CHANGING WHAT'S POSSIBLE

Advanced Management and Protection of Energy storage Devices (AMPED)

Annual Meeting 2015

Patrick McGrath, Ph.D.

Program Director, ARPA-E

March 31st, 2015

ARPA-E Team

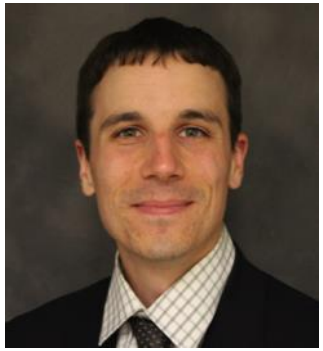
Ellen Williams
Director

Eric Rohlfing
Dep. Dir. for Technology

Ping Liu
Program Director

Susan Babinec
Senior Comm. Advisor

Ryan Umstattd
Senior Comm. Advisor



Michael Kane
ARPA-E Fellow

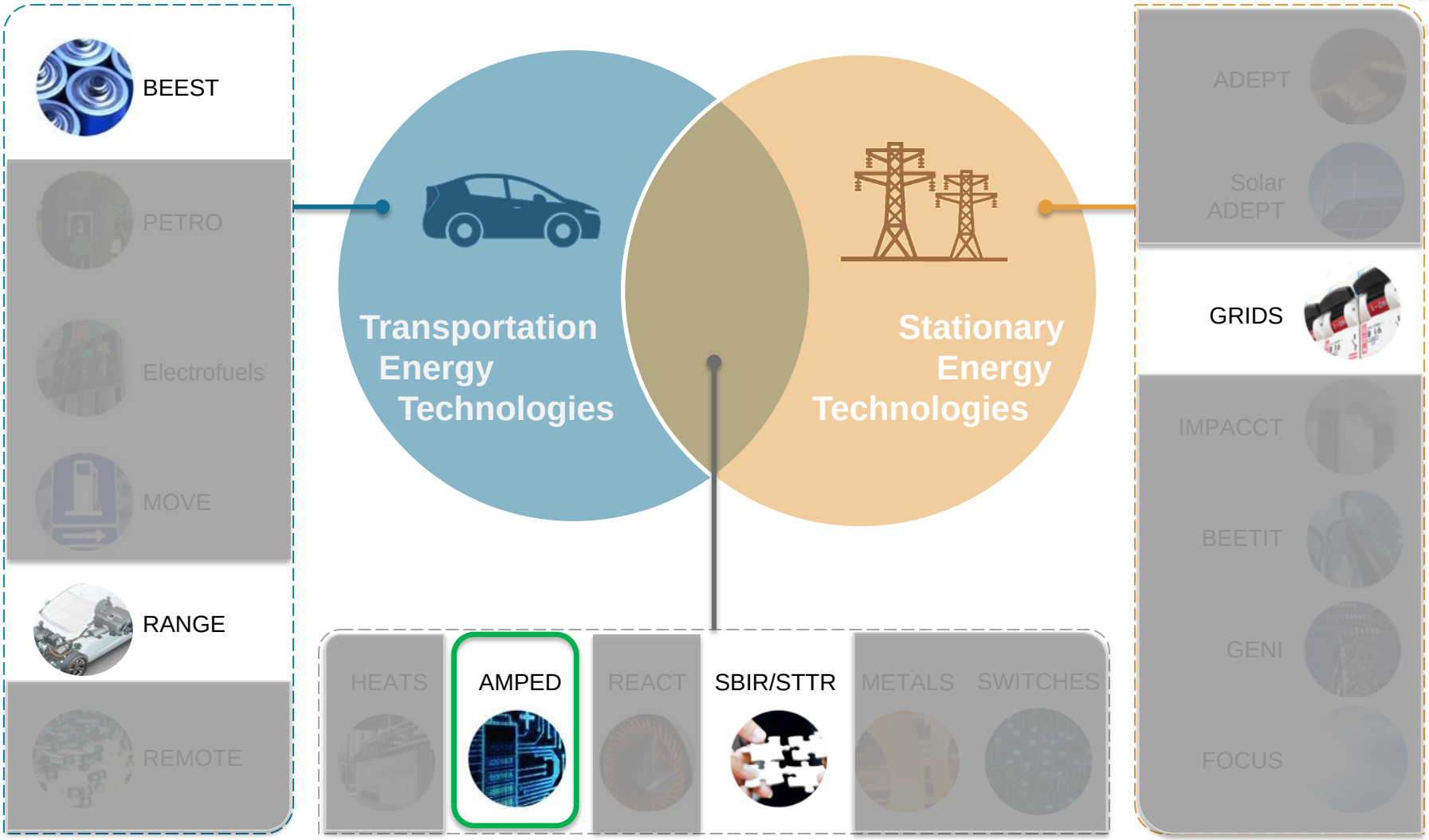
AMPED Program Team

Patrick McGrath
Program Director

Russel Ross
Technical SETA

Kevin Thompson
Program SETA

Focused Programs



BMS: Not a lot of info, but a lot to worry about

Given I,V,T, (and t), you must protect against:

- Circuit faults
- Electrolyte oxidation
- Electrolyte reduction
- Dendrite growth
- Cracking
- Graphite exfoliation
- Changes in porosity
- Solvent co-intercalation
- Lithium plating (Dendrites)
- Internal cell defects
- Current collector corrosion
- Overcharge
- Over discharge
- Voltage imbalance
- Separator shutdown
- Current-collector dissolution
- Gas evolution
- Binder decomposition
- Thermal runaway
- SEI dissolution
- Lithium loss
- Active material islanding
- Solid phase transformations/disordering
- Power fade
- Spurious corrosive side reactions

