Review of Common Obstacles in the Development Cycle for Novel Battery Electrode Active Material Commercialization

Joint Service Power Expo 2015

Dr. James Fleetwood

BIC
BATTERY INNOVATION CENTER

Vision

A non-profit, public-private partnership joining academia, industry, and government to rapidly develop, test, and commercialize the next generation of safe, reliable, and lightweight energy storage systems.

Distinguishing Features

1. Catalyze technologies by reducing long, expensive innovation-to-commercialization development cycle
2. Does not hold patent rights, reducing concerns to jointly develop
3. IP-secure, US-based facility generating reliable data using common techniques & equipment

Core Offerings

1. Low volume cell manufacturing & prototyping
2. Full suite of test & evaluation capabilities
   - Cells, Modules, Packs, & Systems
   - Certification
3. Applied Research & Consulting
   - Design for packs, BMS, and systems
   - Competitive analysis

Advanced Energy Systems Testing and Validation Capabilities

Battery System Testing and Evaluation

- Full spectrum of T&E equipment for individual cells up to whole systems of 1MW+
- Access to environmental and abuse testing facilities at NSWC Crane that include more than $150M in hardened test labs

Microgrid Systems Testing

- Utility scale grid simulator
- Integrated solar and wind renewables on site
- Residential, community, and grid energy storage systems on site
- Facility designed with access to >6MW of available power with net metering (MISO High Voltage Node)

Cell and Pack Manufacturing

- 1% Humidity Dry Room & 10,000 Class Clean Rooms
- Commercial quality cell manufacturing equipment for multiple cell formats
- Pack design and assembly equipment

Description of Overall Development Cycle

- Theory/Model
- Electrochemical testing
  - Active material evaluation
  - Individual electrode systems
  - Paired electrodes
  - Electrolyte selection
- Cell format progression
  - Split cell testing
  - Half cell (coin) testing
  - Full cell (coin) testing
  - Large format pouch/prismatic/cylindrical cell testing
- Electrode fabrication progression
  - Laboratory process
  - Slip table / doctor blade
  - Continuous coating
    - Comma bar coater dryer
    - Slot die coater dryer

Description of Overall Development Cycle

- Theory/Model

Element
mAh/g
mAh/cm^3

Anodes (Conversion)

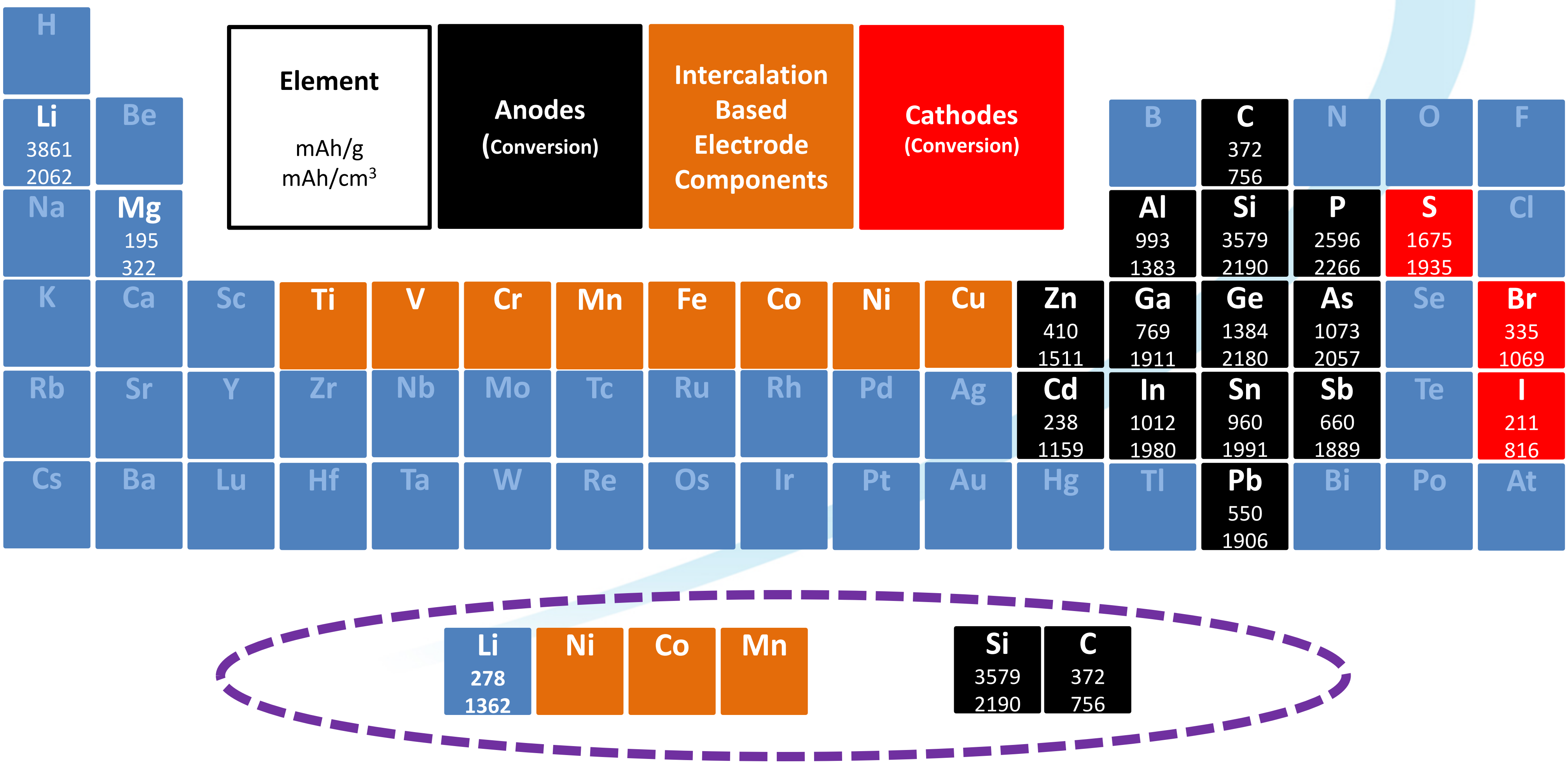
Intercalation Based Electrode Components

Cathodes (Conversion)

H																
Li 3861 2062	Be											B	C 372 756	N	O	F
Na	Mg 195 322											Al 993 1383	Si 3579 2190	P 2596 2266	S 1675 1935	Cl
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn 410 1511	Ga 769 1911	Ge 1384 2180	As 1073 2057	Se	Br 335 1069
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd 238 1159	In 1012 1980	Sn 960 1991	Sb 660 1889	Te	I 211 816
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb 550 1906	Bi	Po	At

