Summary of 2017 NASA Workshop on Assessment of Advanced Battery Technologies for Aerospace Applications

Dr. Ajay Misra
NASA Glenn Research Center

Presentation at 2018 SciTech Forum, Kissimmee, FL, January 11, 2018

NASA Workshop on Battery Technologies for Future Aerospace Applications, Cleveland, OH, August 16-17, 2017

Key Objectives of the workshop:

- Assess the battery needs for future aerospace missions
- Assess the state of battery technology and projected technology advances
- Assess the need for additional investments for future aerospace missions.

Participants:

- 109 participants, 85 non-NASA
- Leaders from DOE, DOE labs (ANL, PNNL, ORNL), Aerospace companies (Boeing, Airbus, Bell Helicopters, GE, P&W, Honeywell), Automotive companies (GM, Chrysler), Battery manufacturers (cell and pack manufacturers), academia, small businesses (many funded by venture capitalists)

Sessions:

- First day – 19 short (~20 min) overview presentations
- Second day morning – 3 breakout sessions – (1) requirements, (2) chemistry and materials, (3) packing and integration

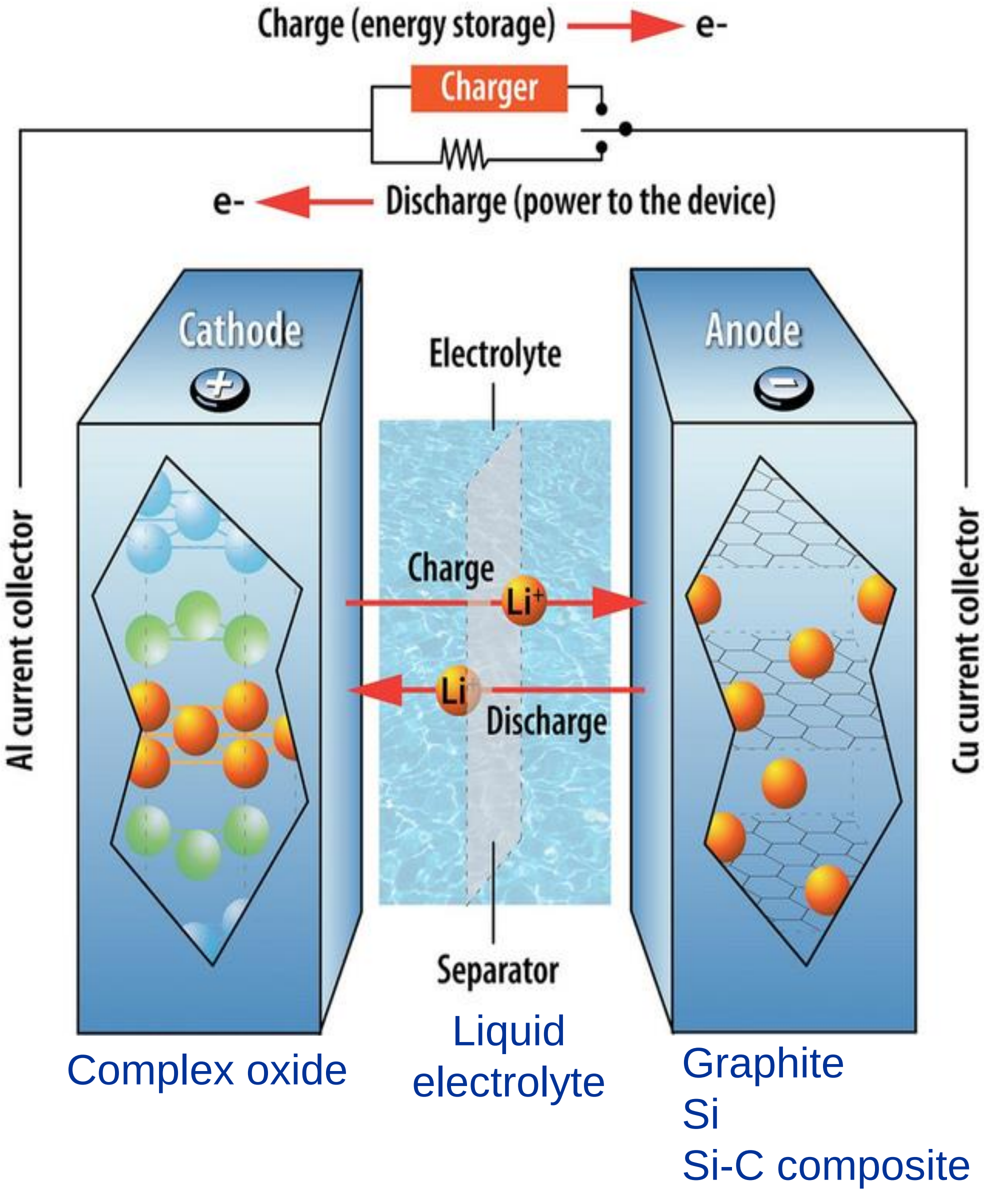
Primary focus was on batteries for Electrified Aircraft Applications

