LLNL-TR-648044

LAWRENCE LIVERMORE NATIONAL LABORATORY

ARPA-E Program: Advanced Management Protection of Energy Storage Devices (AMPED) - Monthly Report - November 2013

J. Farmer

December 19, 2013

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LLNL-TR-648044 – LLNL Wireless BMS Project
ARPA-E AMPED Program – Monthly Report for November 2013

ARPA-E Program: Advanced Management Protection of Energy Storage Devices (AMPED)

Funding Opportunity Announcement: DE-FOA-0000675

Control Number: 0675-1577

Award Identification: 12/CJ000/05/01/0 (DE-AR0000281)

Date of Monthly Report: 12/13/2013

Reporting Period: 11/01/2013 to 11/30/2013

Prime Recipient: Lawrence Livermore National Laboratory

Project Title: Novel Battery Management System with Distributed Wireless and Fiber Optic Sensors for Early Detection and Suppression of Thermal Runaway in Large Battery Packs

ARPA-E AMPED Program Management Team: Ilan Gur, Ph.D., Russ Ross, Ph.D., Kevin Thompson, Ph.D.

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Active Co-Investigators: John Chang, Ph.D.; Jim Zumstein, Senor Electrical Engineering Technician; Jack Kovotsky, Ph.D.; Frank Puglia, Research Director, Yardney Technical Products; Arthur Dobley, Ph.D.; Gregg Moore, Ph.D.; Sebastian Osswald, Ph.D.; Kevin Wolf, Senior Mechanical Engineer, Program Manager, United States Navy; James Kaschmitter, M.S., Chief Executive Officer, Polystor Energy Corporation; Steve Eaves, Chief Executive Officer, Eaves Devices

Section I. Executive summary (less than one page): Utilize this section to address the general state of the project and highlight points of success and/or concern. Examples might include: exceeding major milestones, attracted follow-on investment, schedule slippage, met a milestone early or late, etc.

Technology has been developed that enables monitoring of individual cells in high-capacity lithium-ion battery packs, with a distributed array of wireless Bluetooth 4.0 tags and sensors, and without proliferation of extensive wiring harnesses. Given the safety challenges facing lithium-ion batteries in electric vehicle, civilian aviation and defense applications, these wireless sensors may be particularly important to these emerging markets. These wireless sensors will enhance the performance, reliability and safety of such energy storage systems. Specific accomplishments to date include, but are not limited to: (1) the development of wireless tags using Bluetooth 4.0 standard to monitor a large array of sensors in battery pack; (2) sensor suites enabling the simultaneous monitoring of cell voltage, cell current, cell temperature, and package strain, indicative of swelling and increased internal pressure, (3) small receivers compatible with USB ports on portable computers; (4) software drivers and logging software; (5) a 7S2P battery simulator, enabling the safe development of wireless BMS hardware in the laboratory; (6) demonstrated data transmission out of metal enclosures, including battery box, with small variable aperture opening; (7) test data demonstrating the accurate and reliable operation of sensors, with transmission of terminal voltage, cell temperature and package strain at distances up to 110 feet; (8) quantification of the data transmission error as a function of distance, in both indoor and outdoor operation; (9) electromagnetic interference testing during operation with live, high-capacity battery management system at Yardney Technical Products; (10) demonstrated operation with live high-capacity lithium-ion battery pack during charge-discharge cycling; (11) development of special polymer-gel lithium-ion batteries with embedded temperature sensors, capable of measuring the core temperature of individual of the cells during charge-discharge cycling at various temperatures, thereby enabling earlier warning of thermal runaway than possible with external sensors. Ultimately, the team plans to extend this work to include: (12) flexible wireless controllers, also using Bluetooth 4.0 standard, essential for balancing large-scale battery packs. LLNL received $925K for this project, and has $191K remaining after accomplishing these objectives.

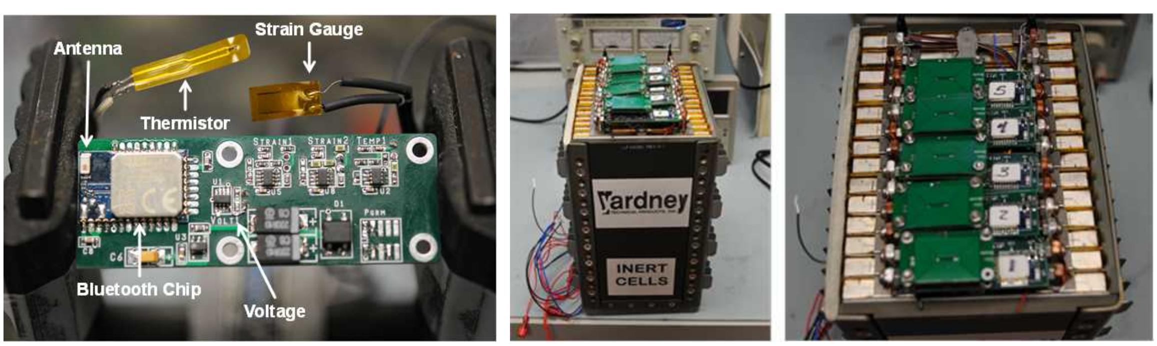

Figure 1 – Wireless tags, sensors and battery simulator that have been delivered.

