Sensor Enhanced and Model Validated Life Extension of Li-Ion Batteries for Energy Storage

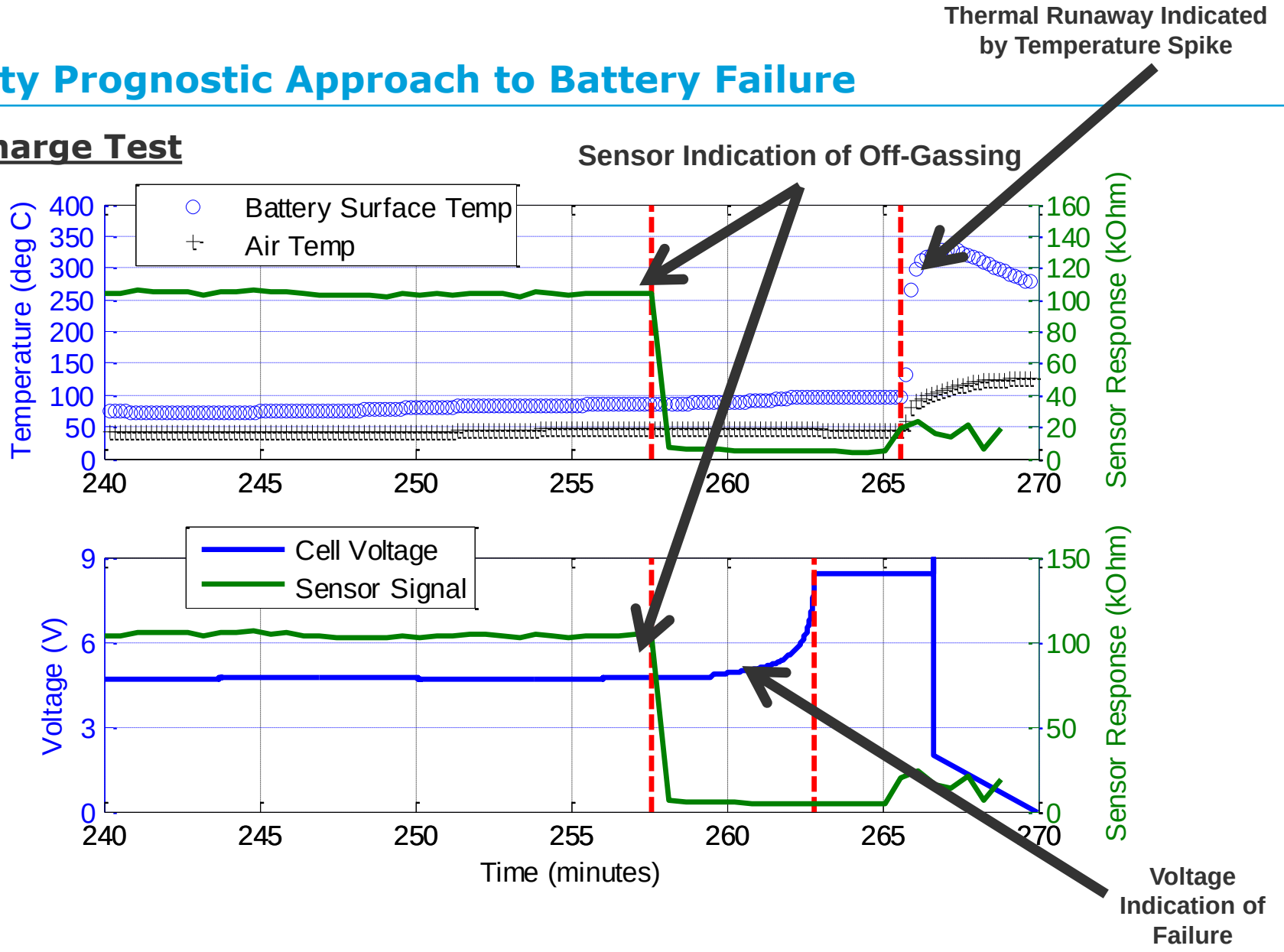
DNV GL, NexTech Materials, Beckett Energy Systems

Value Propositions (derived from list of Battery Challenges)