Description of Overall Development Cycle

- Theory/Model



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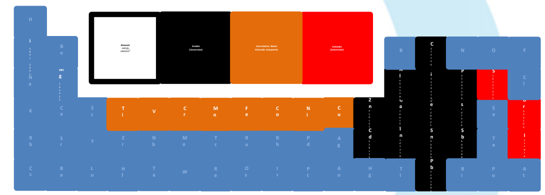
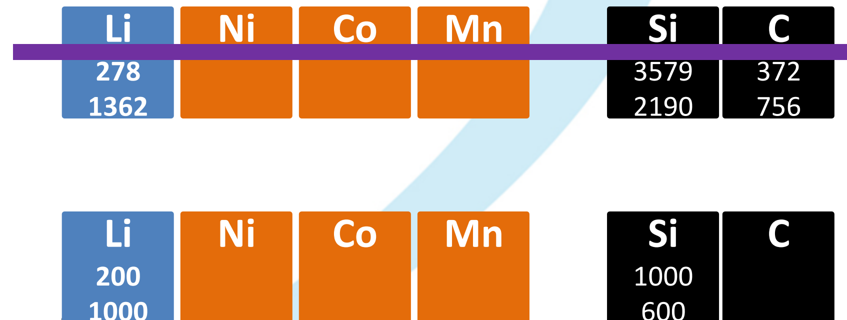
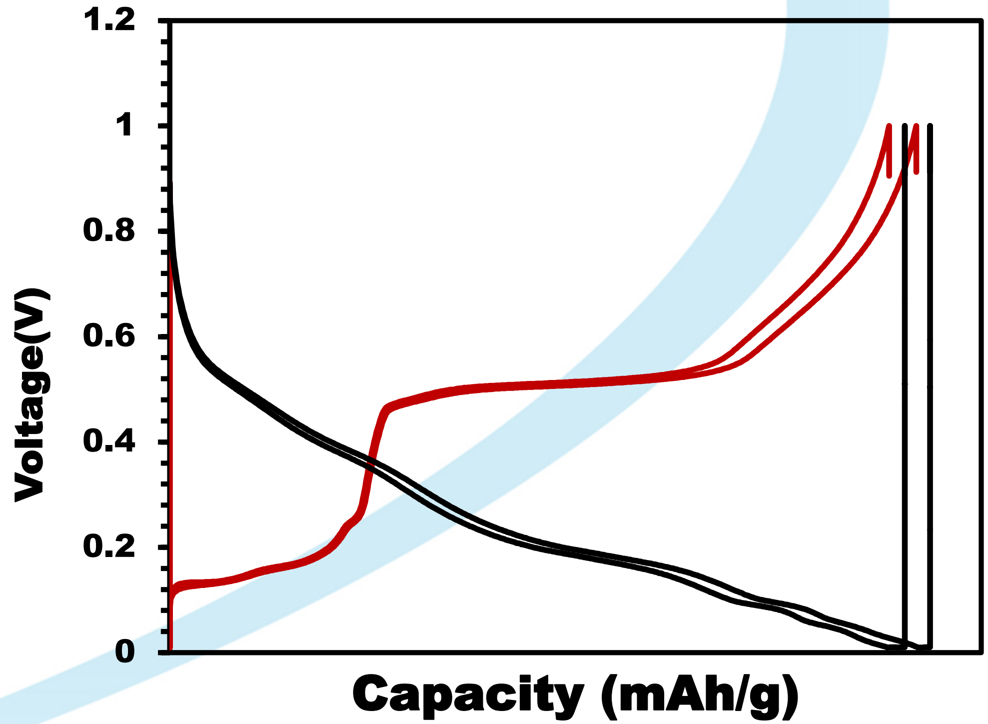




Electrochemical Testing

- Active material evaluation
  - Split cells
- Individual electrode systems
  - Half cells
- Paired electrodes
  - Full Cells
- Electrolyte selection
- Key performance metrics
  - Specific capacity (mAh/g)
  - C-Rate
  - Cycle life
  - Coulombic efficiency
  - Irreversible capacity
  - Temperature range
  - Safety



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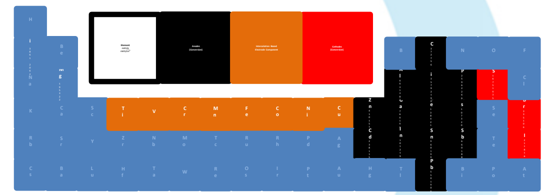
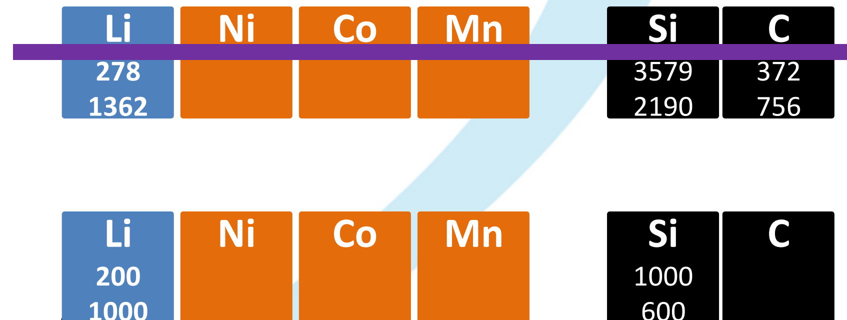
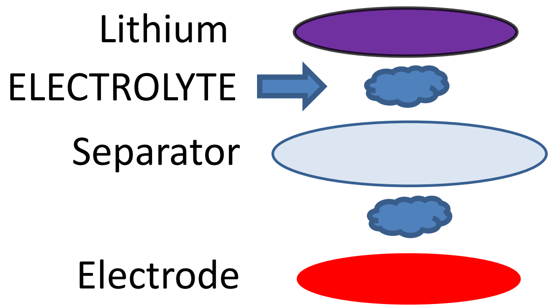
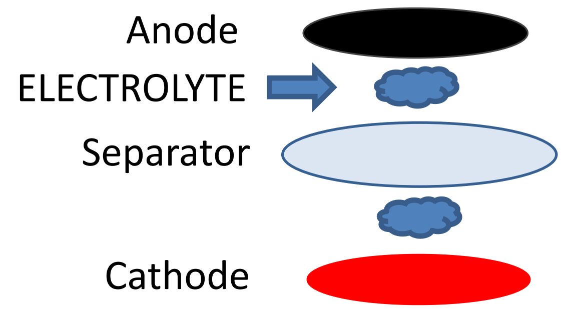




Half Cell vs. Full Cell

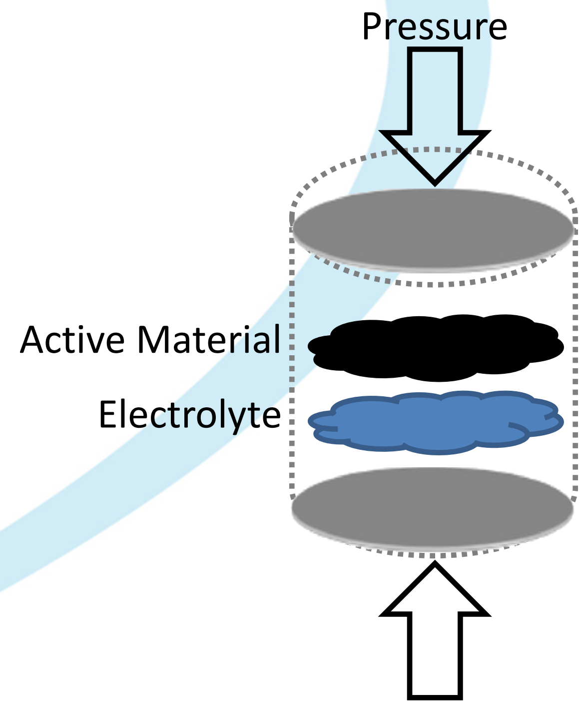




- Half Cell
  - Simple system without need for balanced electrodes
  - Limited cycling due to risk of lithium dendrite formation
  - Effectively unlimited Li available
- Full Cell
  - Complete cell system with performance characteristics like that of end-use / commercial cells
  - Capable of long term and more in depth testing

