CHANGING WHAT'S POSSIBLE

AMPED Program Overview

C. PROGRAM OVERVIEW

Energy storage can significantly improve U.S. energy independence, efficiency, and security by enabling a new generation of electric vehicles and by enhancing the capabilities of the U.S. electricity grid.[1] While rapid advances are being made in research and development of new battery materials and storage technologies, few transformational innovations have emerged in the management of energy storage systems.[2,3,4] Batteries are complex systems, and developing techniques to cost-effectively monitor, manage, and predict important performance measures remains a key technological challenge. As a result, many battery systems are over-designed and operated well below their maximum energy and power capabilities to meet operational requirements that minimize the risk of premature or catastrophic failure. AMPED seeks to develop breakthrough technologies that can be practically deployed for superior management of commercial battery systems.

A Critical Need for Advances in Energy Storage Management Technology

Advances in energy storage management can rapidly accelerate the widespread adoption of electric vehicles and grid-scale energy storage. Today's electric vehicles illustrate the potential impact of superior management of energy storage devices. A typical electric or plug-in electric vehicle generally employs between 25% and 100% excess energy capacity (beyond what is required to propel the vehicle) in order to provide a conservative buffer to avoid unwanted cell degradation. A further 25-100% burden on weight, volume, and cost is levied by the various assemblies and components required to safely and reliably interconnect and manage these cells in a full battery pack.[5] In the worst case, this results in a vehicle battery system that is oversized by a factor of four. This overdesign directly translates into added weight, volume, and upfront capital cost to the consumer and presents a major barrier to mass-market adoption of electric vehicles.

Even with such conservatively engineered systems, the safety and lifetime of batteries remain a liability for automakers. Cases of premature failure in automotive batteries have already led to significant consumer dissatisfaction.[6] Meanwhile, automotive OEM concerns over safety have escalated with recent battery recalls and fires, an issue that in recent years cost hundreds of millions of dollars to consumer battery manufacturers in recalls and litigation.[7,8,9,10] Safety and lifetime risks meanwhile prohibit rapid charging of most electric vehicles, which has been shown to be a key market inhibitor.[11] While the full impact of safety concerns on electric vehicle adoption requires further investigation, it is clear that uncertainties over battery safety and life can directly affect the cost and risk of deployment.[12,13]

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[1] Goodenough, J. B. *et al.* Basic research needs for electrical energy storage. *Report of the Basic Energy Sciences Workshop for Electrical Energy Storage*, Department of Energy: Washington, DC, 2007.
[2] Armand, M. and Tarascon, J.M. Building better batteries. *Nature*, 451, 7179 (2008).
[3] http://arpa-e.energy.gov/ProgramsProjects/BEEST.aspx
[4] http://arpa-e.energy.gov/ProgramsProjects/GRIDS.aspx
[5] Raghavan, S. and Khaligh, A. Electrification potential factor: Energy-based value proposition analysis of plug-In hybrid electric vehicles. *IEEE Transactions on Vehicular Technology*, 61, 3, 1052-1059 (2012).
[6] Bensinger, K. Fix for Civic hybrids' dying batteries may hurt gas mileage, acceleration. *Los Angeles Times*, August 14 (2010) http://articles.latimes.com/2010/aug/14/business/la-fi-honda-20100815.
7 Trudell, C. and Ohnsman, A. A123 replacing batteries that led to Fisker Karma shutdown. *Bloomberg*, March 26 (2012) http://webfarm.bloomberg.com/news/2012-03-26/a123-replacing-defective-batteries-that-led-to-fisker-shutdown.html.
8 Green, J. *et al*. GM volt fire after crash said to prompt lithium-battery probe. *Bloomberg,* November 12 (2011) http://www.bloomberg.com/news/2011-11-11/gm-volt-battery-fire-is-said-to-prompt-u-s-probe-into-electric-car-safety.html.
9 NHTSA Statement on conclusion of chevy volt investigation. *NHTSA.gov*, January 20 (2012) http://www.nhtsa.gov/About+NHTSA/Press+Releases/2012/NHTSA+Statement+on+Conclusion+of+Chevy+Volt+Investigation.
10 Arendt, S. Sony battery recall costs $429 million. *PCMag.com*, October 26 (2006) http://www.pcmag.com/article2/0,2817,2040936,00.asp.
11 Hidrue, M. *et* al. Willingness to pay for electric vehicles and their attributes. *Resource and Energy Economics*, 33, 3, 686-705 (2011).
12 In the early 2000s, the United States Navy and United States Special Operations Command, developed and operated the Advanced SEAL Delivery System (ASDS). Unfortunately, the ASDS project came to a dramatic halt after a massive fire destroyed the one and only prototype submarine. The submersible's newly installed lithium ion batteries, during charging, ignited a fire which burned for nearly six hours, destroying the interior of the submarine. This unfortunate incident has contributed to the inability to use high energy and power storage devices on military platforms.
13 Cavas, C. Fire deals new setback to Navy's heralded mini-sub. *Navy Times*, *NavySEALs.com*, December 15 (2008) http://www.navyseals.com/fire-deals-new-setback-navys-heralded-mini-sub.