(Note: partial list)

AMPED: Achieving more with today's battery chemistries

AMPED Objectives:

- Safety & Reliability
- Performance
- Prognostics

Areas of interest:

1. Online sensing
2. Characterization for fast monitoring and prediction
3. Active cell control
4. Integration of dissimilar devices
5. New control capabilities

AMPED Portfolio

1. Direct Sensing

- Internal cell temperature
- Intercalation strain
- Optical sensing
- Gas signatures

2. Modeling & controls

- Real-time physical state estimation
- Adaptive degradation models

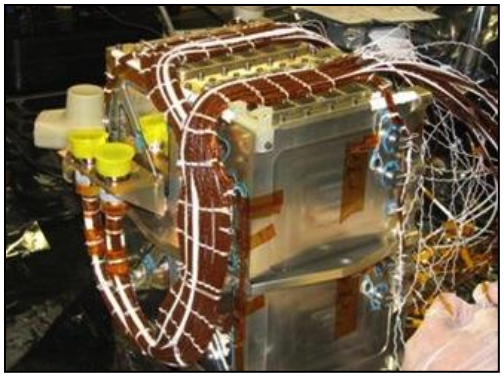
3. Flexible Power Systems

- Cost effective cell-level power management
- Flexible power architectures
- Wireless communications
- Intra-cell thermal management

4. Diagnostics & prognostics

- High-precision columbic efficiency
- Real-time load prediction

Staying connected w/o accruing mass



Mars Rover Pack Courtesy of YTP

Web image of Model S Pack

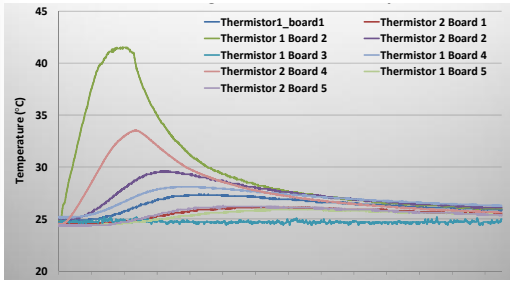
Increasing the number of sensors yields critical information

- System cost: standard solutions incur complexity, weight, expense, and safety penalties

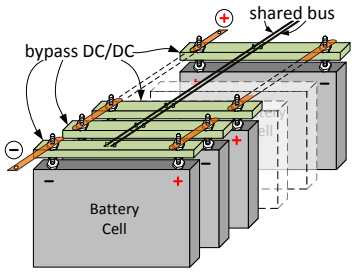
AMPED teams have devised multiple paths to increasing pack information while minimizing penalties