What is Included in This Presentation

- Findings from the workshop

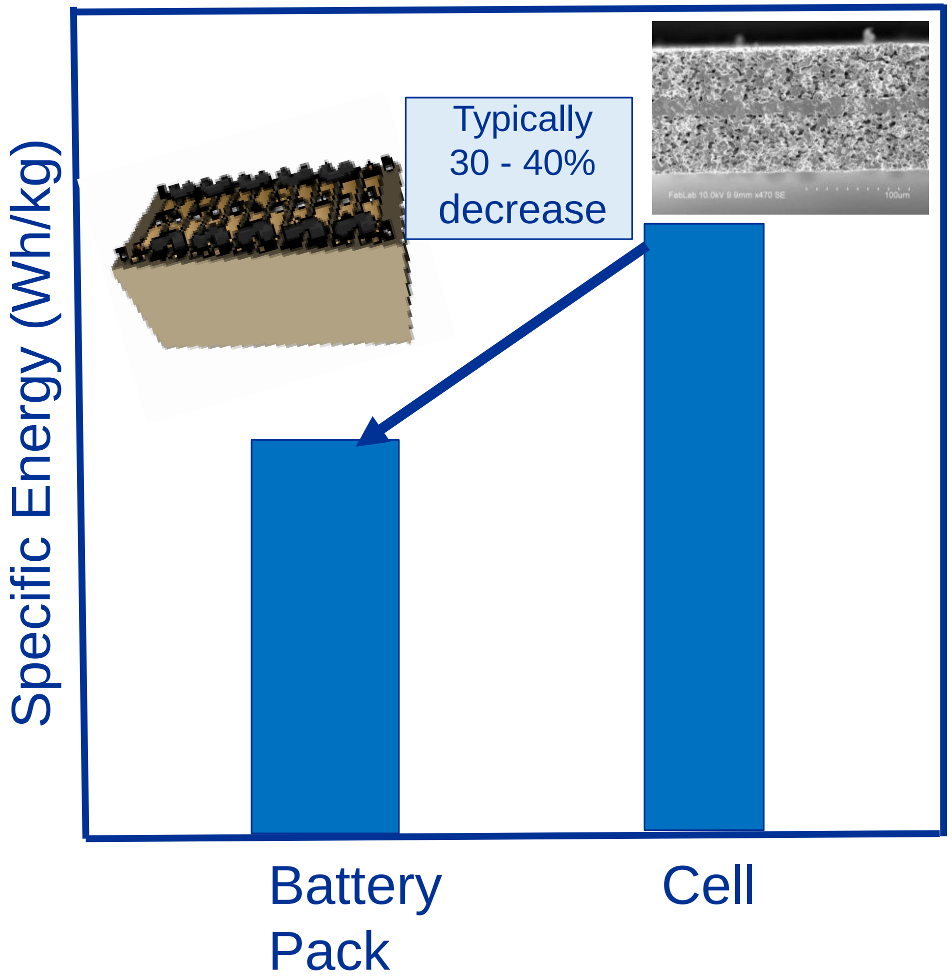
- Additional facts gathered from multiple sources after the workshop
  - System analysis
  - Recent reviews of battery technology