One proposed approach to maximize payback and offset the high cost of energy storage is to employ battery systems in secondary applications, either concurrent with or subsequent to primary use. Recent studies have shown that vehicle-to-grid energy storage use has the potential to provide sufficient capacity to enable large-scale adoption of intermittent renewable power (e.g. up to 50% wind) on the U.S. grid, meanwhile allowing vehicle owners to offset a significant portion of the cost of their electric vehicle battery.[14,15] Presently, a major technological barrier that prevents the dual-use of battery systems is the inability to accurately assess, predict, and maximize remaining battery life and value after retirement from its primary application.[16,17]

The need for advanced battery management is similarly pronounced for energy storage systems designed specifically to provide grid support. These battery systems suffer from similar under-utilization losses as those that plague automotive batteries.[18] Meanwhile, the inability to accurately predict and maintain long life batteries is a key barrier to commercial adoption, since viability of grid-storage systems depends entirely on the ability to offer a solid case for return-on-investment over a 20-30 year asset life. Finally, safety is a major concern for grid-scale energy storage systems due to the sheer size of these battery systems and the commensurate risk. Recent examples of catastrophic failure of grid-scale energy storage batteries highlight the need for improving the detection of potential safety events in large-scale grid-storage battery system.[19]

The Challenges of Battery Management and Opportunities for Breakthrough Technology Development

The challenge of battery management stems from the complexity of battery devices, compounded by the aggressive operational demands and severe cost constraints of intended applications.[20] Even the simplest charging and discharging scheme of an electrochemical battery depends on a wide-range of thermodynamic, kinetic, and transport processes. These processes are coupled with and dependent on the operating conditions of the battery.[21] To some extent, these processes can be represented by theoretical models; however, even the best models cannot predict the complex degradation and failure mechanisms that emerge from the confluence of highly coupled reactions with unpredictable operating and environmental stresses, defects, chemical impurities and other physical realities.[22,23,24] As a result, industry relies on years of empirical testing to identify and validate failure mechanisms.

To ensure the reliability of their products, manufacturers impose tight constraints on battery operating conditions that help guarantee battery life and safety. For example, most commercial lithium-ion battery systems only allow access to a fraction of the capacity stored by the device (ranging from 10% to 80%, depending on the application),[25] and power capabilities are likewise tightly restricted. Limiting battery utilization to achieve design life and safety is unavoidable due to the fundamental nature of degradation and failure mechanisms; however, today's restrictions are very conservative, severely limiting performance and increasing cost.

Conservative rule-based control is relied upon in part to deal with uncertainties in degradation and lifetime, but also to accommodate an inability to accurately determine a battery's state and vulnerability to failure. In theory, operating constraints are intended to manage the physical state of a battery cell and limit its susceptibility to adverse reactions. In practice, however, we lack the ability to probe parameters that directly reflect key physical

14 Jaffe, S. Economic and cost modeling of the repurposing of electric vehicle batteries for stationary storage applications. *Biennial International Conference on Electrical Energy Storage Applications and Technology*, October (2011) http://www.sandia.gov/eesat/2011/papers/Tuesday/19_Jaffe_ESSAT_Abstract.pdf.