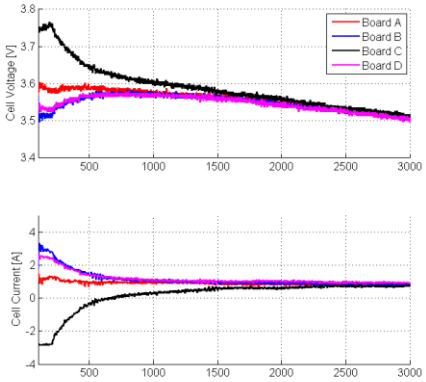
AMPED: Increasing real-time pack information

Wireless Communication

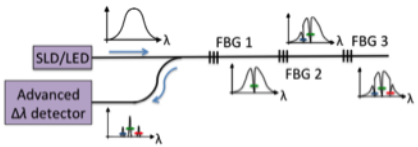


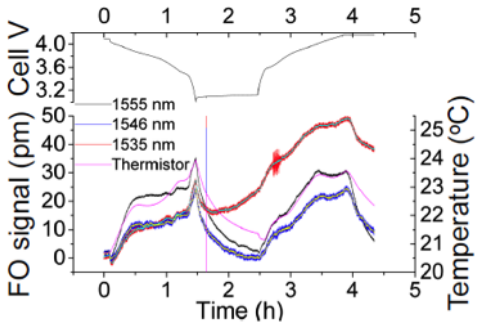
Power Line Communication



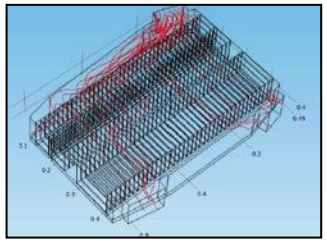


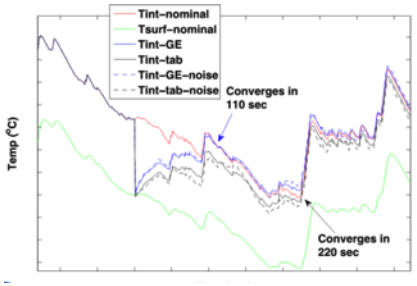
Optical Communication



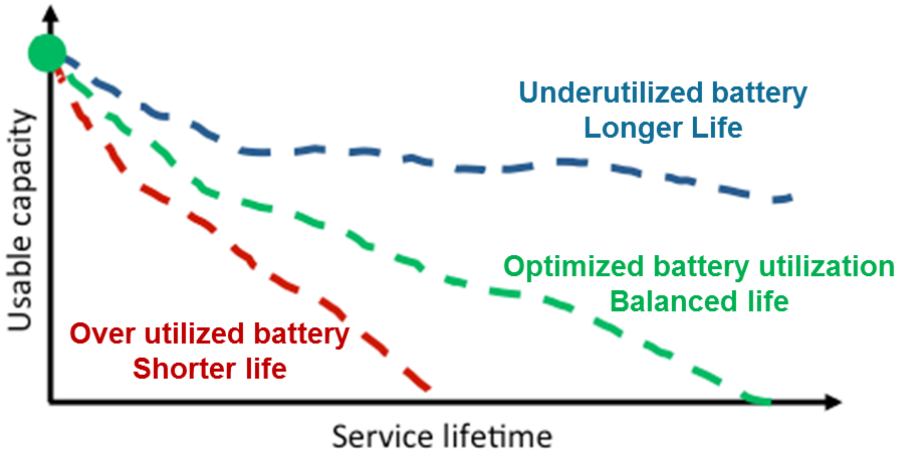


Modeled Observer





Valuing certainty of state information



The identified value of enhanced system awareness:

- **Increased capacity utilization**
- **Ability to right size**
- **End-of-Life prediction**

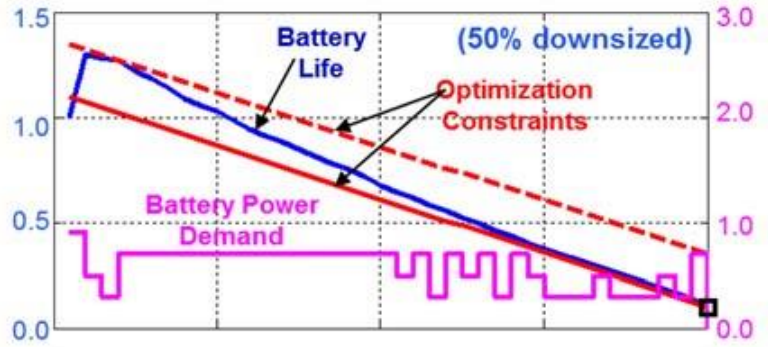
Both downsizing potential and utilization are application dependent.