State-of-the-art: Li-Ion Battery



SOA:
- Cell: 250 Wh/kg
- Pack: 150 – 170 Wh/kg

Potential:
- Cell: 300 Wh/kg
- Pack: ~200 Wh/kg



Notional Battery Requirements for Different Classes of Aircraft

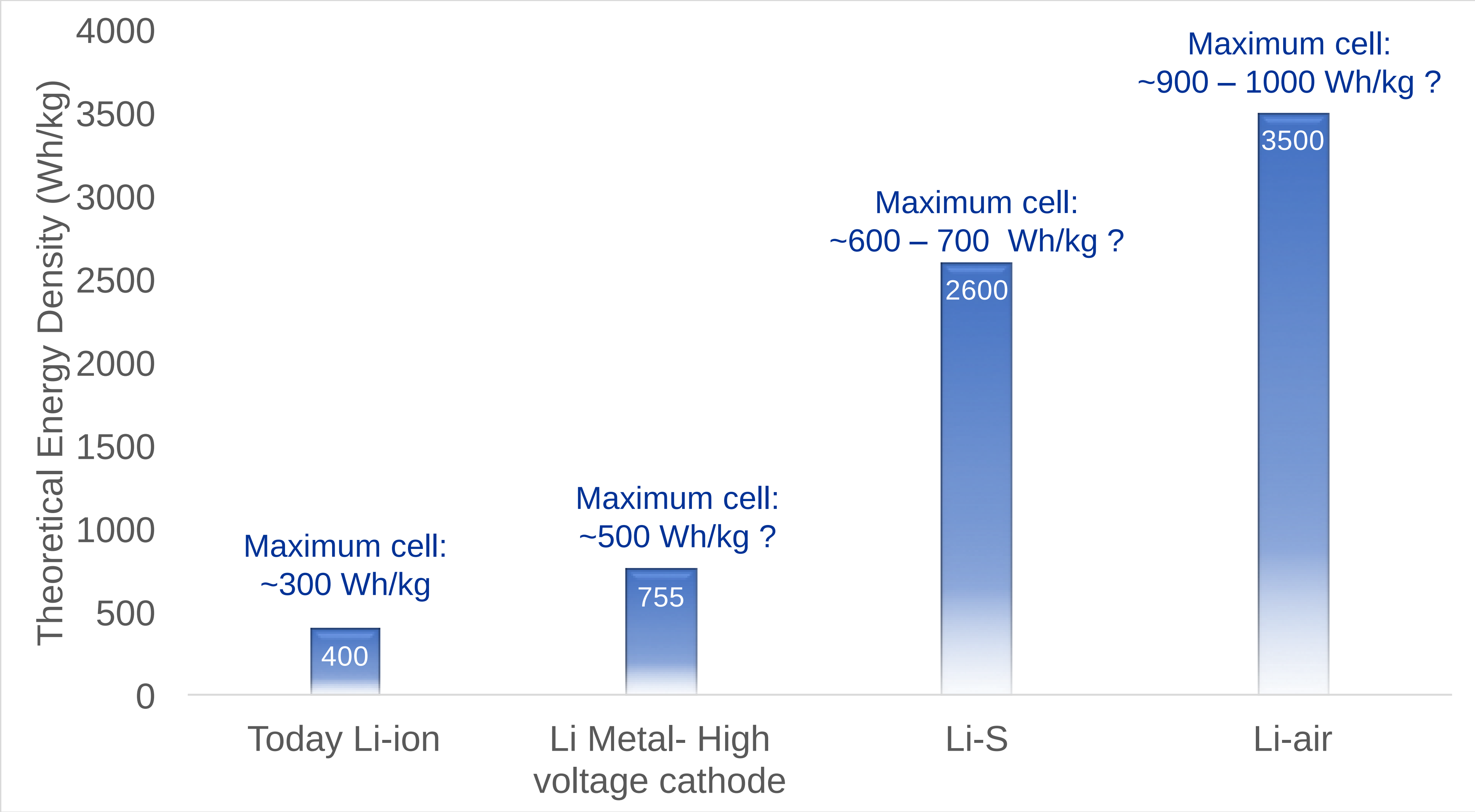
	1	2	3	4
Cell level	**250 Wh/kg**	**~400 Wh/kg**	**~600 Wh/kg**	**~1000 Wh/kg**
Pack level	**Current capability, 150 – 170 Wh/kg**	**300 Wh/kg**	**400 - 500 Wh/kg**	**> 750 Wh/kg**
	• 2-3 passenger, CTOL, 200 miles, all electric • 2 – 3 passenger, VTOL, 40-50 miles, all electric • 6 – 10 passenger, CTOL, 300 – 600 miles, all electric	• 4 – 10 passenger, VTOL, 60 – 200 miles, all electric • 30 passenger, CTOL, 300 miles, all electric • 50-70 passenger, CTOL, 300 miles, hybrid electric • Light utility helicopter, 100 miles, hybrid electric • Extended range for everything in Box 1	• 50 – 70 passenger, CTOL, > 300 miles, all electric ?? • 100 -150 passenger, CTOL, 300 miles, hybrid electric ?? • VTOL - Multi-mission helicopter, hybrid electric, 100 miles ? • Extended range for everything in Box 2	• 737 type hybrid electric aircraft with at least 900 mile range, CTOL • Extended range for everything in Box 3