15 Sovacool, B. and Hirsh, R. Beyond batteries: An examination of the benefits and barriers to Plug-in Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-Grid (V2G) transition. *Energy Policy*, 37, 1095–1103 (2009).

16 Kempton, W. and Tomic, J. Vehicle to grid power fundamentals: Calculating capacity and revenue. *Journal of Power Sources*, 144, 268–279 (2005).

17 Hilletal, D. *et al*. Fleet operator risks for using fleets for V2G regulation. *Energy Policy*, 41, 221–231 (2012).

18 Campbell C., Vartanian C. A123's Advanced grid storage, extending our experience to distributed resource applications and microgrids. *2nd International Conference in Microgeneration and Related Technologies*, April (2011) http://microgen11.supergen-hidef.org/microgenII/CD/full_papers/p154vFINAL.pdf.

19 Q&A concerning the NAS battery fire, December (2011) http://www.ngk.co.jp/english/announce/111031_nas.html.

20 Linden, D. and Reddy, T. Handbook of Batteries 3rd Edition, *McGraw-Hill*, 2001.

21 Newman, J. and Thomas-Alyea, K.E., Electrochemical Systems 3rd Edition, *Wiley-Interscience*, 2004.

22 Ramadesigan, V. *et al.* Modeling and simulation of lithium-Ion batteries from a systems engineering perspective. *J. of Electrochemical Soc*. 159, 3 (2012).

23 Vetter, J. *et al.* Aging mechanisms in lithium-ion batteries. *J. Power Sources*, 147, 1-2 (2005).

24 Broussely M. *et al.* Main aging mechanisms in Li-ion batteries. *J. Power Sources*, 146, 1-2 (2005).

25 Turrentine, T. Plug-in Hybrid Electric Vehicle Research Roadmap. *UC Davis Plug-In Hybrid Electric Vehicle Research Center*, June 2011.

properties related to the degradation and failure of batteries. State estimation in current battery management is based on simple voltage, current, and temperature measurements, which provide little direct information on the physical and chemical state internal to the cell. Moreover, these measurements generally lack the spatial and/or temporal resolution to adequately probe localized phenomena that can be key contributors to failure. With enhanced real-time state determination, not only could the fixed operating constraints imposed today be narrowed, they could be adjusted and optimized dynamically to ensure maximum utilization at any given point in time. Advanced physical and electrochemical models that are able to deconvolve state-measurements to calculate and predict individual cell behavior is one possible enabler. Due to their high degree of complexity and long time to validation, these models have been of limited utility in setting real-time operational constraints and managing control of commercial systems. This is unlikely to change without entirely new tools and approaches to creating and validating such models for commercial use. Meanwhile, a compelling and underexplored alternative is to obviate the need for complex models by employing sensing technologies that can dramatically enhance the fidelity of current state-measurements, or *directly* probe physical parameters, such as structure and chemical composition, that would allow active and dynamic cell monitoring and management.

Moving from conservative rule-based management to control algorithms that rely instead on high-accuracy physical and electrochemical state determination could allow for dramatic improvements in performance. A recent study estimated that charging rates, overall power density, and available energy could be increased by approximately 50%, 22%, and 212%, respectively, for a hybrid-electric vehicle battery pack (6 Ah, 72 cell, 276 V Li-ion), by basing control on physical saturation/depletion and side reaction limits rather than more conservative fixed voltage limits.[26] ARPA-E believes that similar or even larger performance enhancements are possible with advanced battery management technologies based on better state determination and dynamic control.