Section II. Bulleted list of summarizing milestones due: Briefly report on milestones scheduled to be completed during the reporting period or that are past due. Milestones that are 100% complete ahead of schedule may also be reported. Please indicate their task number affiliation and whether the milestone is complete, incomplete, or still in progress. Include a sub-bullet to briefly describe the status including any relevant key data or references to figures, tables, and charts (generally no more than 2-3 lines each).

- Additional EMI Testing Relevant to Grid Storage by LLNL
    - Successful Testing Wireless Tags in Capacitor Bank for Large-Scale Pulsed Power System During Charge/Discharge of Twenty 22-kV 22-kJ Capacitors
- Modified Tasks, Milestones & Deliverables Based Upon LLNL-YTP Testing with Submission to ARPA-e Sponsor for Review and Comment
    - These modified tasks, milestones and deliverables, including a revised T2M plan, are given in Section IV of this report.
    - Concentrating on technology transfer for EV and grid storage
    - Comparisons of wireless approach to two-wire multiplex systems
    - Formal 4th Quarter Program Review & Technology Demonstration for ARPA-e Sponsor at LLNL on November 8th 2013 (Figure 2).

Figure 2 – Poster for FY13 Q4 ARPA-e Review and Technology Demonstration at LLNL on November 8th 2013

Section III. Supporting data and additional information (length varies): please provide supporting data to substantiate any claims against milestones, including appropriate figures, tables, etc.

Tests have been done to demonstrate operability in "grid storage type" electromagnetic environment. One of the Team's wireless Bluetooth tags was housed inside a protective plastic box, with full sensor suite, and placed on the upper surface of 22-kV 22-kJ capacitor during charge-discharge testing in LLNL Pulsed Power Laboratory (Figure 3). Figure 4 shows fiber optic and wireless strain gauges, two independent measurements. Note that the wireless strain gauges have not yet been glued down to capacitor surface. Initial tests were designed to demonstrate data transmission in such high-energy high-field environments, relevant for grid storage applications. Successful data transmission has been demonstrated inside "grid storage like" electromagnetic environment, during charge and discharge of twenty 22-kV 22-kJ capacitors, from inside steel cabinet containing a bank of twenty capacitors, as shown in Figures 5 and 6.

Figure 3 – This photograph shows the wireless Bluetooth tag inside protective plastic box, with full sensor suite sitting on upper surface of 22-kV 22-kJ capacitor during charge-discharge testing in LLNL Building 291 basement (pulsed power laboratory).

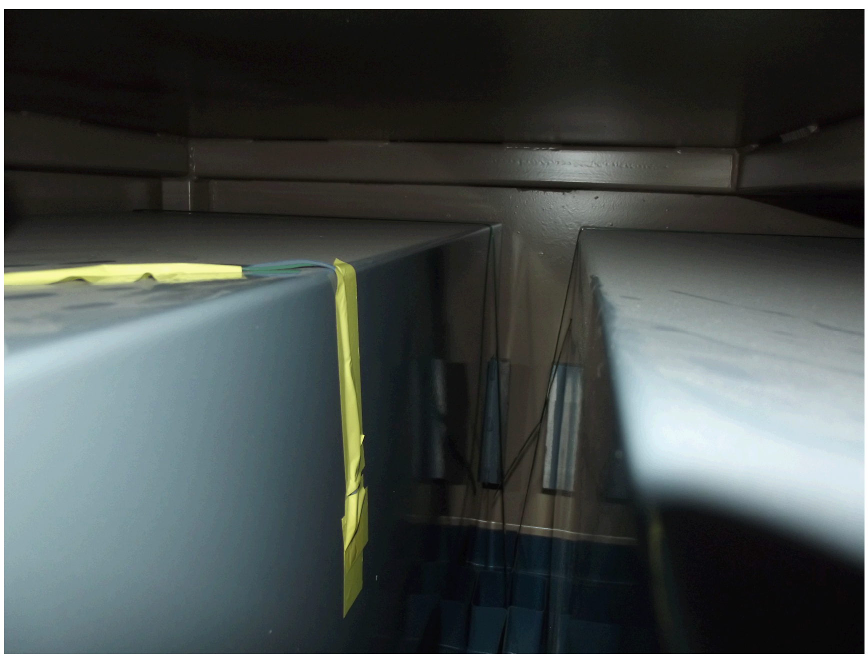

Figure 4 – This photograph shows fiber optic strain gauge being used as independent verification of wireless strain gauges; the wireless strain gauges have not yet been glued down to capacitor surface. Initial tests were designed to demonstrate data transmission in such high-energy high-field environments, relevant for grid storage applications.