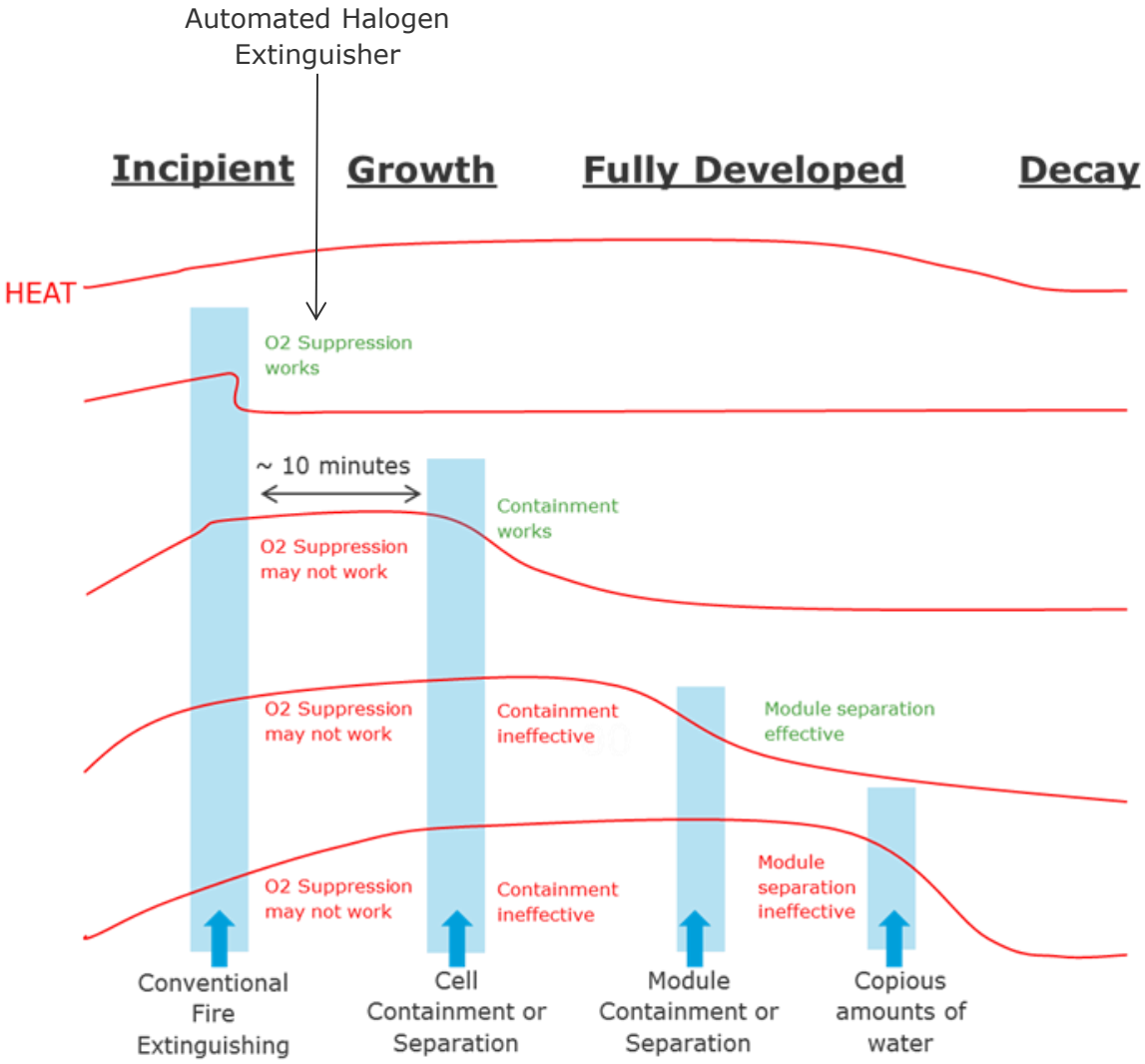
- (Safety) Prognostic approach for battery failure
- Controlling battery packs to extract maximal capacity
- Enables greater safety for fast charging
- Assurance against “perceived” liabilities
- General Safety and prevention – multiple inquiries
- <5% system cost but > 5% value add?
- Integration flexibility
- Value in harsh climates
- Cost vs. complexity
- Non xEV applications (grid storage…)
- Failure modes
- Modularity of system
- Battery and BMS Failure Modes
- Expanding pack lifetime or operational limits