Better EOL prediction impacts all use scenarios:

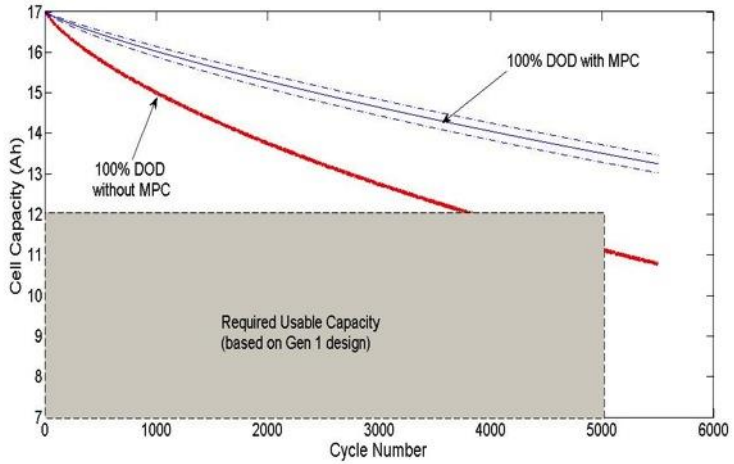
- **Product lifecycle expense**
- **Warranty and Insurance**
- **System integration expenses**

AMPED: Design and control for lifetime

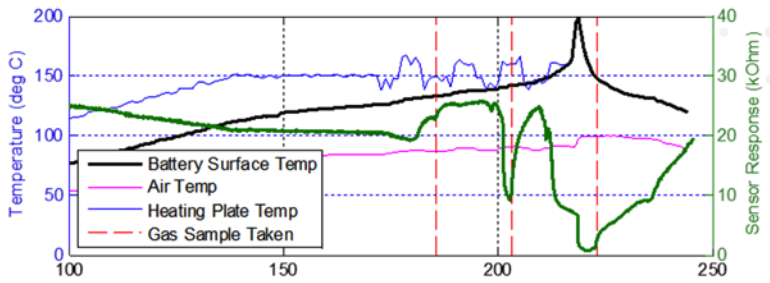
Real-Time Battery Utilization

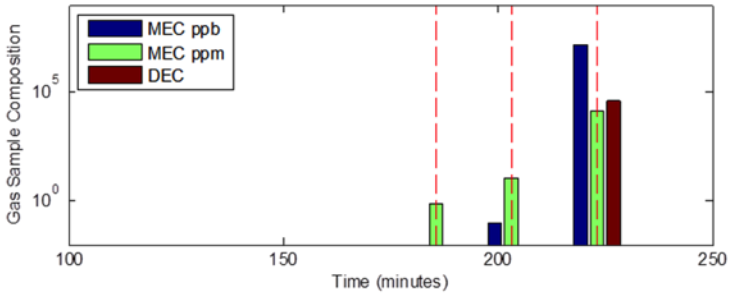


Model Defined Operation



Detection of Operational Hazards





Enabling optimal use of energy storage assets from design to end of life.

Back to the FOA for a bit…

"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."

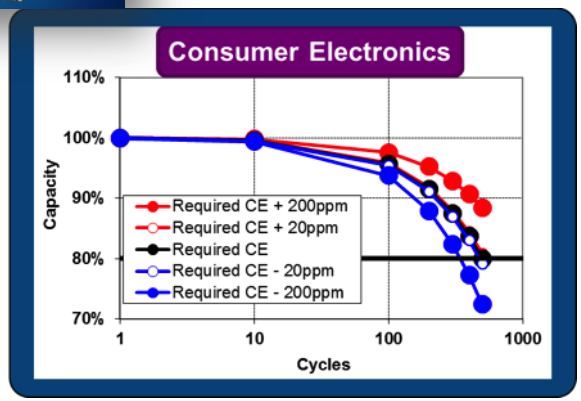
- No AMPED solution is cell specific,
  but *every* AMPED solution requires knowledge of the cell.

- Challenge: How can we expedite the process?

