what degree does the proposed technical team have the skills and knowledge to successfully execute the project plan

- To what degree will ARPA-E funding have a leveraged impact on the development of the proposed technology relative to other funding sources for the project team.