Safety Prognostic Approach to Battery Failure

Overcharge Test

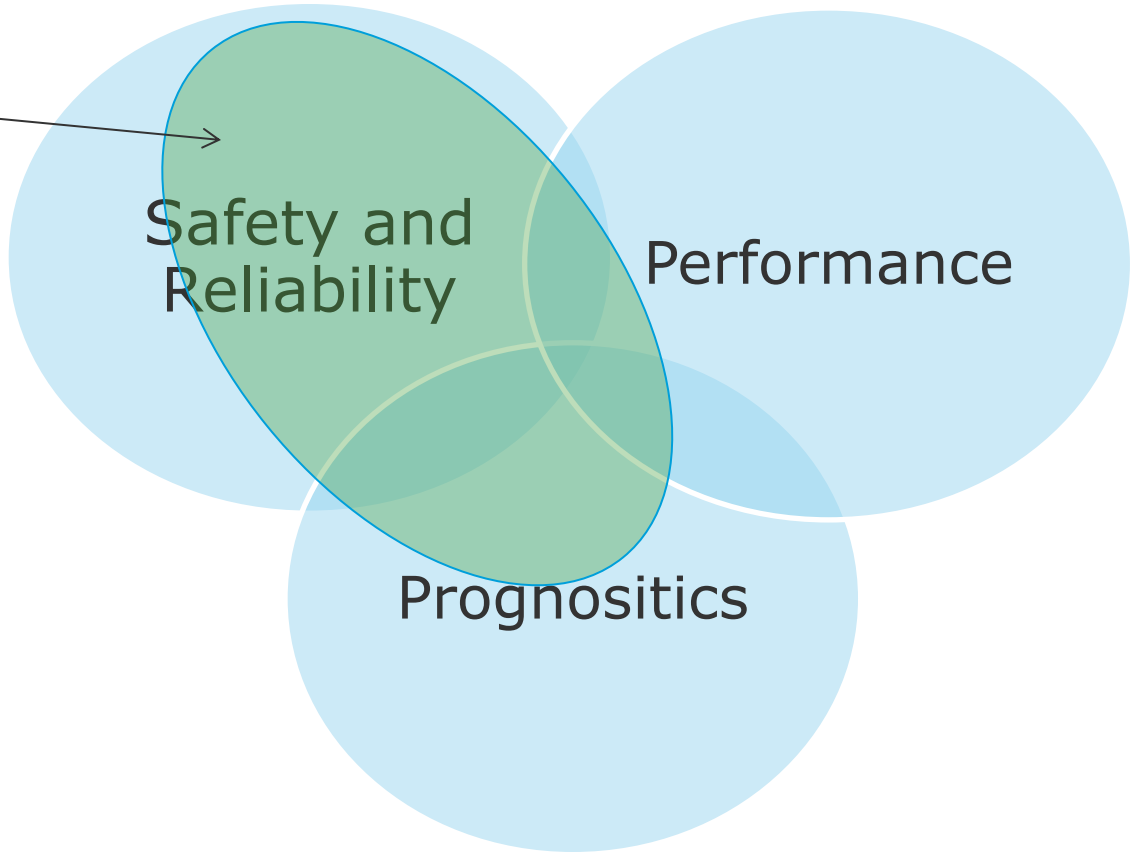


Industry-Wide Problem

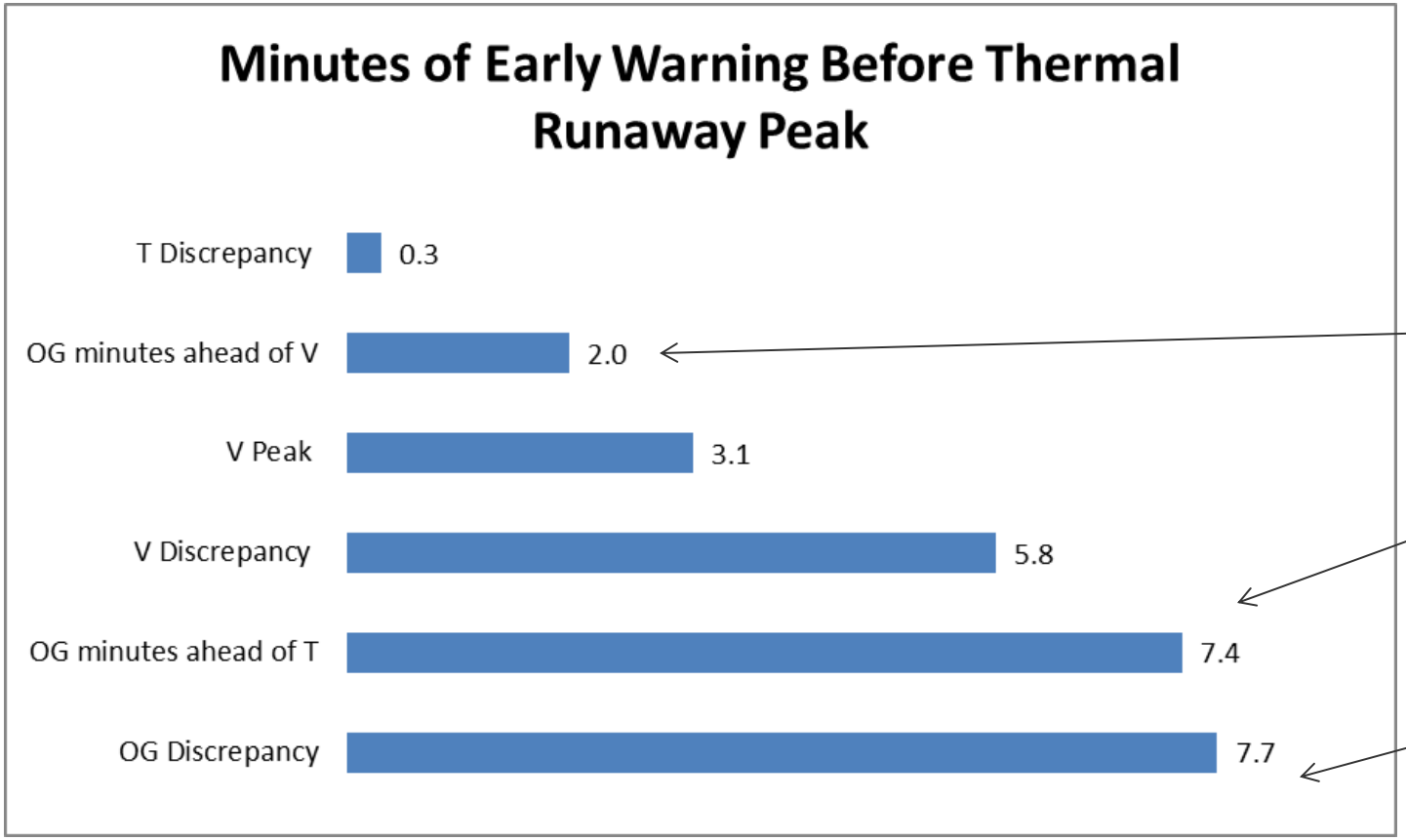


Safety & Reliability

Off gas monitoring



Offgas Monitoring Enables Appropriate Use of Automated Fire Extinguishing

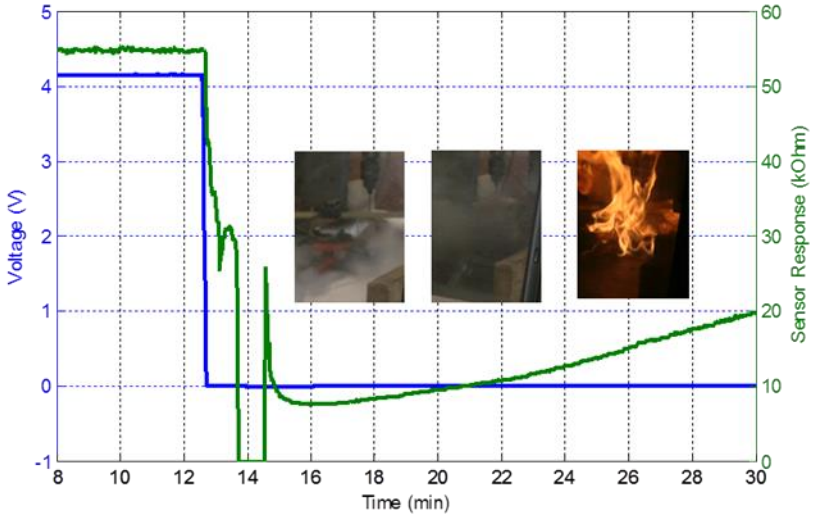


2 minutes ahead of voltage