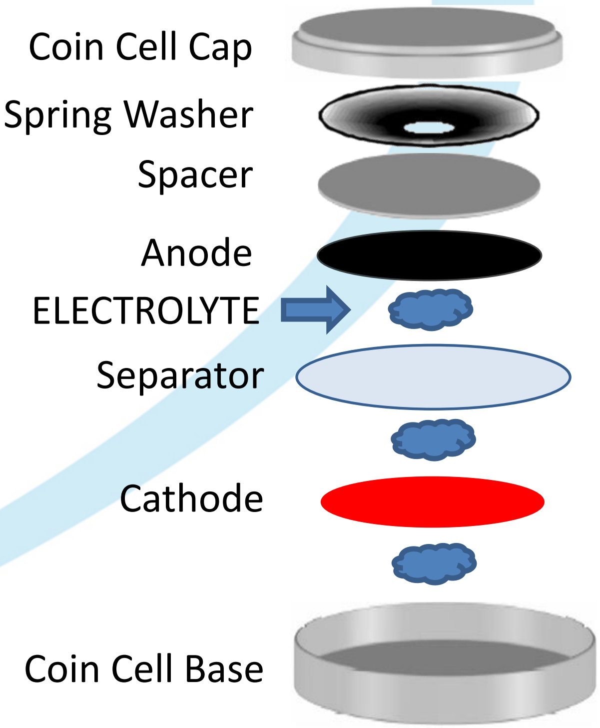
Split Cell Testing

- Benefits
  - Basic empirical comparison to theoretical electrochemical properties
  - Cell system independent evaluation of charge capacity at given cycle rates
  - Indication of potential cycle life
  - Most conservative of available materials
- Drawbacks
  - Time intensive
  - Large free volume for expansion, gassing, and excess electrolyte
  - Can miss mechanical property related failure mechanisms



Coin Cell Testing

- Benefits
  - Easily & quickly constructed
  - Conservative of materials (<50 mg/cell)
- Drawbacks
  - Typically a manual assembly with less control than with split cell tests
  - Large open volumes
  - Relative overlap of anode and cathode can be unrepresentative to larger cell formats



Large Format – Full Cell

- Benefits
  - Commercial formats at industry relevant performance
- Drawbacks
  - Requires more material than small format testing
  - Requires more time per cell to construct
  - Complexity of interactions can make trouble-shooting slower
    - Less free volume in cell for cyclic expansion or gassing
    - Cell heating during cycling more likely
    - Electrode mechanical properties may become a factor

Pouch / Prismatic Cells

- Benefits
  - Minimal mechanical requirements on electrodes
    - Particularly for flat/stacked/Z-fold pouch cells
  - Flexible on geometry and # of electrode layers
- Drawbacks
  - More difficult to monitor gassing
  - Less consistency with electrolyte fill & infiltration

Cylindrical Cells

- Benefits
  - Standardized product
    - Highly commercially relevant
  - Safety features
    - Pressure relief valve
    - Over-temp shut-off
  - Most rigorous test
    - 1-20 Amps may be flowing at a time
    - Contained volume
    - Electrodes wound around tight mandrels
- Drawbacks
  - Most rigorous test
  - Much more equipment required to fabricate than previous cells
  - Must fabricate from continuous coating methods
    - 500-1000 mm electrodes typical

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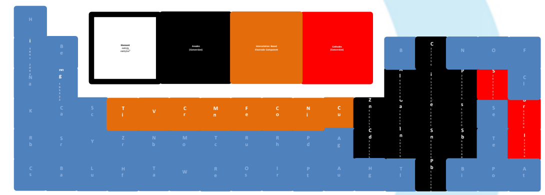

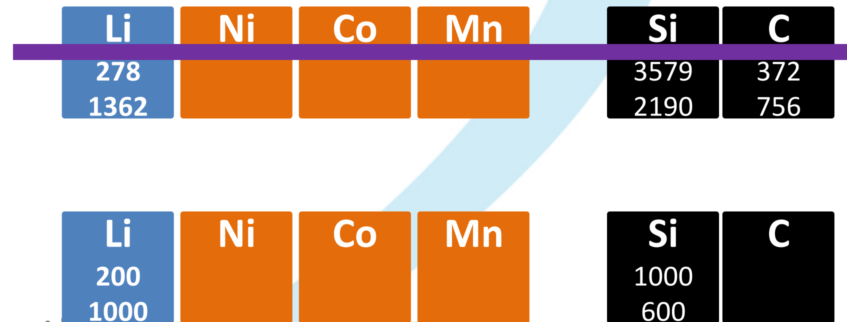

Slip Table Coating Trials

- Benefits
  - Low material requirements (<50 mL of slurry)
  - More flexible on slurry rheology
  - Reveals general ‘coat-ability’ of electrode slurry
- Drawbacks
  - Higher variation between and within coatings
  - Limited production capacity
  - Slower drying rate than industrial processes

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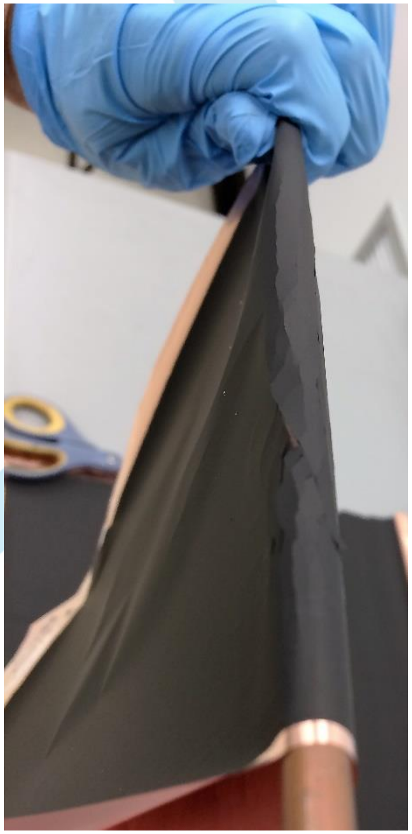
Wet coating

Dried & calendered

Dry coating   Saturated with electrolyte

Comma Bar Coater Dryer

- Benefits
  - More consistent coating & drying over slip table trials
  - High throughput capability
    - Even a laboratory model is capable of 3 m/min coating rates
  - Industry relevant coating process
    - Slot die is the next step up in capabilities
- Drawbacks
  - Slurry rheology governs coating quality
    - Slurry solids content at this point is a dependent variable
    - Less ability to control as-cast electrode porosity
  - Drying rate generally increases over slip table rates
    - Increases residual stresses in electrodes, particularly those with small particle sizes & high specific surface areas