Figure 5 – The USB dongle reader was able to receive high quality data from wireless tag in 20-capacitor module, inside steel cabinet, during charge-discharge test.

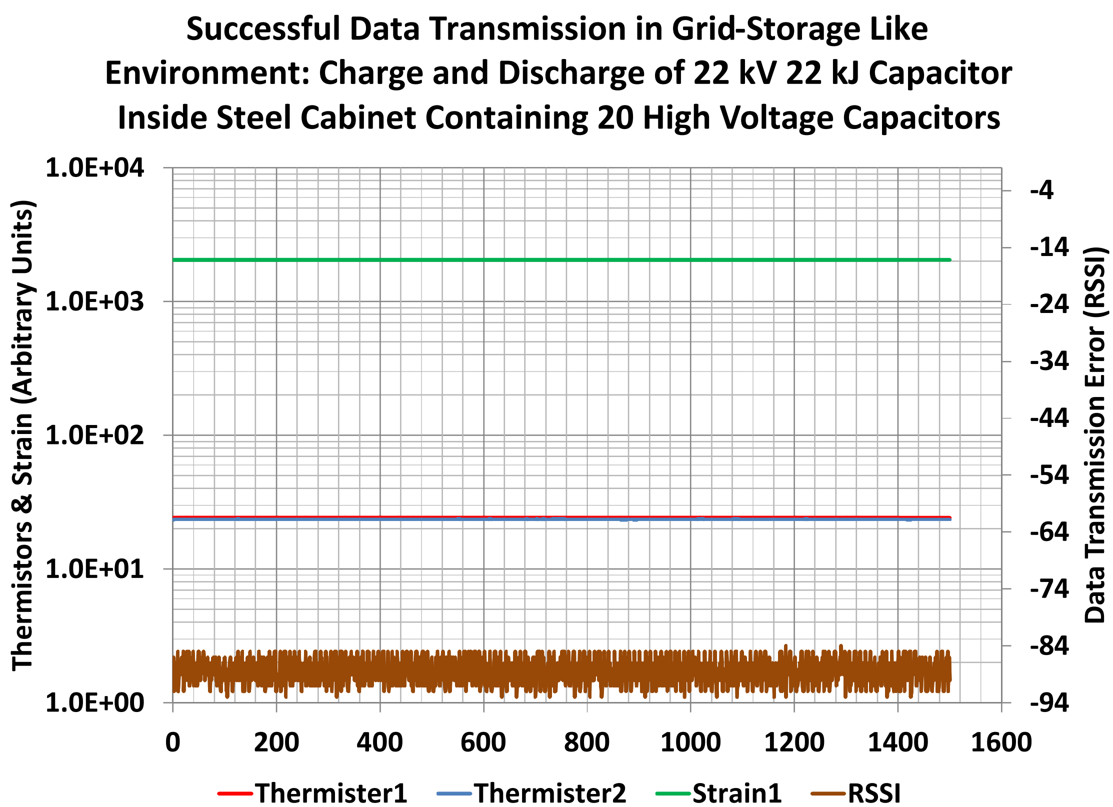

Figure 6 – Successful data transmission inside "grid storage like" electromagnetic environment, during charge and discharge of twenty 22-kV 22-kJ capacitors, from inside steel cabinet containing bank of capacitors. The two thermistors tracked ambient temperature, while the strain gauge continued to function. While a fiber optic strain gauge has been glued to the capacitor surface, the team has not yet permanently attached the wireless strain gauge to the capacitor, though this is planned. During charging, there is a slight observable contraction in the oil-filled capacitor.

Section IV. Major risks to future milestones: please use this section to briefly discuss any actual or anticipated problems, risks, or issues, along with the actions planned or taken to resolve them.