7.4 minutes ahead of temperature

7-8 minutes total

Failure Mode Identification



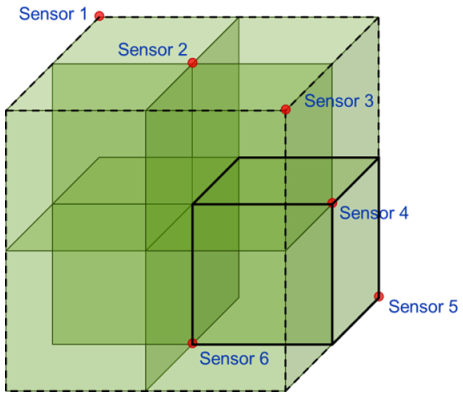
Nail puncture test – coincident with V and T

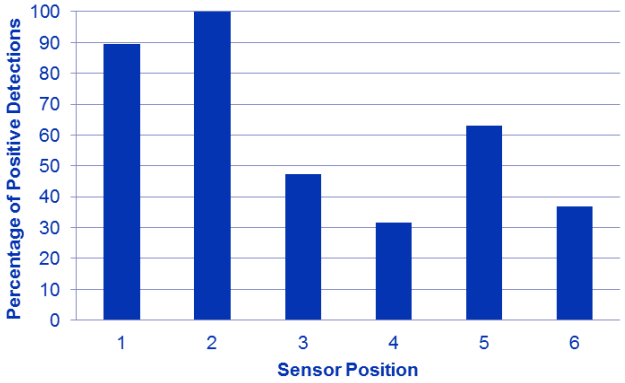
Safety

Prognostics

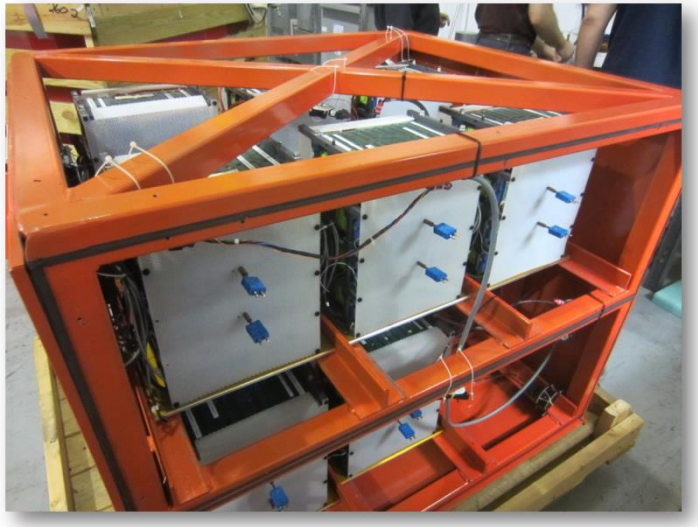
Integration Flexibility, Cost vs. Complexity, and Modularity