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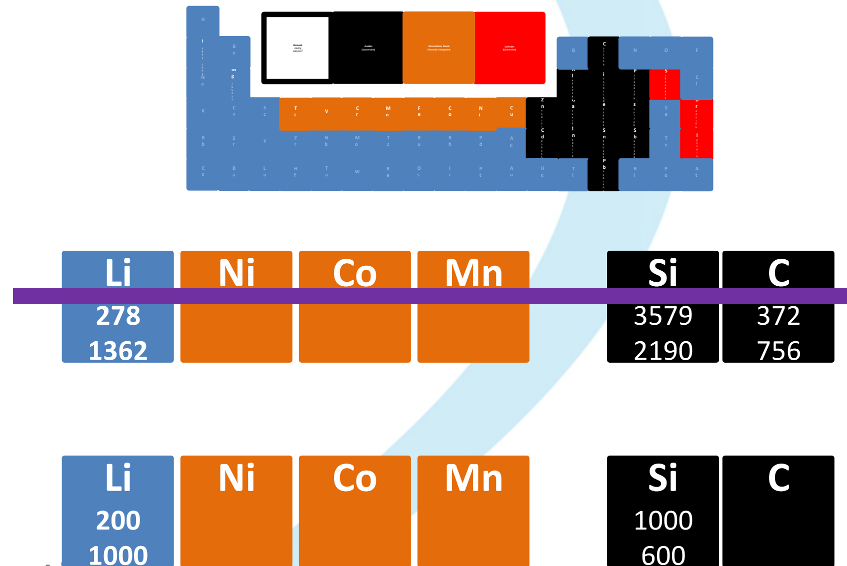

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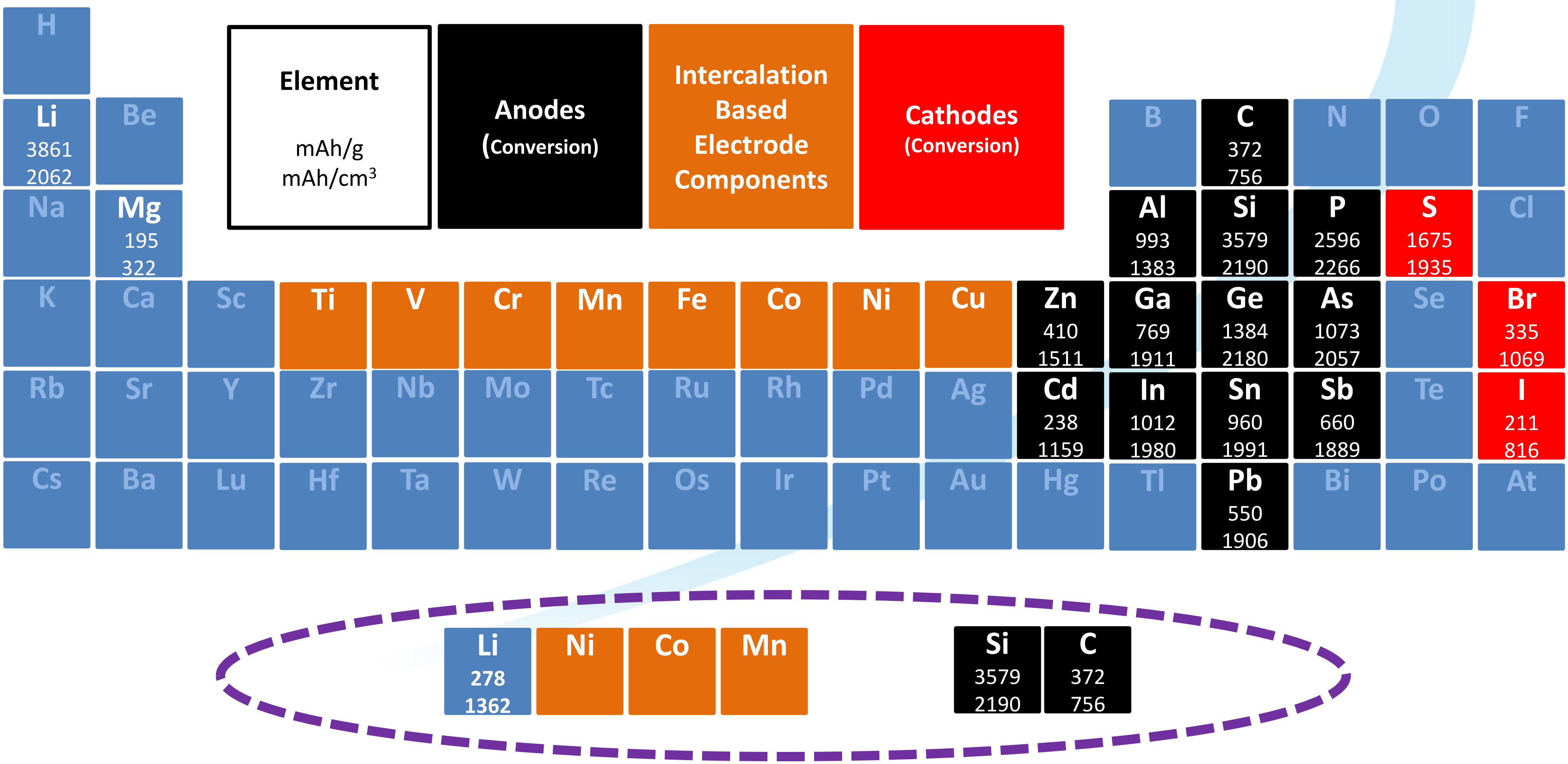

Trends in Battery Active Material Development

- Intercalation based electrodes
  - Charge/discharge based on diffusion of Li^+ to and from lattice sites within the electrode structure
- Conversion based electrodes
  - Tend to have the highest theoretical capacities
  - Undergoes solid-state reaction as part of charge/discharge
  - May not have an initial source of lithium
  - Typically utilizing active materials with large volume changes during cycling
- Electrolyte development
  - Solubility of active material elements
  - Stability of SEI, particularly w.r.t. maximum operating voltage and solubility of electrode elements

Trends in Battery Active Material Development

- Dimension reduction of electrode materials
  - Shortens Li^+ diffusion path for faster charge/discharge rates
  - Increases resistance to mechanical failure due to volume changes for improved cycle life
  - Increases specific surface area (m^2/g)
    - Solid electrolyte interface (SEI) layer increases in relative volume within electrode
    - Electrolyte and SEI stability requirements increase
    - Increases capillary action within electrode
      - Humidity/environmental sensitivity
      - Increases residual stresses incurred during solvent evaporation
  - Increases particle dispersion requirements
    - van der Waals forces mitigate dimension reduction via aggregation

Trends in Battery Active Material Development

- Active material protection & hierarchical microstructures
  - Typically with carbon compounds
  - Encapsulation of active materials
  - Composite electrodes
  - Often limited by complex fabrication techniques
  - Tendency towards atypical surface/interface properties
  - Unknown or low compatibility with common slurry compositions
- Active material composition optimization
  - Focusing on intercalating crystal structures with high capacity and stability over time
  - Typically has very similar optimal slurries compositions to contemporary electrodes

Conclusions

- Intercalation based electrodes are still the standard, with shorter development cycles
- What's holding conversion based electrodes back?
  - Ideal electrolytes & stable SEI layers
  - Mechanical properties & surface science
    - Slurry composition & rheology need earlier consideration during development
    - Nanoscale active materials are much less likely to use standard slurry compositions and mixing procedures