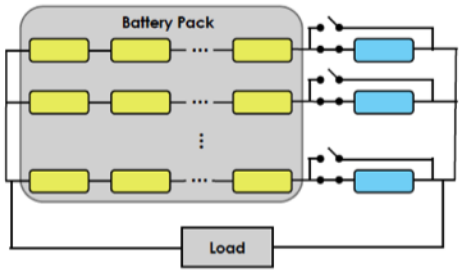
  Can we get from an "unknown" cell to an
  integrated system in a rapid and routine manner?

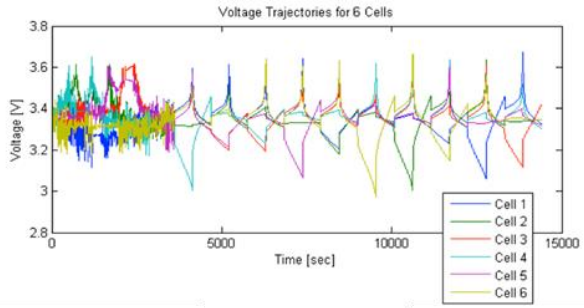
AMPED: Expediting cell characterization

High Precision Measurements



Differential Diagnostics





AMPED Portfolio

1. Direct Sensing

- Internal cell temperature
- Intercalation strain
- Optical sensing
- Gas signatures

2. Modeling & controls

- Real-time physical state estimation
- Adaptive degradation models

3. Flexible Power Systems

- Cost effective cell-level power management
- Flexible power architectures
- Wireless communications
- Intra-cell thermal management

4. Diagnostics & prognostics

- High-precision columbic efficiency
- Real-time load prediction

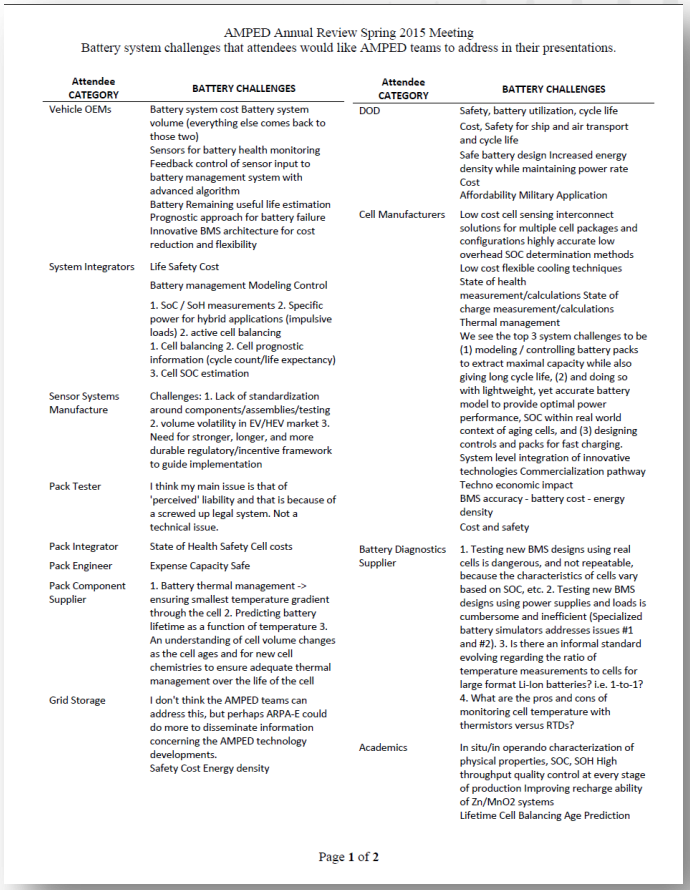
Next steps for AMPED

- Teams entering validation testing in Year 3 of program. Questions to be answered:
  - What is limit of pack downsize for xEV?
  - How far can we push fast charge capabilities?
  - How much can sophisticated models and new control parameters improve the operation and SOX estimates?

BMS Challenges: Attendee Input

What challenges face today's battery systems:

1. System Cost,
2. SOH/Life time expectations,
3. SOC/Utilization,
4. Safety/Reliability
5. Power availability



AMPED Annual Review Spring 2015 Meeting
Battery system challenges that attendees would like AMPED teams to address in their presentations.