- 1-3 sensors within a CES unit

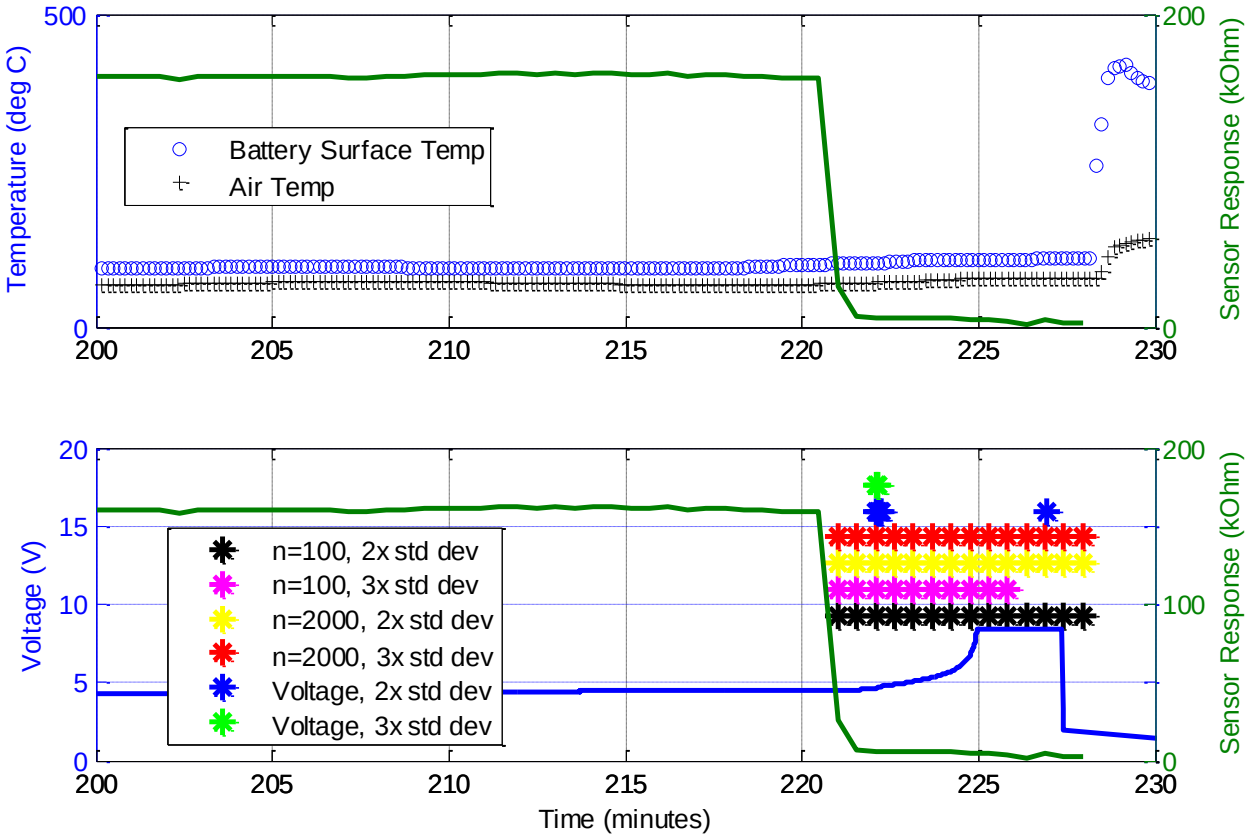




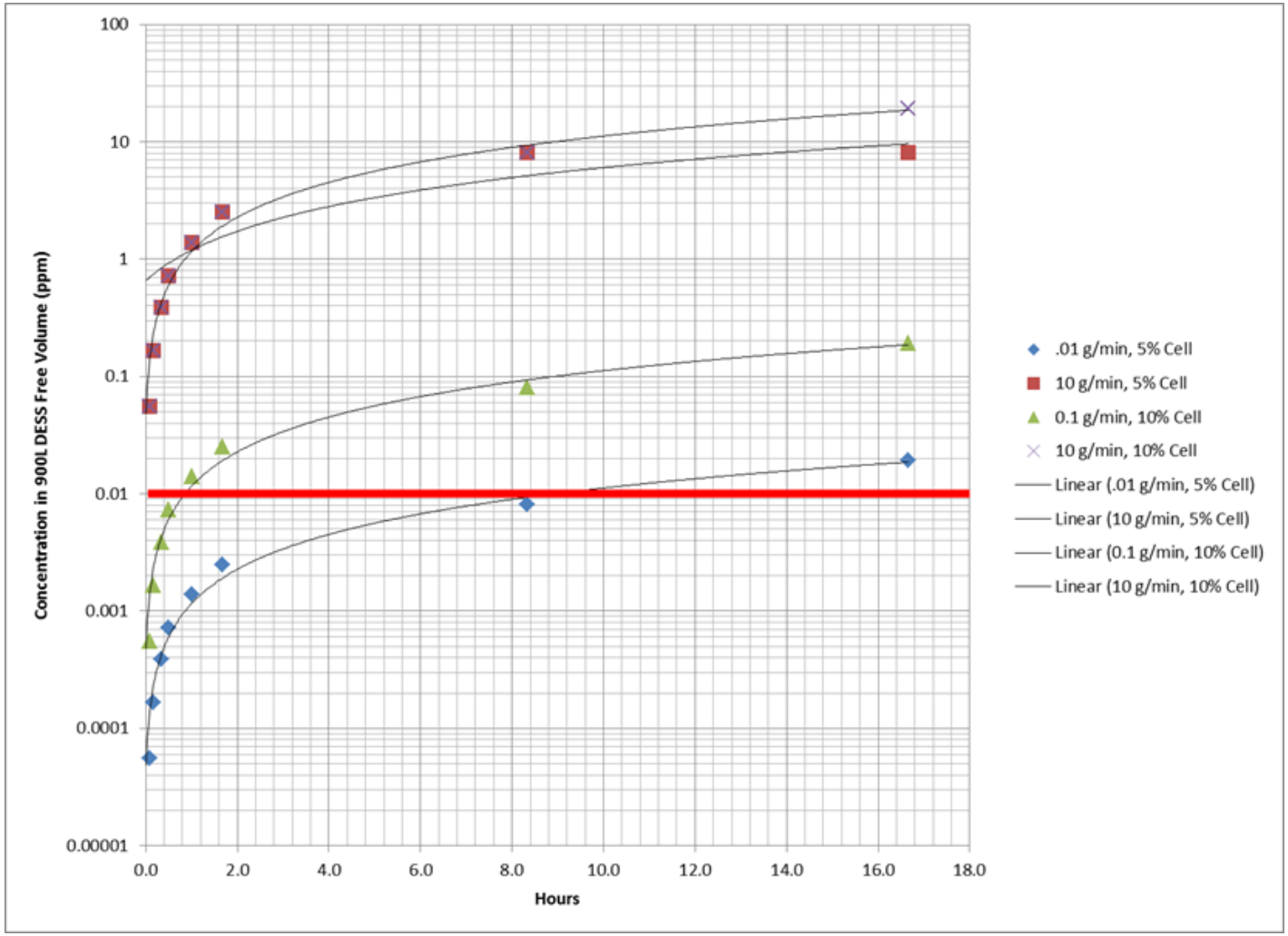
- Pack level monitoring
- Benign offgas events are detectable within minutes
- Catastrophic early warning detectable < 1 min