Managing individual storage devices is a challenge; but even more difficult is the case of managing fully integrated battery systems, where hundreds or thousands of electrochemical cells are electrically coupled to meet energy and power requirements. The cost of monitoring and control of individual cells is currently not practical, so groups of cells in series and parallel configurations have coupled and interacting states. Moreover, cells subjected to different environments experience different degradation, a problem that is then accelerated by inter-cell interactions. This mandates active management of the environment and justifies the need for highly engineered and expensive thermal management. Even harder to manage is cell-to-cell variability, which despite efforts to bin cells for consistency, can cause cells to be driven into different states even when subjected to identical loads and environments.[27,28]

ARPA-E sees opportunity for innovation in design and control of systems to manage the difficulties of maintaining the state of health and safety of batteries. New approaches to achieve higher fidelity, more robust and lower cost sensing and control of the environment across a battery pack are needed. Approaches that optimize dispatch via power electronics could also be employed to achieve performance gains in existing system architectures or to enable new designs that employ hybrid or flexible cell configurations. It is possible that a breakthrough can be achieved through any number of creative approaches; however, no solution will be transformational unless it can provide system level benefits that far exceed its implementation cost. AMPED seeks to support transformational new approaches to render novel system and control solutions that are feasible and cost-effective.

It is unlikely that any one particular innovation will completely solve the challenges of battery management. However, comprehensive system-level solutions that combine data from novel sensors with advanced models, system designs, and control paradigms can allow us to drastically enhance the utilization and rate capabilities of battery systems within safe limits, while extending their life and meeting operational requirements. Such an energy management system would be a game changer—significantly accelerating the adoption of energy storage for primary applications across a multitude of sectors and opening the door to dual or secondary use applications. Moreover, energy storage management breakthroughs will not only improve the capabilities of today's state-of-the-art technologies, but will also be applicable to new battery chemistries, thus providing a multiplier effect to the development of next generation energy storage materials and designs.

[26] Smith, K.A. and Wang, C.-Y. Power and thermal characterization of a lithium-ion battery pack for hybrid-electric vehicles. *J. Power Sources*, 160, 662-673 (2006).
[27] Moore, S. and Schneider, P. A review of cell equalization methods for lithium ion and lithium polymer battery systems. *Society of Automotive Engineers*, 2001.
[28] Dreyer, W. *et al.* The thermodynamic origin of hysteresis in insertion batteries. *Nature Materials,* 9, 448-453 (2010).

D. PROGRAM OBJECTIVES

AMPED seeks to support breakthrough solutions that offer a realistic path to achieve one or more of the targeted capabilities listed below. *Technologies that enable any single capability will be considered for award under this FOA, but a strong preference will be given to system-level solutions that can demonstrate the potential to substantially impact more than one of the objectives.*

Objective 1: Safety and Reliability

AMPED aims to reduce barriers to market-adoption and costs associated with safety risk and liability of current and future advanced battery systems. To constitute a significant improvement over the state-of-the-art, solutions should cost-effectively allow for fail-safe operation without the need for overly conservative energy and power utilization, while minimizing burdensome thermal and isolation system requirements. Approaches should manage known failure modes as well as those that are unexpected, such as events arising from cell design flaws, manufacturing defects, or unforeseen reactions occurring in use. AMPED seeks to enable the following new capabilities for improved safety:

Capability 1.1: Real-time detection of internal cell faults
Solutions should demonstrate the ability to detect internal mechanical faults with the goal of preventing costly and dangerous cell failures.

Capability 1.2: Prevention of catastrophic failure
Solutions should demonstrate the ability to automatically prevent catastrophic failure due to internal cell faults.

Objective 2: Performance

AMPED aims to drive adoption of energy storage systems with breakthroughs in performance enabled through superior energy management technologies. This objective area is intended to capture the following cost and performance improvements that advanced management technologies and architectures may provide:

Capability 2.1: System Performance Improvement
Solutions should demonstrate a significant enhancement in the overall performance of a battery system via a reduction in overdesign (cost, weight, or volume) and/or via an increase in operating performance (lifetime, energy utilization, and/or power utilization) through advances in battery management. Examples of approaches that may be employed to achieve this objective include, but are not limited to:

For Reducing Overdesign

- Approaches that enable more accurate state-of-charge (SOC) estimation for overdesign reduction
- Approaches that reduce battery management system component mass and/or volume (e.g. wiring, sensors, etc.)
- Approaches that enable safe and reliable operation of higher-capacity cells, yielding higher packing factor
- Approaches that relax requirements on other balance of system components (e.g. thermal, isolation, etc.)
- Approaches that reduce over-sizing needed to accommodate end-of-life performance