Summary of Risks to Future Milestones:

- Possible Detrimental Impact of Second Government Shutdown in January 2014
- Any Failure of Patent Applications and Inability to Protect Intellectual Property
- Insufficient Funds to Execute Revised Technology-to-Market Plan
    - Any Inability to Attract and Maintain Interest of Early Adopters Prior to Exhausting Funds Necessary to Support Activity
        - EVs & HEVs
        - Grid Storage
    - Any Inability to Negotiate License Between LLNL and Early Adopters Prior to Exhausting Funds Necessary to Support Activity
        - EVs & HEVs
        - Grid Storage
- Insufficient Funds at Livermore to Support Complete Technical Development of Integrated Wireless BMS at Yardney Technical Products
    - Task/Milestone 1.4.3 – Refine communication software between BMS for 1st YTP product and USB reader (3/15/2014).
    - Task/Milestone 1.4.4 – Successful demonstration of operational BMS for 1st YTP product with wireless communication to distributed array of PCB-type wireless tags with full sensor suite (4/15/2014).
    - Task/Milestone 1.4.5 – Integration of prototypical PCB-type wireless tags with full sensor suite into 1st YTP product (6/15/2014).
    - Task/Milestone 1.4.6 – Successful demonstration of 1st YTP product with truly wireless BMS, based upon PCB-type technology (9/15/2014).

Any Ability to Adequately Protect of Intellectual Property

- ROI, Provisional Patents, and Patent Application Filings Update by Patent Attorney:
  - Patent Application IL 12593 Battery Management Systems with Thermally Integrated Fire Suppression filed February 21, 2013 – Inventors: Joseph C. Farmer and Todd M. Bandhauer (Provisional Application filed May 23, 2012)
  - Patent Application IL 12597 Battery Management System with Distributed Wireless Sensors filed February 21, 2013 – Inventors: Joseph C. Farmer and Todd M. Bandhauer (Provisional Application filed May 23, 2012)
  - Patent Application IL-12749 Li-ion Battery Thermal Runaway Suppression System Using Microchannel Coolers and refrigerant Injections filed May 22, 2013 – Inventors: Todd M. Bandhauer and Joseph C. Farmer (Provisional Application filed May 23, 2012)
  - Patent Application IL-12772 Energy Storage Management System with Distributed Wireless Sensors filed May 22, 2013 – Inventors: Todd M. Bandhauer and Joseph C. Farmer (Provisional Application filed May 23, 2012).
- NDA Execution – Mutual non-disclosure agreements have been executed between LLNL and all team members.
- IP agreements finalized by non-governmental team members and submitted to ARPA-e on February 13, 2013 (members are federal government employees covered by the "Federal Trade Secrecy Act").

Any Inability to Attract and Maintain Interest of Early Adopters in Technology

- Yardney Technical Products.
  - 4.2.1.1 – Battery Packs for Military Aircraft
- Lawrence Livermore National Laboratory.
  - 4.2.2.1 – NIF's Approximately 4000 High-Voltage Capacitors
  - 4.2.2.2 – Battery Packs for Various Mobil Laser Systems
  - 4.2.2.3 – Site 300 Grid Storage Project
- 4.2.3 – Contact early adopters for vehicular applications (01/08/2014).
  - 4.2.3.1 – Electric Vehicles (EVs)
  - 4.2.3.2 – Hybrid Electric Vehicles (HEVs)
  - 4.2.3.3 – Fuel Cell Vehicles (FCVs)
  - 4.2.3.4 – Advanced Starter Lighting Ignition (SLI) Batteries
- 4.2.4 – Contact early adopters for grid storage applications (01/08/2014).
  - 4.2.4.1 – Utility
  - 4.2.4.2 – Power Electronics
  - 4.2.4.3 – Battery Pack Supplier

Need to Execute Exclusive License with Battery Manufacturer

- Clearly Articulate Objectives – Rapid and Successful Establishment of U.S. Manufacturer as the First Supplier in the World with Wireless BMS Sensor Capability for Enhanced Safety
- Identify Knowledgeable Patent Attorney & Protect Intellectual Property – Eddie Scott, Intellectual Property Law, Lawrence Livermore National Laboratory
- Identify Appropriate Laboratory Authority for Licensing Negotiations – Richard Rankin, Director, Industrial Partnership Office, Lawrence Livermore National Laboratory
- Execute Fairness of Opportunity Announcement (FOA) – Standard CBD Announcement Prior to Licensing Negotiations
- Identify Industrial Authority 1 – Frank Puglia, Director of Research & Development, Program Manager, Yardney Technical Products
- Identify Industrial Authority 2 – Any Others Stepping Forward Following FOA
- Negotiate Exclusive License/Licenses for Defense Applications – Timely Meeting to Negotiate and Facilitate Transfer of Technology from LLNL to Industrial Entity/Entities to Enable Further Defense System Development & Marketing to Department of Defense
- Negotiate Field-of-Use Exclusive License/Licenses for Commercial Applications – Timely Meeting to Negotiate and Facilitate Transfer of Technology from LLNL to Industrial Entity/Entities to Enable Further Commercial Product Development & Marketing in Private Sector