Control Strategies to Convert to a Binary Signal

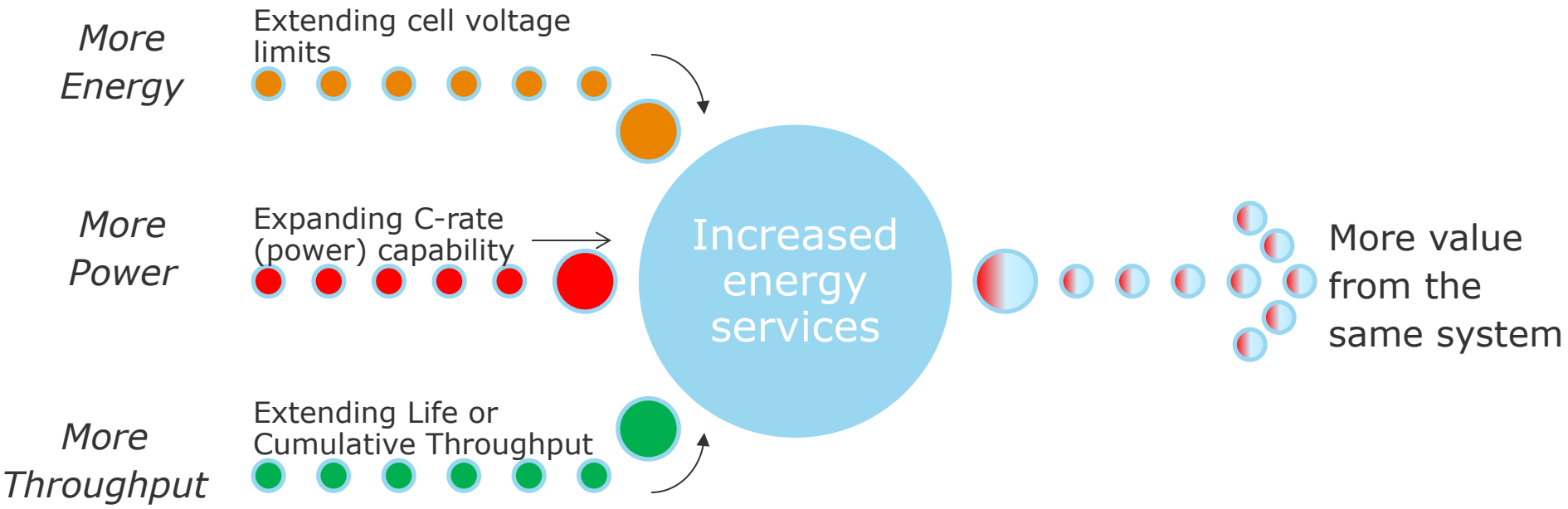


Detection Rates based on Diffusion of Offgas in CES Unit



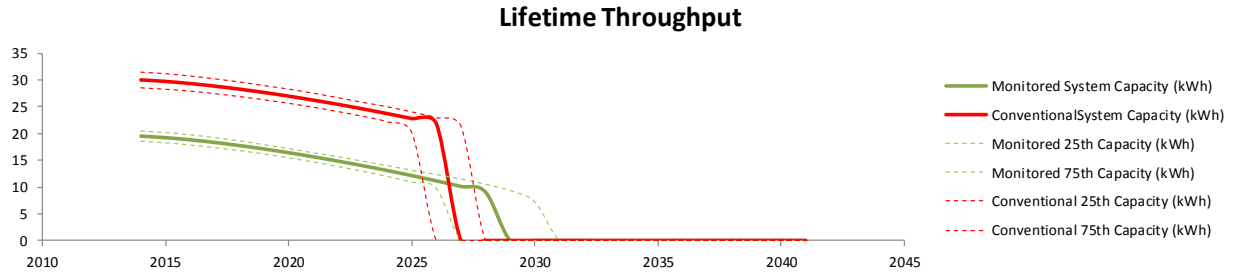
Extraction of Maximal Capacity and Extension of Operational Limits

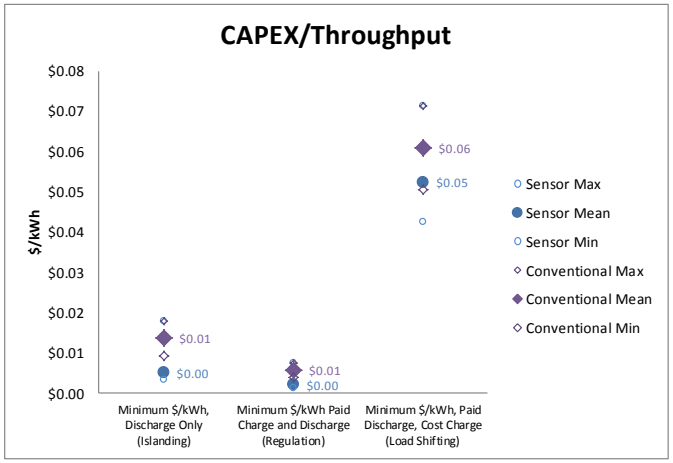
- Use sensor as safety assurance for:

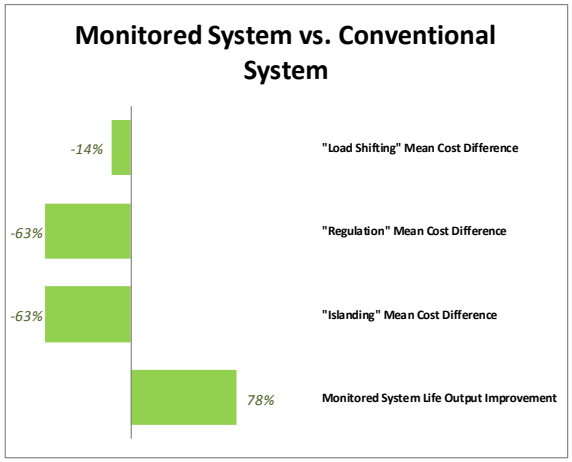


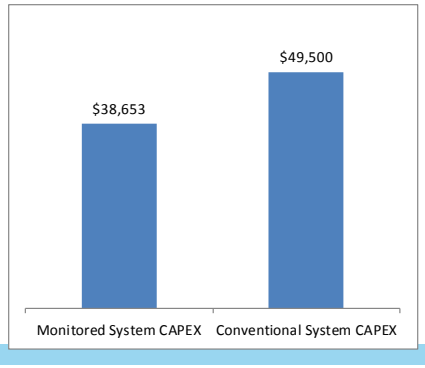
What is the best path for cost reduction?

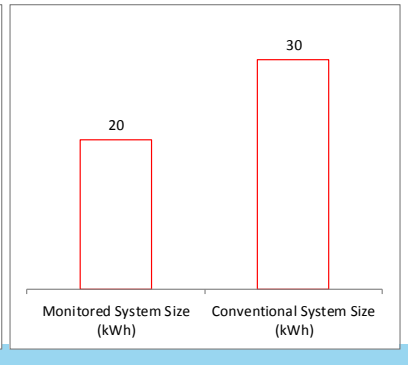
- Monitoring and more aggressive cycling (A)
- Systems that have monitoring and life extension (L)
- Monitoring, life extension, and more aggressive treatment (LA)
- **Life extension and downsizing (LD)**
- Life extension and bypassable modules (LB)
- Life extension, downsizing, and bypassable modules (LDB)
- Life extension, aggressive cycling, downsizing, and bypassable modules (LDBA)

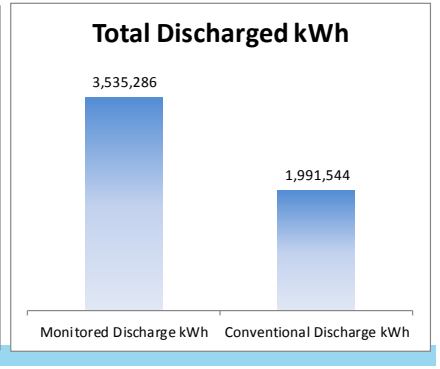












Assurance against perceived and real liabilities

- Perception of decreased safety in longer life
- Real consideration for monitoring in enclosed spaces
- Real consideration for monitoring in populated areas or the built environment

$$Avoided\ Cost = p_d * p_c * C_c$$

Catastrophe avoidance

Where p_c is the probability of a catastrophe, p_d is the probability of detection, and C_c is the costs of that catastrophe.

$$Additional\ Revenue = L * R_{kWh} * E_d * (L_{ex})$$

Life Extension

If the revenue potential per kWh is R_{kWh}, and there is the ability to deliver energy at the rate of E_d (kWh/mo), the expected lifetime of a non-sensor equipped system is L (in months), and the potential life extension percentage is $L_{ex,}$