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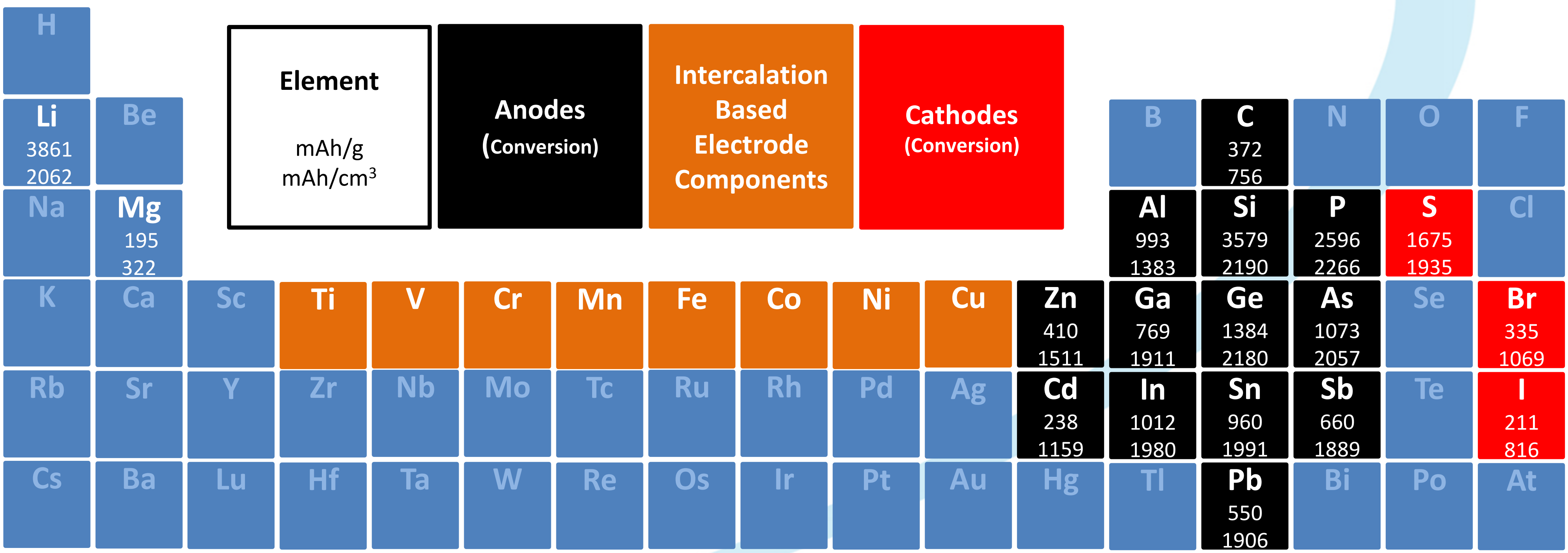