For Increasing Operating Performance

- Techniques that dynamically control SOC allowance to maximize utilization and/or lifetime, without compromising other key performance metrics
- Approaches that dynamically control power capability at high and low SOC to maximize utilization and/or lifetime, without compromising other key performance metrics

Capability 2.2: Charge Rate Improvement
Solutions should demonstrate the ability to enable charging at significantly higher rates than currently achievable, without compromising system safety, energy density, or lifetime. Examples of approaches that may be employed to achieve this objective include, but are not limited to:

- Approaches that enable safe charging at higher rates through the prediction or avoidance of incipient cell faults
- Approaches that enable safe charging at higher rates through novel approaches to system design and/or control
- Approaches that utilize advanced SOC estimation to adaptively determine charging protocols

Objective 3: Prognostics

AMPED aims to reduce uncertainty of remaining battery life and value for primary and secondary applications. Improved prognostics are necessary to fully exploit the benefits of advanced robust and adaptive management solutions in primary applications. Meanwhile, use of batteries in secondary applications can unleash significant value, but remains unfeasible without a clear means to ensure that this additional value outweighs any potential impact on life and safety. AMPED seeks to enable the following new capabilities:

Capability 3.1: Improvement *in lifetime prediction of advanced battery systems*
Solutions should demonstrate the ability to predict how specific duty cycles would impact lifetime of advanced battery systems—more quickly, economically, and with a higher degree of accuracy than currently achievable.

E. TECHNICAL AREAS OF INTEREST

Areas of interest for this FOA include, but are not limited to the following: advanced sensing, diagnostic and prognostic technologies, energy storage system designs, and control capabilities. Specific areas of interest include:

Area 1: Online Sensing

- Sensors that probe internal physical cell properties directly (i.e. structure, chemical composition, temperature, pressure, etc.)
- Sensors leveraging techniques and approaches from other fields
- Sensing approaches leveraging rapid progress in cost-performance learning curves of underlying technologies
- Sensors providing dramatically enhanced spatial and/or temporal resolution relative to the state-of-the-art
- Sensors integrated into cells and/or packs as an added component or in the form of a smart component or additive
  Invasive and non-invasive cell-level or pack-level sensors

Area 2: Offline or Online characterization for fast monitoring and prediction

- Diagnostic and prognostic tools that can be integrated into charging equipment
- Tools that allow for rapid validation and parameterization of diagnostic and prognostic models

Area 3: Technologies that enable active cell-level balancing and control

- Technologies to dramatically enhance capabilities such as signal processing, thermal monitoring, connectors and wiring, communications, safety systems

Area 4: Technologies that facilitate low-cost, high-performance, and/or plug-and-play hybridization and integration of disparate devices.

Area 5: Technologies that offer new control capabilities via advanced models, mechanisms, or actuators.

- Physics-based models and control
- Adaptive/dynamic models and control
- Non-traditional charge/dispatch algorithms
- Stochastic optimization
- Novel load management approaches

Technical Areas Specifically Not of Interest

- Solutions that depend on new active cell chemistries (i.e. solutions that rely on anodes or cathodes not in commercial use today).
- Solutions that only apply to a specific cell chemistry, and fail to offer technical advances that could be adapted to provide similar benefits to other state-of-art or advanced chemistries within the same class. For example, a solution whose benefits would only apply to one specific Li-ion cathode system would not be of interest.
- Approaches focused on optimizing networks of geographically distributed storage devices (e.g. dispatch optimization of distributed grid-tied storage).
- Approaches that fail to show how component innovations will be employed to achieve system benefits.
- Solutions that provide benefit in one or more of the primary objective areas, but have a significant adverse effect on other key performance metrics (unless clearly addressed and justified by the applicant).
- Incremental improvements to, or combinations of, existing products and technologies, wherein no significant advances in technical state-of-the-art, or reductions in technical uncertainty, are achieved.
- Solutions that have already received significant financial support from other government agencies and/or the private sector.