Other Requirements in Addition to High Specific Energy

- Specific power (1 kW/kg for most applications, although some applications might require 2- 3 kW/kg)
- Cycle life (1000 - 2000 ??)
- Discharge rate (C rating)
- Speed of charging
- Calendar life

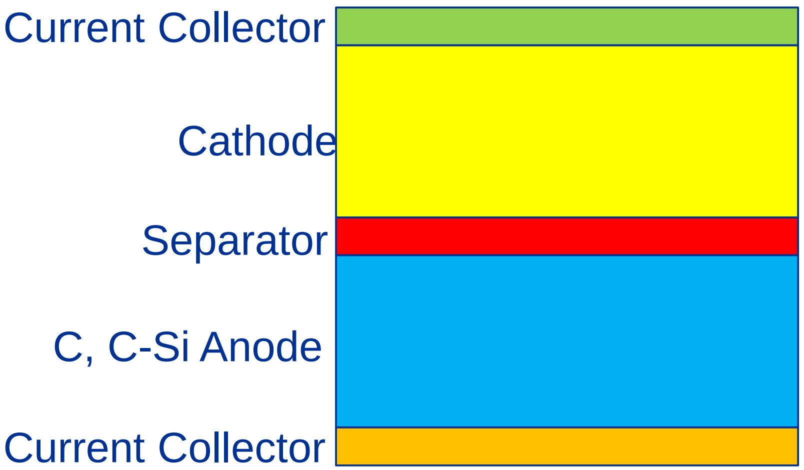
System analysis required to identify detailed requirements