BIC Members

BIC BATTERY INNOVATION CENTER

DUKE ENERGY

Underwriters Laboratories

TSC Technology Service Corporation an employee-owned company

SAIC

TEAM CRANE

STIMULUS ENGINEERING

PURDUE UNIVERSITY

PENNSTATE EC Electro-Optics Center

Chroma Systems Solutions

renewz

EaglePicher Technologies, LLC An OMG Company

MEGTEC

AV aerovironment

Raydar

INDY POWER SYSTEMS

IVY TECH COMMUNITY COLLEGE

TRL Explanation

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DHS S&T Portfolio	N/A	Basic Research			Innovation and Transition					
Technology Phase	Needs Assessment	Science			Technology Development			Product Development		
Technology Readiness Level (TRL)	N/A	TRL 1 – TRL 3			TRL 4 – TRL 6			TRL 7 – TRL 9		
Manufacturing Readiness Level (MRL)	N/A	MRL 1 – MRL 3			MRL 4 – MRL 6			MRL 7 – MRL 10		
Key Objectives	❑ Identify S&T needs or capability gaps ❑ Rough draft operational requirements are developed (if appropriate) ❑ Market Survey ❑ Technology Scan ❑ Assess technology-based solutions to address gaps. ❑ Investigate the value proposition ❑ Establish technical objectives and milestones. ❑ Conduct preliminary IP review. ❑ Initiate Congressional Appropriations Memo, Technology Transition Agreements (TTAs), Technology Commercialization Agreements (TCAs), Program Descriptions (Research and Innovation) and Feasibility Studies	**TRL 1** ❑ "Back of the envelope" environment – new approach ❑Research hypothesis formulated ❑ Basic scientific principles observed ❑ Physical laws and assumptions used in new technologies/sciences defined ❑ Have some concept in mind that may be realizable ❑Paper studies support basic principles (literature search) ❑Formulation of concepts that might be realizable (draft road map) – "If – then" statements ❑Has a Feasibility Study White Paper been developed? ❑Has a potential DHS mission space been identified? ❑Identify interest in technology/science, e.g., sponsor, funding source (users/participants: researchers, national/international, private, government, academia, military) ❑Know who will perform research and where it will be done	**TRL 2** ❑ Basic elements of science/technology identified (math/physics/ chemistry/ analysis/ algorithm) ❑ Components of technology/science partially characterized ❑ Rigorous analytical studies confirm basic principles ❑ Paper studies show that application is feasible ❑ Potential system or component application(s) identified – proof of principle ❑ Individual parts of the technology work ❑ Develop research plan ❑Qualitative idea of risk areas (cost, schedule, performance) ❑ Identify DHS area supported ❑ Requirement tracking system defined-slow requirements creep ❑ Begin market research (Who is interested, outreach, market survey) ❑ Develop a Technology Roadmap.	**TRL 3** ❑ Science known to extent that models and simulations are possible ❑Preliminary system performance characteristics and measures have been identified and estimated ❑ Predictions of elements of technology capability validated by Analytical Studies ❑ Experiments carried out with small representative data sets ❑ Laboratory experiments verify Scientific feasibility ❑ Scaling studies have been started (size, environment, component integrations) ❑ Customer/user identified and participates in requirements definition/ generation. ❑ Risk areas and mitigation strategies identified ❑ Global Research Services search performed ❑ Develop Quality Control Plan standards conformance, reliability ❑ Develop Marketing Plan to include market size and research.	**TRL 4** ❑ All required technology components integrated for Proof of Concept ❑ Proof of Concept conducted ❑ The customer briefed on the Proof of Concept results ❑Cross-technology uses assessed and identified ❑ FRD finalized ❑ SEMP finalized and updated (TRL 4, 5, & 6) ❑ TEMP completed and updated (TRL 4, 5, & 6) ❑ Configuration Management Plan exists ❑ PMP updated (TRL 4, 5, and 6) ❑ Risk Management Plan updated (TRL 4, 5, and 6) ❑ Program Cost Analysis updated (TRL 4, 5, and 6) ❑ Quality Assurance Plan exists ❑ Begin transition planning.	**TRL 5** ❑ ORD and CONOPS developed ❑ Security Assessment updated ❑ OMB 300 and Acquisition Plan completed (if required) ❑ IPT certified readiness for the transition of the Technology ❑ Program Transition Manager assisted in transition documentation development ❑ Technology scan and market survey (ongoing) ❑ Analysis of Alternatives developed and updated (TRL 5 & 6) ❑ Entry Criteria Checklist completed and delivered to the TM ❑ PDD created, approved, and signed (TRL 5 & 6) ❑ Director approved the transition	**TRL 6** ❑ Execute TTA / TCA as applicable ❑ Program Manager identified. ❑ Successful T&E in a simulated operational environment conducted. ❑ End user / customer briefed on the results of T&E. ❑ Initial Security Guidelines developed ❑ Draft Program Assessment Rating Tool (PART) plan exists, if required ❑National Environmental Policy Act (NEPA) plan / assessment ❑ Interoperability Assessment	**TRL 7** ❑ S&T and the end-user / customer develop final transition plan; (TRL 7 and 8) ❑ Technology successfully demonstrated in an operational environment. (TRL 7 and 8) ❑ Updates made to the ORD. ❑ Risk Management Plan, Program Cost Analysis and PMP updated. ❑Strategic Program Planning conducted. ❑ Operations and Maintenance Manual completed / updated. ❑ Security Manual developed. ❑ Interoperability demonstrated. ❑ MDs reviewed for compliance.	**TRL 8** ❑ Technology components are form, fit, and function compatible with an operational system. ❑ Technology production addressed and planned by DHS and the end-user / customer. ❑ Training Plan developed and implemented. (TRL 8 and 9) ❑ Operational Test Report completed. ❑ Limited User Test (LUT) Plan developed. ❑ Physical and functional interfaces clearly defined	**TRL 9** ❑ All critical program documentation completed. ❑ Planning underway for the integration of the next generation technology into the existing program components. ❑ End-user fully demonstrates the technology in CONOPS. ❑ Lessons Learned completed. ❑ After Action Review completed. ❑ Sustainment Plan is completed.
		MRL1 ❑ Basic manufacturing implications identified	**MRL2** ❑ Manufacturing concepts identified	**MRL 3** ❑ Manufacturing proof of concept developed ❑ Producibility for key components identified	**MRL 4** ❑ Materials, machines and tooling have been demonstrated in a laboratory environment ❑ Producibility assessments initiated	**MRL 5** ❑Manufacturing cost/goals identified. Potential materials sources identified. ❑ Capability to produce prototype components in product relevant environment	**MRL 6** ❑Capability to produce system prototype in product relevant environment. ❑ Production cost drivers and goals analyzed and set	**MRL 7** ❑Production pilot begins ❑ Producibility of system in production representative environment	**MRL 8** ❑ Manufacturing pilot complete, ready for low-rate production	**MRL 9/10** ❑Manufacturing processes established and deliver quality products ❑ MRL 10 – System is at full production rate. Products meet all engineering, performance, quality and reliability requirements.
							Specific to Commercialization ❑ Finalize Manufacturing Plan. ❑ Finalize engineering documentation. ❑ Update Marketing Plan. ❑ Develop and implement a test plan for quality control.	**Specific to Commercialization** ❑ IP Protection and Licensing. ❑ Prepare sales release package. ❑ Verify and update quality control requirements.		**Specific to Commercialization** ❑ Finalize quality plan. ❑ Finalize marketing plan. ❑ Finalize manufacturing and assembly routines.
Key Deliverables	❑ Preliminary market assessment and technology scan. ❑ Congressional Appropriations Memo, Technology Transition Agreements, Program Descriptions (Research and Innovation), and Feasibility Studies lead to Program and Budget Execution.	❑Feasibility Study (White Paper) ❑Initial scientific observations reported in journals/conference proceedings/technical reports ❑Literature search report ❑Road Map (draft) ❑ Written report of findings and recommendations (preliminary product plan). ❑ Feasibility Review meeting.	❑Program Cost Analysis ❑Study showing application is feasible ❑Modeling & Simulation Report used to verify physical principles ❑Market survey identifying potential customer interest ❑Analytical studies reported in scientific journals/conference proceeding/technical reports ❑Qualitative idea of risk areas (cost, schedule, performance, impacts of idea) ❑5 year Investment Strategy/Funding requirements documented ❑ Preliminary product plans (approved and ongoing). ❑ New Technology roadmaps (approved for further development and implementation). ❑ Updated market assessment and technology scan. ❑ Demonstrate ability to manufacture prototype components	❑Technology Maturity Assessment ❑Program Cost Analysis (updated) ❑Functional Requirements (draft) ❑Proof of Concept ❑Program Management Plan (PMP) draft ❑User/Customer Status Review ❑Analytical study/test reports. ❑ Detailed product and marketing plan. ❑ Quality control plan. ❑ Optimization Review meeting. ❑ Manufacturing concepts defined	❑ Proof of Concept Report. ❑ Functional Requirements Document. ❑ SEMP (TRL 4, 5, and 6) ❑ TEMP (TRL 4, 5, and 6) ❑ Quality Assurance Plan. ❑ Configuration Plan Management. ❑ PMP (updated). (TRL 4, 5, & 6) ❑ Risk Management Plan (updated). (TRL 4, 5, and 6) ❑ Program Cost Analysis (updated). (TRL 4, 5, and 6) ❑ End-user / Customer Status Review.	❑ ORD and CONOPS. ❑ Security Assessment (updated). ❑ Program Definition Document (PDD). ❑ OMB 300 Capital Asset Plan. ❑ Acquisition Plan. ❑ Entry Criteria Checklist. ❑ Analysis of Alternatives. (TRL 5 and 6) ❑ Initial producibility of component technology completed ❑ Initial Manufacturing Plan developed.	❑Technology Transition Agreement (TTA), or Technology Commercialization Agreement (TCA) as applicable ❑ Initial Security Guidelines. ❑ Draft Program Assessment Rating Tool (PART) plan, if required. ❑ National Environmental Policy Act (NEPA) initial assessment, if required. ❑ Interoperability Assessment.	❑Transition Plan (draft). ❑ ORD / FRD Documentation ❑ Risk Management Plan ❑Program Cost Analysis ❑PMP (updated). ❑ Strategic Program Planning Documentation (if conducted). ❑ Operations/Maintenance Manual ❑ Security Manual. ❑ Finalized Interoperability Assurance Report. (TRL 7 and 8)	❑Limited User Test (LUT) Plan. ❑ Deployment or Transition Plan. ❑ Training Plan. ❑ Operational Test Report. ❑ Customer Acceptance Document. ❑ Initial Systems-level Metrics Assessment.	❑Customer Feedback. ❑ Lessons-learned. ❑ After-action Review. ❑ Sustainment Plan is completed (a. Spiral Development Assessment, b. Preplanned Product Improvement, c. Emerging Threat(s) Assessment, d. Technology Refresh / Insertion, e. Quality Assurance / Metrics Report, f. Risk Management Reassessment)
							Specific to Commercialization ❑ Engineering documentation release ❑ Updated marketing plan. ❑ Test plan for quality control. ❑ Development Phase Review meeting.	**Specific to Commercialization** ❑ IP Protection and Licensing. ❑ Manufacturing and sales plan release package is to be distributed. ❑ Pilot Phase Review meeting	**Specific to Commercialization** ❑ Demonstrate that a defect-free product can be produced on schedule and at a cost within the target price points.	**Specific to Commercialization** ❑ Finalized product plan sales release package is to be distributed. ❑ Sales Release Phase Review mtng. ❑ Execution of acceptance, shipment, and after-sales support of the product.