F. TECHNICAL PERFORMANCE TARGETS

Applicants are encouraged to carefully review the program objectives and areas of interest above for guidance in preparing their proposals. Applications will not be considered for funding unless they have a well-justified, realistic potential to meet or exceed all of the primary technical targets for at least one of the stated target capabilities by the end of the period of performance for the proposed project. Preference will be given to system-level solutions that can demonstrate the potential to substantially impact more than one of the Objectives.

a. Primary Technical Targets

The application must clearly address the following program elements and primary technical targets:

Objective 1: Safety

Capability 1.1: Real-time detection of internal cell faults

The proposed solutions must demonstrate the ability to detect an internal mechanical cell fault before such a fault leads to cell failure or causes any appreciable thermal elevation in the cell.

- The proposed solution must approach 100% diagnostic sensitivity, and exhibit not less than 95% diagnostic specificity, under normal operation.
  - Sensitivity = (true positive)/(true positive + false negative)
  - Specificity = (true negative)/(true negative + false positive)

- Applicant must show that the proposed solution is based on a detection mechanism that could credibly detect mechanical faults stemming from a range of sources, including but not limited to, cell design flaws, manufacturing defects, unforeseen reactions, and abusive or aggressive operation.

- Validation protocol should ideally establish all of the following performance attributes:
  - Diagnostic performance
    - Time-before-failure detection capability
    - Sensitivity
    - Selectivity
  - Robustness to detect faults stemming from different causes
  - Ability to detect in a practical system environment (i.e. ability to detect for cells coupled in series or series/parallel configurations)

Capability 1.2: Prevention of catastrophic failure

The proposed solution must demonstrate the ability to prevent catastrophic failure due to internal cell faults with 100% effectiveness.

- The proposed solution must not significantly degrade cell performance capabilities under normal operation.

- If the prevention mechanism will impact cell performance (e.g. render the cell unusable), it should not be triggered unless an impending failure is imminent.

- Applicant must show that the proposed solution is based on a prevention mechanism that can reliably prevent failures stemming from a range of sources, including but not limited to, cell design flaws, manufacturing defects, unforeseen reactions, and abusive or aggressive operations and environments.

- Validation protocol should establish the following performance attributes:
  - Reliability of prevention
  - Robustness to preventing catastrophic failures stemming from different causes

Objective 2: Performance

Capability 2.1: Overall System Improvement:

- Applicant must demonstrate that the proposed solution can offer a significant enhancement in the overall performance of a battery system via a reduction in overdesign (cost, weight, or volume) and/or via an increase in operating performance (lifetime, energy utilization, and/or power utilization). For example:

  - For Vehicles: greater than 25% reduction in up-front cost, weight, or volume at the system level vs. what is achievable with state-of-the-art management, without impacting performance.
  - For Grid: greater than 2X increase in total generated revenue through dispatch of the battery system vs. what is achievable with state-of-the-art management.

- Specific targets proposed by Applicant should be constructed in relation to a specific application, and Applicant must clearly justify how reaching the stated targets in a commercial system would lead to significantly greater adoption and impact.

Capability 2.2: Charge Rate Improvement

- Applicant must demonstrate that the proposed solution can enable Commercially viable charging from a depleted state to 80% nameplate capacity at an average rate that:
  - Is at least 2x faster when compared against charging specifications for the best-in-class commercial system utilizing the same chemistry; and
  - Allows for such charging at no greater than 20 minutes

- Applicant must quantify and justify any adverse impact on cost or performance associated with their proposed fast charging method, based on the application and use-case.

Objective 3: Prognostics

Capability 3.1: Improvement in Lifetime Prediction of Advanced Battery Systems

- Given a battery with unknown environmental and operational history, the proposed solution should demonstrate the ability to predict remaining lifecycle energy throughput against any given duty cycle to within ±10% accuracy.