Attendee CATEGORY	BATTERY CHALLENGES
Vehicle OEMs	Battery system cost Battery system volume (everything else comes back to those two) Sensors for battery health monitoring Feedback control of sensor input to battery management system with advanced algorithm Battery Remaining useful life estimation Prognostic approach for battery failure Innovative BMS architecture for cost reduction and flexibility
System Integrators	Life Safety Cost
	Battery management Modeling Control
	1. SoC / SoH measurements 2. Specific power for hybrid applications (impulsive loads) 2. active cell balancing 1. Cell balancing 2. Cell prognostic information (cycle count/life expectancy) 3. Cell SOC estimation
Sensor Systems Manufacture	Challenges: 1. Lack of standardization around components/assemblies/testing 2. volume volatility in EV/HEV market 3. Need for stronger, longer, and more durable regulatory/incentive framework to guide implementation
Pack Tester	I think my main issue is that of 'perceived' liability and that is because of a screwed up legal system. Not a technical issue.
Pack Integrator	State of Health Safety Cell costs
Pack Engineer	Expense Capacity Safe
Pack Component Supplier	1. Battery thermal management -> ensuring smallest temperature gradient through the cell 2. Predicting battery lifetime as a function of temperature 3. An understanding of cell volume changes as the cell ages and for new cell chemistries to ensure adequate thermal management over the life of the cell
Grid Storage	I don't think the AMPED teams can address this, but perhaps ARPA-E could do more to disseminate information concerning the AMPED technology developments. Safety Cost Energy density
DOD	Safety, battery utilization, cycle life Cost, Safety for ship and air transport and cycle life Safe battery design Increased energy density while maintaining power rate Cost Affordability Military Application
Cell Manufacturers	Low cost cell sensing interconnect solutions for multiple cell packages and configurations highly accurate low overhead SOC determination methods Low cost flexible cooling techniques State of health measurement/calculations State of charge measurement/calculations Thermal management We see the top 3 system challenges to be (1) modeling / controlling battery packs to extract maximal capacity while also giving long cycle life, (2) and doing so with lightweight, yet accurate battery model to provide optimal power performance, SOC within real world context of aging cells, and (3) designing controls and packs for fast charging. System level integration of innovative technologies Commercialization pathway Techno economic impact BMS accuracy - battery cost - energy density Cost and safety
Battery Diagnostics Supplier	1. Testing new BMS designs using real cells is dangerous, and not repeatable, because the characteristics of cells vary based on SOC, etc. 2. Testing new BMS designs using power supplies and loads is cumbersome and inefficient (Specialized battery simulators addresses issues #1 and #2). 3. Is there an informal standard evolving regarding the ratio of temperature measurements to cells for large format Li-Ion batteries? i.e. 1-to-1? 4. What are the pros and cons of monitoring cell temperature with thermistors versus RTDs?
Academics	In situ/in operando characterization of physical properties, SOC, SOH High throughput quality control at every stage of production Improving recharge ability of Zn/MnO2 systems Lifetime Cell Balancing Age Prediction

Page 1 of 2

AMPED Annual Meeting Day #1

	Day 1 Agenda	Location
11:00-1:00	**Registration** *** Poster Set-up Will Take Place in* 4th Floor Prefunction *Area***	4th Floor Prefunction Area
1:00-1:30	**Welcome and Introduction** **Patrick McGrath**, ARPA-E, AMPED Program Director **Eric Rohlfing**, ARPA-E, Deputy Director of Technology	Gold Coast Ballroom
1:30-2:00	**DoD Challenges in BMS and a Update of HESM Program** Don Hoffman, ONR; John Heinzel, NAVSEA; Ed House, NAVSEA Jack Taylor Mitre/OSD; Sean McNeal, AFRL; Andrew Corbishdale, OASD(R&E)	Gold Coast Ballroom
2:00-2:30	**Electrochemical energy storage research at Argonne and highlight of potential BMS challenges originating from advanced materials** **Kevin Gallagher** Argonne National Lab	Gold Coast Ballroom
2:30-3:00	**Battery Management System Benchmark and Standardization** **Robert Ratz** Ricardo Inc.	Gold Coast Ballroom
3:00-5:30	**Poster Session/Networking Session**	4th Floor Prefunction Area

CHANGING WHAT'S POSSIBLE