RDP Partnership Opportunities and Vehicles

- Special Projects Office
- Interagency Office
- Technology Transfer Office
- National Labs and S&T Labs Research and Development
- Long Range Broad Agency Announcement
- University Program Grants and Research Development
- SBIR Phase I
- SBIR Phase II
- SBIR Phase III
- ICPO International Research Grants
- ICPO International Agreements
- FutureTECH Program (TRL 1-6)
- SECURE Program (TRL 5-9)
- SAFETY Act Developmental T&E:TRL 6-7 Designation: TRL 7-9 & Certification: TRL9

U.S. Department of Homeland Security
Research & Development Partnerships July 2011
Legend:
Black Type – Primary Public Sector
Blue Type – Primary Private Sector
Red Type – Manufacturing related activities
Definition of acronyms on reverse page.

Energy Storage Technology

The Water Analogy

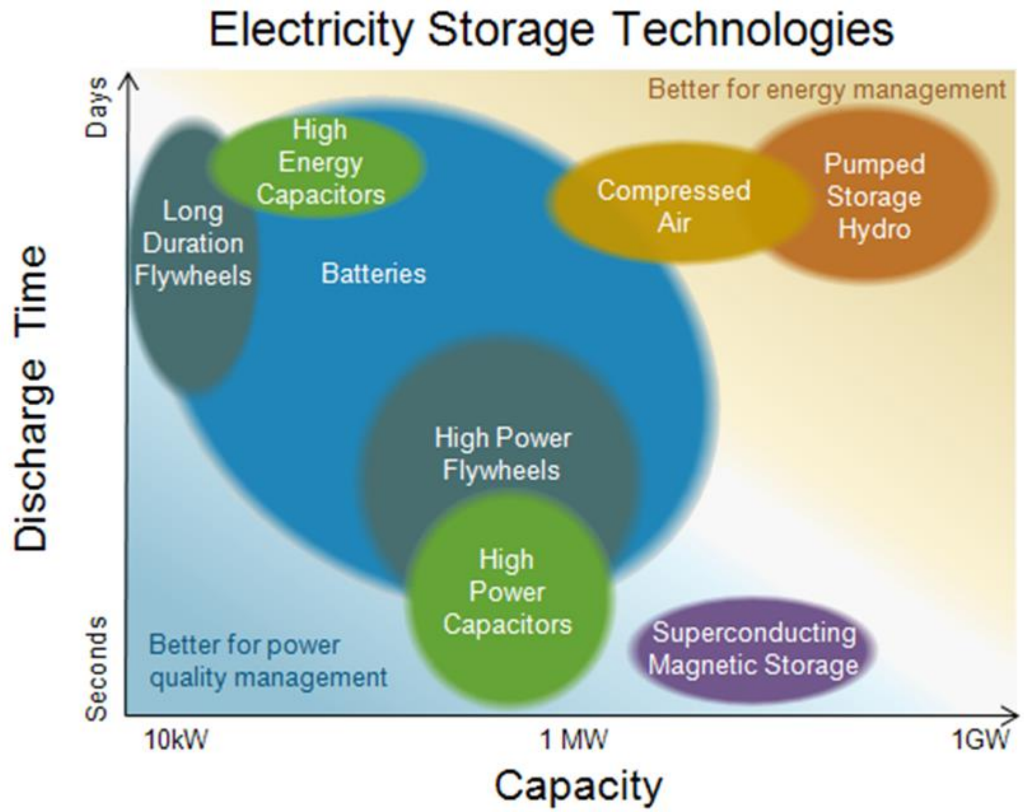
- Want water when needed, not only when it rains
- We want the right amount (i.e., energy)
- We want the right speed (i.e., power)
- ***Independence & Security***
    - *ISIS: $3.2mm / day from oil*

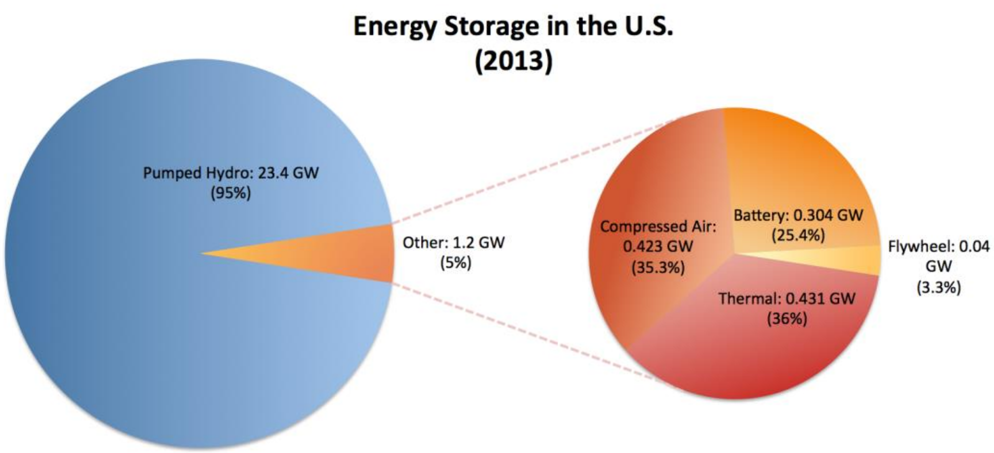
Why So Many Ways to Store?

- Natural resources
- Application requirements
    - stationary v. mobile?
    - backup v. peak demand v. renewable?
- Technological advancements

Why Focus on Batteries?

- Well known manufacturing methods (commodity)
- Flexible format
- Flexible technical performance
- Mobile and can be stable





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- Reports of novel electrode active materials with seemingly paradigm shifting performance improvements over current commercial technologies are relatively common, yet the minimally reported challenges of cost, scale, and reproducibility continue to hold back the development process. The key issue in creating this gap between initial low technical readiness level (TRL) positive results and reliable high TRL performance is a lack of awareness of the full development cycle and the common obstacles presented at each stage, **such as those faced in designing stable electrode slurries, balancing ionic/electronic conductivity, and ensuring long term adhesion/cohesion of electrodes.** While each of these examples represent well researched fields in the materials science of battery electrodes, the hurdle is in the requisite adaptation of this knowledge base to the specific properties of any given new active material, its synthesis method, and the morphology derived thereof.
-
- The basic steps in the development cycle of new active materials on the cell level are split cell testing, half cell coin testing, full cell coin testing, and large format testing, such as planar stacked pouch cells or cylindrical wound 18650 cells. Each stage of development introduces new complexities and potential interactions, such as **maintaining uniform dispersion of the increasing volumes of slurry needed, differing drying rates as electrode mass loading is increased or larger scale coater-dryer equipment is used in production, and the effects of residual drying stresses on the ductility of electrodes wound around the small radii of curvature utilized in cylindrical cells.** When developing a new active material, often initial capacity results are focused on the material itself, independent of the electrode structure necessary to facilitate its operation, any electrolyte interaction, and an appropriately balanced counter electrode. Additionally, development can continue from the cell level into module and pack testing, with a focus on safety, thermal, and power management, but for the purpose of this report, this late stage development will be discussed solely in terms of the relevant constraints it places on cell development.