Need to Reformulate Original Tasks & Milestones Consistent with Accomplishments

- Milestone 1 (Revised): Develop individual wireless sensors & tags capable of being operated in either passive or active mode (6/24/2013).
- Milestone 2 (Revised): Demonstrate one-to-five wireless tags with voltage, temperature & strain sensor, in both active and passive mode, with battery simulator and live battery pack (6/24/2013); 1st integration into YTP product (6/15/2014); destructively test actual YTP product with distributed array of wireless sensors integrated (6/15/2015).
- Milestone 3 (Revised): Demonstrate passive and active wireless sensors & tags (6/24/2013); conduct comparative studies of passive vs. active approaches (12/15/2013); create first international Standard for wireless BMS (3/15/2014); 1st revision of standard (3/15/2015).
- Milestone 4 (Revised): Technology-to-Market (T2M) Plan & Analysis & Evaluate Cost Reduction Strategies Based Upon Existing Printed-Circuit Board (PCB) Type Wireless Tags & Sensors; Focus on Electric Vehicles & Grid Storage; Direct Comparison of Wireless Bluetooth BMS Technology (LLNL/YTP) to Competing Two-Wire Multiplexed Option (01/08/2014).
- Milestone 5 (Revised): Technology-to-Market (T2M) Plan – Quantify Cost Possible Reduction Based Upon ASIC and FPGA Production of Wireless Tags & Sensors (3/15/2014).
- Milestone 6 (Revised): Distributed Array of Wireless Controllers for Wireless BMS System: develop low-drain switch to control of current flow to each cell based upon sensed voltage, that can be controlled wirelessly by BMS, and can be used as distributed array in pack; develop low-drain operational amplifier circuits to charge each individual cell in pack with potential control; each operational amplifier will be capable of being wirelessly controlled by BMS, and can be used as distributed array in pack.
- Detailed descriptions of these revised tasks and milestones are described in the following pages.

Milestone 1: Develop Wireless Tags & Sensors Capable of Active or Passive Operation

- 1.1.1 – Design of 20-Ah simulation cells and battery pack simulator incorporating Li-ion liquid-prismatic simulation cells (6/24/2013).
- 1.1.2 – Fabrication of components and assembly of 20-Ah Li-ion liquid-prismatic simulation cells (6/24/2013).
- 1.1.3 – Assembly of 7S2P battery pack simulator with 20-Ah Li-ion liquid-prismatic simulation cells (6/24/2013).
- 1.2.1 – Design wireless tags and sensor boards capable of either active or passive operation based upon Bluetooth 4.0 (6/24/2013).
- 1.2.2 – Select and procure 1st lot of printed circuit boards, components to populate boards, wireless reader, and voltate, temperature & strain sensors (6/24/2013).
- 1.2.3 – Fabricate 1st lot of prototypical active and passive wireless tags with voltage, temperature & strain sensors (6/24/2013).
- 1.3.1 – Quantify power consumption of wireless tags and sensors through experimental measurement (6/24/2013).
- 1.3.2 – Test wireless tags and at least one sensor in both active and passive mode, with receiving and transmitting antennas (6/24/2013).
- 1.3.3 – Demonstrate performance of voltage, temperature and strain sensors with both active and passive wireless tags (6/24/2013).
- 1.3.4 – Document performance of wireless tags and sensors, in both active and passive mode in LLNL technical report (in progress)
- 1.3.5 – To enable initial integration into product by YTP procure: 2nd lot of printed circuit boards & components to populate boards; readers; and voltage, temperature & strain sensors (10/15/2013).
- 1.3.6 – To enable initial integration into product, fabricate 2nd lot of prototypical active and passive wireless tags, with voltage, temperature & strain sensors (10/15/2013).
- 1.4.1 – Document software enabling USB reader to communicate with arrays of LLNL's Bluetooth 4.0 wireless tags (12/15/2013).
- 1.4.2 – Integration of USB reader with BMS for 1st YTP product, demonstrating BMS & USB reader communication (12/15/2013).
- 1.4.3 – Refine communication software between BMS for 1st YTP product and USB reader (3/15/2014).
- 1.4.4 – Successful demonstration of operational BMS for 1st YTP product with wireless communication to distributed array of PCB-type wireless tags with full sensor suite (4/15/2014).
- 1.4.5 – Integration of prototypical PCB-type wireless tags with full sensor suite into 1st YTP product (6/15/2014).