- Prognostic methods should adhere to the following restrictions
  - Testing should not involve more than 10 charge-discharge cycles and not more than 48 hours of testing to the battery system
  - Testing must not involve any techniques that have a significant adverse effect on the performance or lifetime of the device

- Applicants must clearly describe and justify the commercial relevance of the prediction method and anticipated use-cases (e.g. applicability to online control optimization, repurposing, new product validation, etc.)

- Validation protocol should ideally establish all of the following performance attributes:
  - Prognostic accuracy
  - Ability to predict lifetime for systems exposed to different operating histories and against new duty cycles

Additional Primary Targets for All Areas

In all cases, applicants must present data to quantitatively describe all of the following:

- The anticipated performance metrics of the proposed technology concept.

- The performance metrics of the current state-of-the-art and why the proposed metrics are a significant advance.

- Practical integration issues including signal fidelity, communication, data processing, and other aspects of implementation.

- Specifically how the proposed technology will affect system-level performance in key performance areas. Solutions that provide benefit in one or more of the primary objective areas, but have a significant adverse effect on other key performance metrics must be clearly justified.

- Specifically how the proposed technology will be leveraged to achieve system-level benefits, and the extent of those benefits. Note: Any projections or estimations of benefits must be supported by techno-economic model(s) with explicitly stated assumptions and variables.

- A clear protocol for testing and quantitatively evaluating the degree to which the stated performance targets have been achieved. Whenever possible, improvements enabled by the battery management system should (1) be validated on test systems employing state-of-the-art commercial cells from an established large-volume manufacturer, and (2) demonstrate applicability of the solution to practical systems (i.e. packs integrating multiple cells and with capacity >5kWh) within targeted applications in vehicles and/or the grid.

- The market relevance of the proposed solution.

- The ease with which the proposed solution, if successful, may be adapted to provide benefits to other state-of-the-art or advanced battery systems and chemistries.

Performance targets must be clearly stated, and the applicants shall propose final deliverables that are aligned with all targets.

Project Teams

AMPED aims to demonstrate advanced technologies that can offer significant system-level benefits for vehicle and grid energy storage applications. While some proposals may focus on component-level solutions, an understanding of the system and application will be important in order to assess how the technology will be used and how it will provide the intended benefit. As a result, we strongly encourage the formation of project teams that include complementary expertise in all aspects of the proposed solution, thus making the team uniquely suited to effectively demonstrate the technical capability as well as its relevance and applicability in commercial systems. In addition, applicants should note the following project team requirements:

- Applicants developing solutions that primarily focus on modeling should have significant involvement from an OEM or system integrator.
- Applicants developing solutions that rely on internal modifications to battery cells should have significant involvement from a battery manufacturer, component supplier, or other organizations with high-quality cell fabrication capability.

Seedling/Proof of Concept Funding Category for Novel Partial Solutions

ARPA-E recognizes that there may be new high-impact ideas related to the aforementioned areas of interest that are exploratory in nature and may not yet be mature enough to meet the scale and degree of validation required in the primary targets above. For such unproven and yet promising ideas, ARPA-E seeks smaller seedling applications to conduct experiments to achieve a proof-of-concept. In this case, the proof-of-concept experiments must be designed in a way that the results obtained clearly indicate paths to approach full system applicability. See Section II.A below for further details.

G. APPLICATIONS SPECIFICALLY NOT OF INTEREST

The following types of applications will be deemed nonresponsive and will not be reviewed or considered (see Section III.C.2 of the FOA):

- Applications that fall within the "Technical Areas Specifically Not of Interest" specified in Section I.E of the FOA.
- Applications for basic research aimed at discovery and fundamental knowledge generation.
- Applications for large-scale demonstration projects of existing technologies.
- Applications for proposed technologies that represent incremental improvements to existing technologies.
- Applications for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Applications that do not address at least one of ARPA-E's Mission Areas (see Section I.A of the FOA).
- Applications for proposed technologies that are not transformational, as described in Section I.A of the FOA. Transformational, as illustrated in Figure 1 in Section I.A of the FOA, is the promise of high payoff in some sector of the energy economy.
- Applications for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress (see Figure 1 in Section I.A of the FOA).