Commercial Offerings

BIC
BATTERY INNOVATION CENTER

Residential

- Dozens of off-the-shelf products available
- Samsung, LG, GS Yuasa, SMA, Eaton, ABB, NEC, Toshiba
- TESLA!!
  - Marketing & price point ($3500 for 2.5 days of energy)

Community / Industrial / Government

- Again, dozens of offerings
- Applications include:
  - Emergency location backup
  - Renewable integration
  - Peak Shaving
  - Power Quality

Grid / Microgrid

- Smaller number of vendors, but still 10-15
- Applications include:
  - Renewable integration
  - Frequency regulation
  - Replace generation, transmission, distribution assets

Microgrids

Why not create my own "grid"?

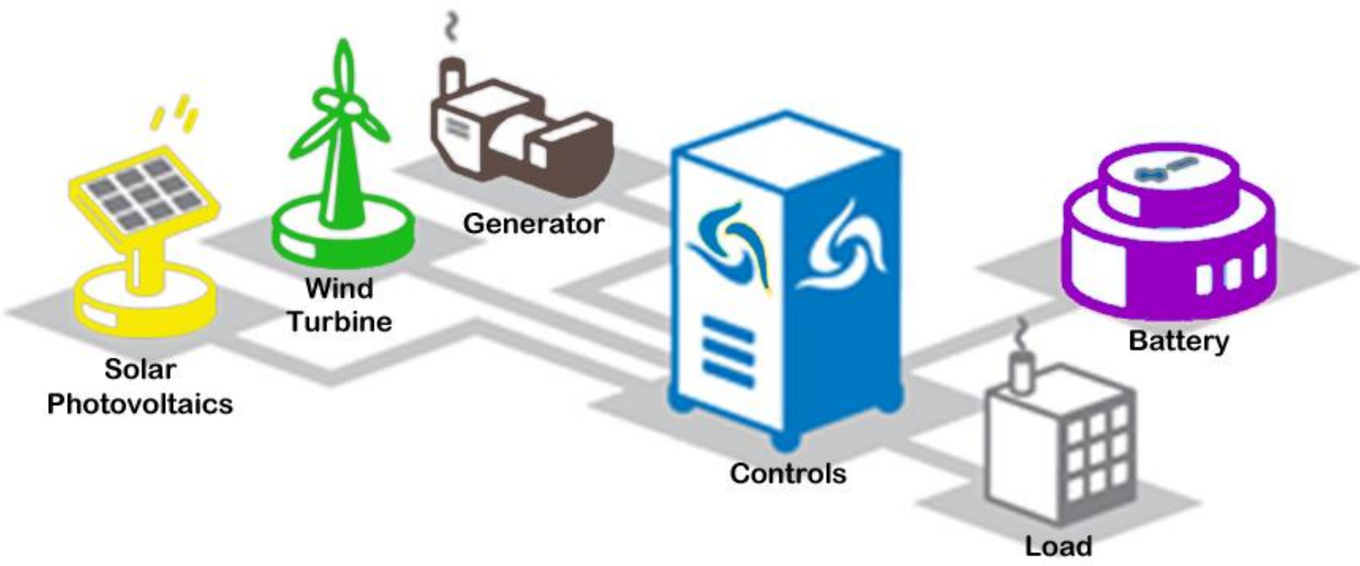
- Local generation + storage + management software = microgrid
- Why not municipal water AND a well??

And if I have my own grid, why not make it "smart"?

- Devices called smart inverters and special software can shift between generation sources and grid

Microgrid Applications

- Remote service areas, hospitals, data centers, communication centers, municipal buildings, homes



Microgrid Laboratory

- Goal: create setting to test algorithms & controls for microgrids
- Point: BIC can test the interoperability of components and provide unbiased evaluations
- Impact: Two microgrids deployed at Indiana highschools
- Next Steps:

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Takeaways

Is your energy infrastructure resilient?

- Terrorist Attacks: Sutton's Law
- Natural Disasters
- Too Many Renewables?

Can policy decisions impact energy security & independence?

- Is storage required for renewable projects by your state utility commission?
- Are you encouraging customers to embrace storage with your policies and incentives?

How can the BIC help?

- Competitive analysis and consulting
    - david.roberts@bicindiana.com
    - 317-225-6112

BIC
BATTERY INNOVATION CENTER

Vision

A non-profit, public-private partnership joining academia, industry, and government to rapidly develop, test, and commercialize the next generation of safe, reliable, and lightweight energy storage systems.

Distinguishing Features

1. Catalyze technologies by reducing long, expensive innovation-to-commercialization development cycle
2. Does not hold patent rights, reducing concerns to jointly develop
3. IP-secure, US-based facility generating reliable data using common techniques & equipment

Core Offerings

1. Low volume cell manufacturing
2. Full suite of test & evaluation capabilities
   - Cells, Modules, Packs, & Systems
   - Certification
3. Applied Research & Consulting
   - Design for packs, BMS, and systems
   - Competitive analysis

Advanced Energy Systems Testing and Validation Capabilities

Cell and Pack Manufacturing

- 1% Humidity Dry Room & 10,000 Class Clean Rooms
- Commercial quality cell manufacturing equipment for multiple cell formats
- Pack design and assembly equipment

Battery System Testing and Evaluation

- Full spectrum of T&E equipment for up individual cells up to whole systems of 1MW+
- Access to environmental and abuse testing facilities at NSWC Crane that include more than $150M in hardened test labs

Microgrid Systems Testing

- Utility scale grid simulator
- Integrated solar and wind renewables on site
- Residential, community, and grid energy storage systems on site
- Facility designed with access to >6MW of available power with net metering (MISO High Voltage Node)

Microgrid Capabilities

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Solar Array with Integrated EV Charging

Large Grid Storage Device (approx. 1MW)

Low Velocity/ High Efficiency Wind Turbines

Facility Designed with Access to >6 MW of Available Power (MISO Energy HV Node)

Integrated Power System (IPS) Supporting Solar and Wind Data Collection and Remote Management

Critical Testing, Evaluation and Consultation for Energy Storage Solutions

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MT-30
Module Testing

ABC-170CE
Pack Testing

AV-900
Battery/Array Testing

Altitude Testing

Humidity Testing

Thermal Cycling

Strategic Partnerships

- UL agreement announced in February 2015
  - exclusive test facility for all of UL's large-format ESS testing in U.S.
  - undergoing ISO 17025 certification
  - BIC selected because of breadth of equipment and capabilities

- NSWC Crane: CITE agreement in final negotiation will allow personnel to access Crane's extensive hardened T&E capabilities
  - when combined with BIC facility it will create broadest T&E capability in the U.S., if not the world
  - approved in principle; finalizing logistics of access & use

Strategic Partnerships

- Duke Energy grant for microgrid simulation
  - Announced March 2015
  - To establish microgrid testbed environment with controls and communications infrastructure sufficient to evaluate microgrid components
    - Procuring 5 ESS
    - Receiving 1MW inverter
    - Leverage installed and new renewable generation
    - Communication protocol using emerging MESA standard
  - Final supplier identification and notification in process

- Multiple Federal grant applications recently submitted with Purdue University & private industry partners; developing proposals with IUPUI

BIC BATTERY INNOVATION CENTER

For more information on how BIC can be your trusted partner and resource, please contact:

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