- 1.4.6 – Successful demonstration of 1st YTP product with truly wireless BMS, based upon PCB-type technology (9/15/2014).
- 1.5.1 – Plan for integration of internal temperature sensors integration with individual polymer-gel lithium-ion cells (4/15/2013).
- 1.5.2 – Fabrication of at least two polymer-gel lithium-ion cells with internal and external temperature sensors at PSEC (4/15/2013).
- 1.5.3 – Testing of at least two polymer-gel Li-ion cells with internal and external temperature sensors in NPS autoclaves (6/24/2013).
- 1.6.1 – Plan for integration of internal reference electrode integration with individual polymer-gel lithium-ion cells (10/15/2013).
- 1.6.2 – Fabrication of at least two polymer-gel lithium-ion cells with internal reference electrode at PSEC (11/15/2013).
- 1.6.3 – Testing of at least two polymer-gel Li-ion cells with internal reference electrodes in NPS autoclaves (12/15/2013).
- 1.6.4 – Fabricate & test cells with internal temperature sensors and reference electrodes (3/15/2014).

Milestone 2: Testing of Wireless Tags & Sensors with Battery Simulator & Live Pack

- 2.1.0 – Demonstrate at least one (1) wireless tag with voltage, temperature & strain sensors, in both active and passive mode, with battery simulator (6/24/2013).
- 2.1.1 – Bench testing of LLNL of at least one (1) wireless tag with voltage, temperature & strain sensors at YTP, in both active and passive mode, with verification of operability by YTP (6/24/2013).
- 2.1.2 – Demonstrate transmission of individual voltage, temperature and strain data from wireless tag to USB reader and laptop at sampling rate of 1 Hertz for duration of 1 hour (6/24/2013).
- 2.1.3 – Demonstrate simultaneous transmission of voltage, temperature and strain data from tag to USB reader and laptop at sampling rate of 1 Hertz for duration of 1 hour (6/24/2013).
- 2.1.4 – Bench testing of YTP battery simulator at YTP with verification of operability of simulation cell heaters and pressurization system, and thermistors by LLNL (6/24/2013).
- 2.1.5 – Initial electromagnetic interference (EMI) testing of at least one (1) wireless tag with voltage, temperature and strain sensors, in both active and passive mode, in close proximity to energized battery management system (BMS), demonstrating interference-free operation of wireless tag, reader and BMS (6/24/2013).
- 2.2.0 – Demonstrate at least five (5) wireless tags with voltage, temperature & strain sensors, in both active and passive mode, with battery simulator (6/24/2013).

- 2.2.1 – Bench testing of at least five (5) wireless tags with voltage, temperature & strain sensors at YTP, in both active and passive mode, with verification of operability by YTP (6/24/2013).
- 2.2.2 – Demonstrate transmission of individual voltage, temperature and strain data from wireless tag to USB reader and laptop at sampling rate of 1 Hertz for duration of 1 hour (6/24/2013).
- 2.2.3 – Demonstrate simultaneous transmission of voltage, temperature and strain data from tag to USB reader and laptop at sampling rate of 1 Hertz for duration of 1 hour (6/24/2013).
- 2.2.4 – Bench testing of YTP battery simulator with at least five (5) LLNL wireless tags with distributed array of voltage, temperature & strain sensors at YTP (6/24/2013).
- 2.2.5 – Initial electromagnetic interference (EMI) testing of at least five (5) wireless tags with voltage, temperature and strain sensors, in both active and passive mode, in close proximity to energized battery management system (BMS), demonstrating interference-free operation of wireless tag, reader and BMS (6/24/2013).

Milestone 3: Conduct Comparative Studies & Establish Standard for Wireless BMS

- 3.1.0 – Comparative analysis of active and passive wireless tags, with voltage, temperature & strain sensors, with quantification of their relative performance (6/15/2014)
- 3.1.1 – Establish standardized physical and electromagnetic test environments (STEs) representative of those expected for prototypical battery packs. STEs may include: 7S2P battery-pack simulator in air without enclosure; 7S2P battery-pack simulator in air with metal enclosure and variable aperture; actual lithium-ion battery-pack in air without enclosure and during cycling; actual lithium-ion battery-pack in air without enclosure and during cycling with metal enclosure and variable aperture; YTP 120-V lithium-ion battery pack or suitable alternative, with and without energized BMS system (6/24/2013)
- 3.1.2 – Quantify signal integrity (SI): measure bit error rate (BER) as a function of time and range for wireless tags with full suite of sensors, in both passive and active mode, in each standardized test environment (STE), with the results presented in the form of BER graphs. Communication rates will be varied from 1 Hz to up to 10 Hz, with the signal dropout rate measured at each operating frequency (10/15/2013).
- 3.1.3 – Quantify electromagnetic interference (EMI): determine the performance of wireless tags with full suite of sensors, in both passive and active mode, in each STE (11/15/2014).