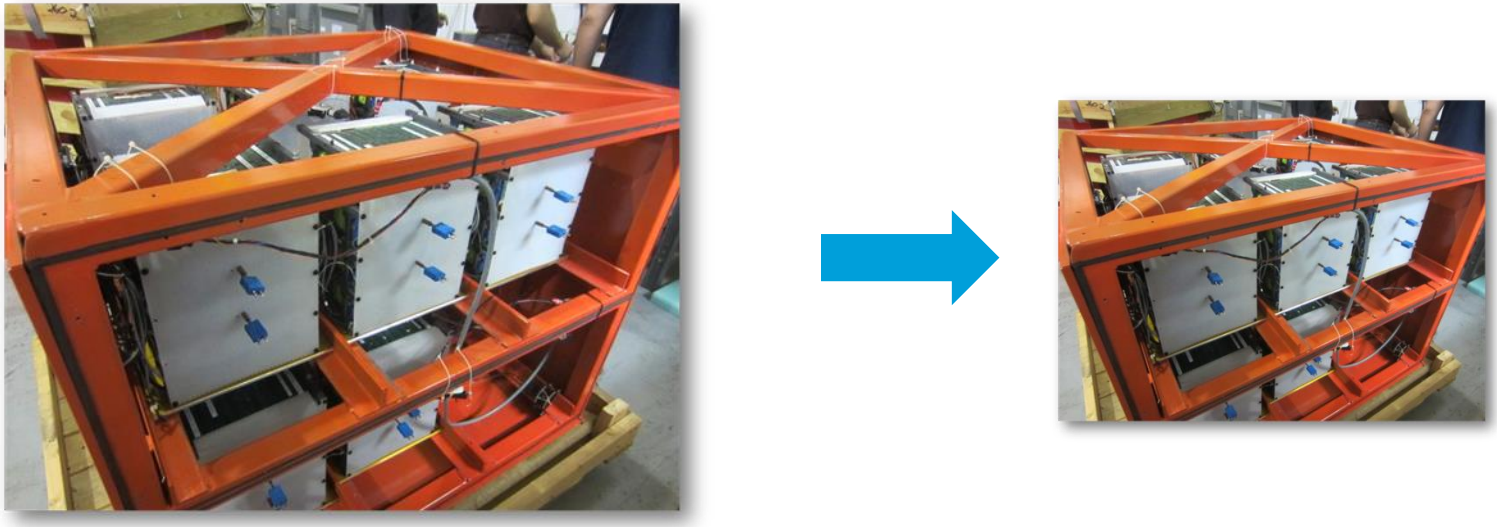
Additional Cost Opportunity

$$Capacity\ Capital\ Cost\ Reduction = (Baseline\ Capacity - Downsized\ Capacity) * \frac{\$_{capacity}}{kWh} - Sensor\ System\ Cost$$

Reducing overcapacity

$$Cooling\ Capital\ Cost\ Reduction = (Baseline\ Cooling - Downsized\ Cooling) * \frac{\$_{cooling}}{kWh} - Sensor\ System\ Cost$$

Reducing cooling load



Non xEV Applications

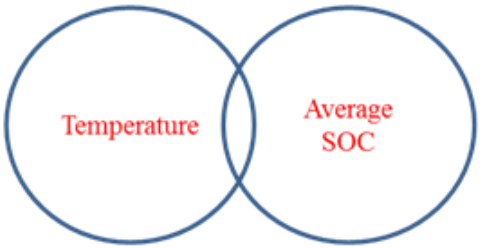
Offshore oil & gas

- Dynamic Positioning Shuttle Tanker =**18 MW for 30 minutes of backup power** for maneuvering during a blackout. Vessel is **300 m** long.
- Drilling applications – **5-6 MW** transients in **<1 minute**
- Harbor and offshore tugs: **7-8 MW** electric only pulling

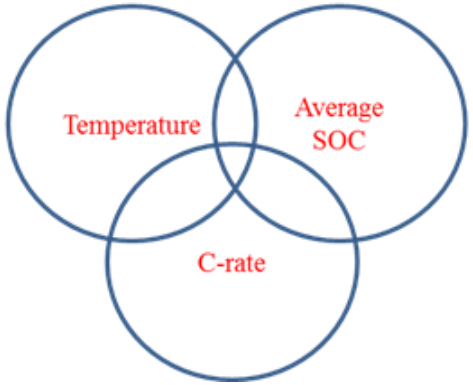
Harsh Environments < -- > Extended Performance

- Higher temperature
- Cooling load and burden
- Physical, ingress, humidity, or mechanical hazards

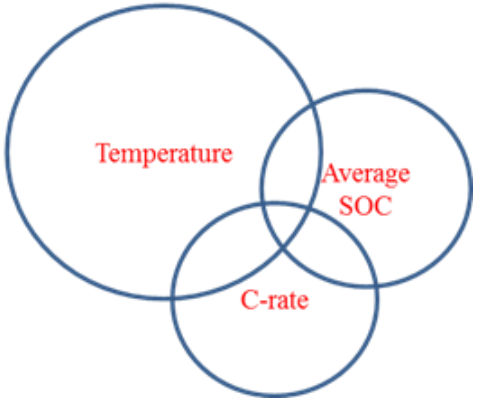
Conservative Management: 25°C, 1C/1C charge and discharge rates



Power applications, 2C rates or higher

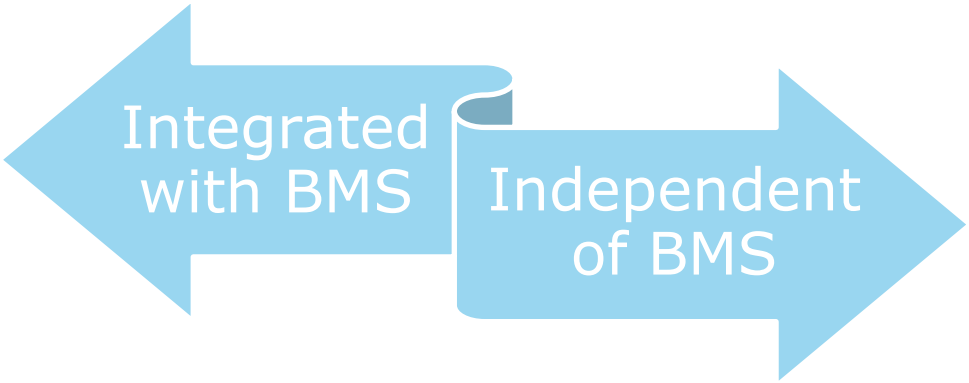


Extreme conditions (high temperature)



Battery and BMS failure modes

- **Expanded Operation**
- **"Pull back" from extremes**
- **Redundancy in Shut Down**
- **Bypassable Modules**



- **Automated Class D Extinguisher**
- **Redundancy**
- **Maintenance Alarms**
- **Distinguish cell anomaly from catastrophic failure**

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