- 3.1.4 – Quantify range of wireless tags: measure bit dropout rate as a function of distance for wireless tags with full suite of sensors, in both passive and active mode, in each STE(12/15/2013).
- 3.1.5 – Quantify power consumption: measure power consumption for single wireless tag with full suite of sensors, in both passive and active mode, as a function of STE and range; calculate the drain from lithium-ion battery pack for active mode (1/15/2014).
- 3.1.6 – Quantify economy of scale: perform engineering economic analysis to determine specific costs associated with transitioning "one-of-a-kind" active and passive printed circuit board (PCB) prototypes to mass-produced "N-of-a-kind" PCB tags (3/15/2014).
- 3.1.7 – Quantify form factor and flexibility: perform detailed engineering analysis based on design of printed circuit boards, antennas, ancillary hardware, and packaging, determining the characteristic external dimensions for active and passive PCB-type prototypes; determine suitability for various commercially available lithium-ion battery packs (6/15/2014),
- 3.1.8 – Demonstrate compliance of wireless tags and sensors, integrated into battery pack simulator and live battery pack with energized BMS to automotive and aerospace standards; specifically demonstrate compliance to CISRP 25 (automotive applications) and Mil-STD-461 (aerospace and military applications) (9/15/2014).
- 3.1.9 – Collaboratively test YTP battery pack, with active and passive tags, and with voltage, temperature and strain sensors at NTS or comparable sub-contractor (9/15/2015).

Milestone 4: Technology-to-Market (T2M) Plan & Analysis & Evaluate Cost Reduction Strategies Based Upon Existing Printed-Circuit Board (PCB) Type Wireless Tags & Sensors

- 4.1 – Initial protection of wireless BMS technology by LLNL with: formal records of invention (01/30/2012), provisional patents (submitted), and patent applications (01/30/2012).
  - 4.1.1 – IP agreements to be finalized by all non-governmental team members; government team members are not required to sign; initial version completed and submitted to ARPA-e (02/13/2013)
  - 4.1.2 – Technology to Market (T2M) Plan submitted to ARPA-e for approval; revision of T2M plan; acceptance of T2M plan (done)
  - 4.1.3 – Identify possible early adopters for various applications that are key to market entry, including defense, aerospace, automotive, test equipment, UPS, and grid storage (6/24/2013).
  - 4.1.4 – Investigate viability of wireless tags and full sensor suite for grid storage; document findings in formal report (12/15/2013).
- 4.2 – Contact early adopters of wireless BMS technology, identifying opportunities
  - 4.2.1 – Yardney Technical Products (12/15/2013).
    - 4.2.1.1 – Battery Packs for Military Aircraft
  - 4.2.2 – Lawrence Livermore National Laboratory (12/15/2013).
    - 4.2.2.1 – NIF's Approximately 4000 High-Voltage Capacitors
    - 4.2.2.2 – Battery Packs for Mobile Laser Systems
    - 4.2.2.3 – Site 300 Grid Storage Project
  - 4.2.3 – Contact early adopters for vehicular applications (01/08/2014).
    - 4.2.3.1 – Electric Vehicles (EVs)
    - 4.2.3.2 – Hybrid Electric Vehicles (HEVs)
    - 4.2.3.3 – Fuel Cell Vehicles (FCVs)
    - 4.2.3.4 – Advanced Starter Lighting Ignition (SLI) Batteries
  - 4.2.4 – Contact early adopters for grid storage applications (01/08/2014).
    - 4.2.4.1 – Utility
    - 4.2.4.2 – Power Electronics
    - 4.2.4.3 – Battery Pack Supplier

- 4.3 – Emphasis will be focused on a direct comparison the following specific alternatives using remaining funds (01/08/2014):
  - 4.3.1 – Utah Two-Wire Multiplex System
  - 4.3.2 – LLNL/YTP Wireless Bluetooth System
- 4.4 – The Team will begin gathering detailed information on competing approach being pursued by Utah State (01/08/2014):
  - 4.4.1 – Telephone conversations with Utah State will be used to gain a better understand the wired option and our ARPA-e competition;
  - 4.4.2 – They will write 3-5 page formal report discussing Utah's approach, its purported benefits, and any perceived advantages of wireless.
- 4.5 – A prototypical lithium-ion battery pack will be postulated, and used as the basis for preparing conceptual "two-wire multiplex" and "wireless Bluetooth" BMS designs. They will assess key parameters including (01/08/2014):
  - 4.5.1 – Lengths of cable and connections,
  - 4.5.2 – Cost of hardware including (but not limited to): chips, boards, electronic components, readers, software, cable and connections
  - 4.5.3 – Increases in volume and weight with each of the proposed BMS enhancements (two-wire and wireless), assuming current state of technology, and future technology with size reduction through manufacturing enhancements
- 4.6 – The Pros and Cons will be summarized in a brief white paper for the sponsor, and will complete commitments for work at LLNL with existing funding (01/08/2014).

Section V. Budget Summary (generally less than 1 page): identify if the project was on budget, overspent, or under spent for the period, why, and how this will affect your future management of the project and expenses.

LLNL received $925K for this project, and has $68K remaining at the end of November, 2013, after accomplishing many of the project's objectives. See Table 3 (following page) for details.

As requested by the PI, the LLNL Resource Manager updated the attached financial table to enable preparation of this report (Table 3). This report is normally required on a quarterly basis. Therefore, the Quarterly Expenditure header was modified by the Resource Analyst to reflect the accounting of costs for only October and November of 2013. Furthermore, the Cumulative Expenditure header was modified to reflect that those costs are only through November 2013.

Table 3 – All Project Expenses at LLNL through November 2013

CATEGORY	Total Project Cost	Quarterly Expenditures FY14 Oct/Nov	Cumulative Expenditures FY14 Nov	Remaining Balance FY14 Nov
a. Personnel	208,298	35,383	209,164	(865)
b. Fringe Benefits	127,062	22,574	125,707	1,355
c. Travel	15,362	-	3,711	11,651
d. Equipment	100,404	-	84,700	15,704
e. Supplies	10,000	-	13,502	(3,502)
f. Contractual			-	-
Sub-recipient	-	-	-	-
Vendor	-	-	-	-
FFRDC	-	-	-	-
Total Contractual	-	-	-	-
g. Construction	-	-	-	-
h. Other Direct Costs	50,768	157	34,816	15,951
Total Direct Costs	511,894	58,114	471,600	40,295
i. Indirect Charges	413,106	64,539	385,370	27,736
Total Project Cost	925,000	122,653	856,970	68,030

On a side note, there are currently two tasks opened for this project: 38381:040101 and 38381:040107. Task 040107 was set up to track the TT&O costs (technology transfer). ARPA-e wanted to track/document these costs separately, which align with execution of those tasks inovled with execution of the Technology-to-Market (T2M) Plan. This task number will now be used as appropriate, including upcoming meetings with ARPA-e and/or Yardney meetings. This TT&O task had an original budget of approximately $50,000 (Table 4). LLNL spent approximately $34,000 last year. Consistent with current guidance, we anticipate spending the remaining $16,238 in this task area.

Table 4 – Expenses Specifically Attributed to T2M Execution through November 2013

CATEGORY	Total Project Cost	Quarterly Expenditures FY14 Oct/Nov	Cumulative Expenditures FY14 Nov	Remaining Balance FY14 Nov
a. T2M Personnel	20,128		9,177	10,950
b. T2M Fringe Benefits	12,278		5,436	6,842
c. T2M Travel	18,362		2,109	16,253
d. T2M Equipment			-	-
e. T2M Supplies			-	-
f. T2M Contractual			-	-
Sub-recipient	-		-	-
Vendor	-		-	-
FFRDC	-		-	-
Total Contractual	-		-	-
g. T2M Construction	-		-	-
h. T2M Other Direct Costs			461	(461)
T2M Total Direct Costs	50,768		17,183	33,584
i. T2M Indirect Charges			17,347	(17,347)
T2M Total Project Cost	50,768		34,530	16,238

Accomplishments to date include: (1) the development of wireless tags using Bluetooth 4.0 standard to monitor a large array of sensors in lithium ion battery pack; (2) sensor suites enabling the simultaneous monitoring of cell voltage, cell current, cell temperature, and package strain, indicative of swelling and increased internal pressure, (3) small receivers compatible with USB ports on laptops; (4) software drivers and logging software; (5) a 7S2P battery simulator, enabling the safe development of wireless BMS hardware in the laboratory; (6) demonstrated data transmission out of metal enclosures, including battery box, with small variable aperture opening; (7) test data demonstrating the accurate and reliable operation of sensors, with transmission of terminal voltage, cell temperature and package strain at distances up to 110 feet; (8) quantification of the data transmission error as a function of distance, in both indoor and outdoor operation; (9) electromagnetic interference testing during operation with live, high-capacity battery management system at Yardney Technical Products; (10) demonstrated operation with live high-capacity lithium-ion battery pack during charge-discharge cycling; (11) development of polymer-gel lithium-ion batteries with embedded temperature sensors, capable of measuring the core temperature of individual of the cells during charge-discharge cycling at various temperatures, thereby enabling earlier warning of thermal runaway than possible with external sensors; (12) successful testing wireless tags and sensors in high-voltage high-energy pulse-power system relevant to survivability in grid storage application; and (13) initial comparisons of wireless approach to BMS to a competing approach using two-wire multiplexed option.

Ultimately, the team hopes to extend this work in the future to include: (14) use ASIC fabrication of reducing cost of individual wireless tags and sensors to less than $10 per unit; and (15) flexible wireless controllers, also using Bluetooth 4.0 standard, essential for balancing large-scale battery packs.

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