Beyond Li - Ion

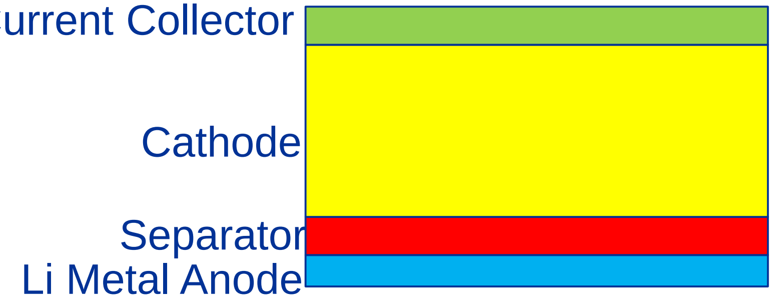


Li Metal With Liquid Electrolyte and Conventional cathode

Conventional Li-Ion



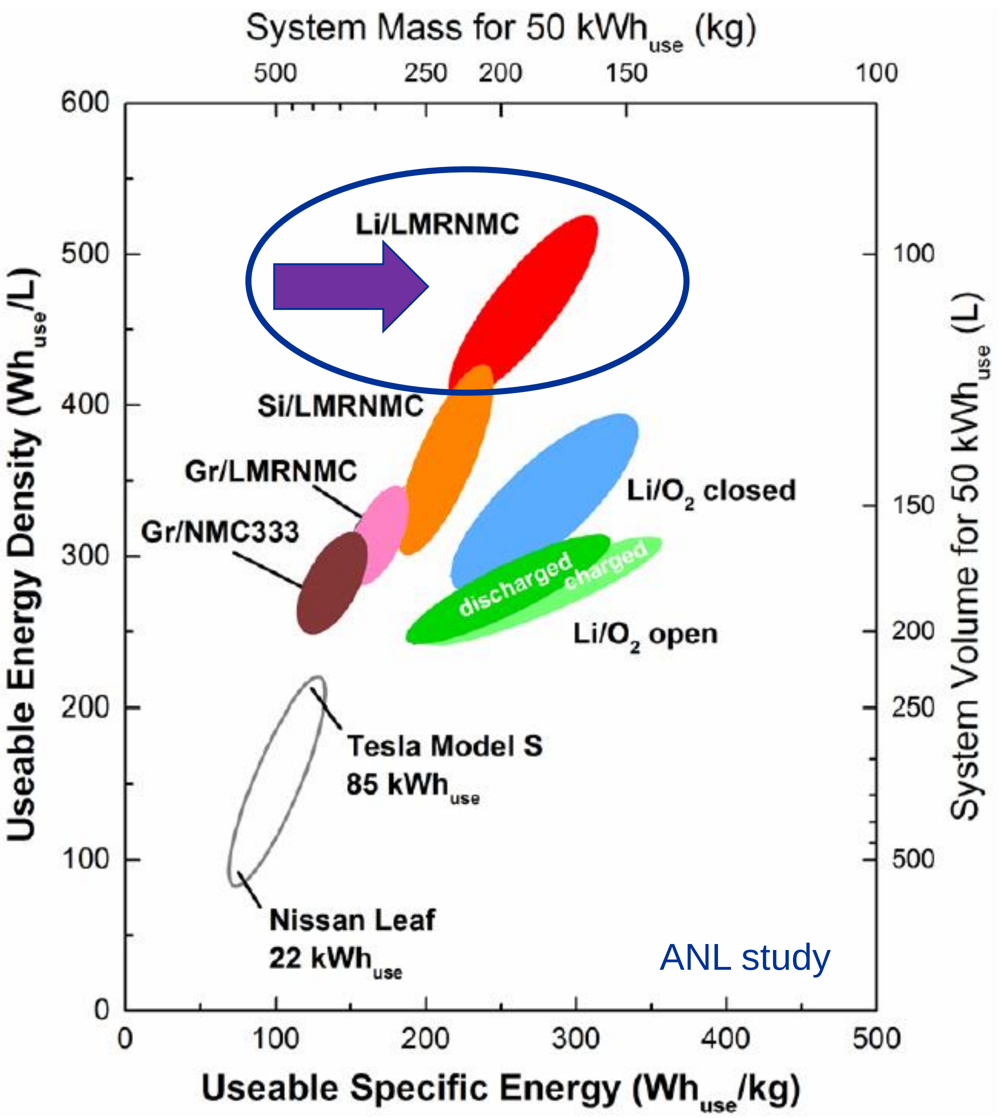
Li Metal



Except for Li metal anode, everything else very similar to SOA Li-ion battery

- Claims of 400 – 450 Wh/kg at cell level by startup companies
- Probably low cycle and long-term life (no publicly available data)
- Optimistic claim for commercial introduction in electric vehicles in 2020 (????) – might need serious interest from a major manufacturer
- Focus of DOE BAT-500 program

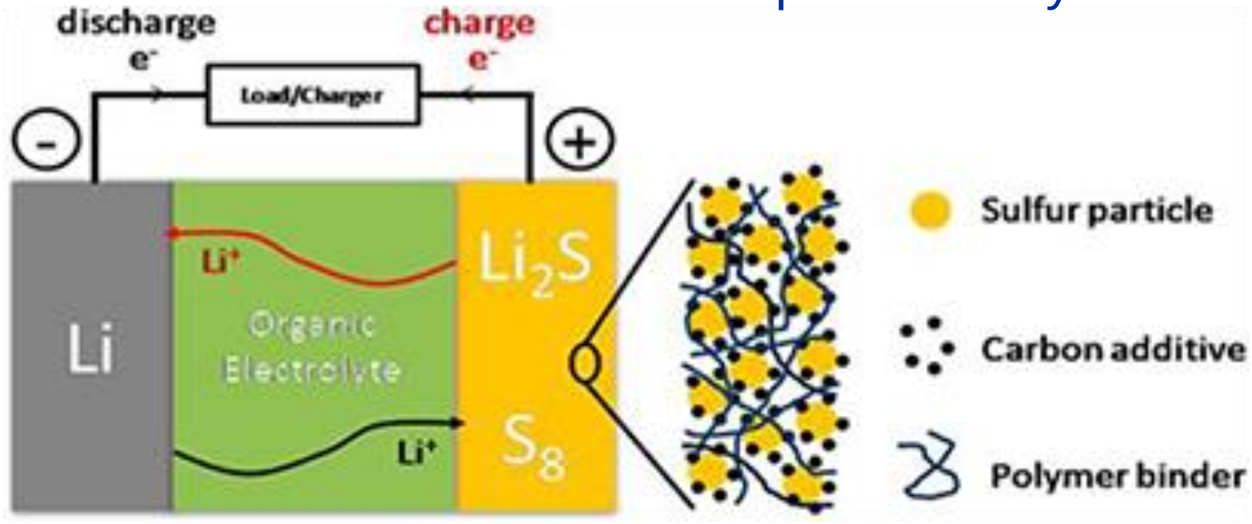
300 Wh/kg achievable at pack level



Pack Level

Li – S Batteery

Liquid electrolyte

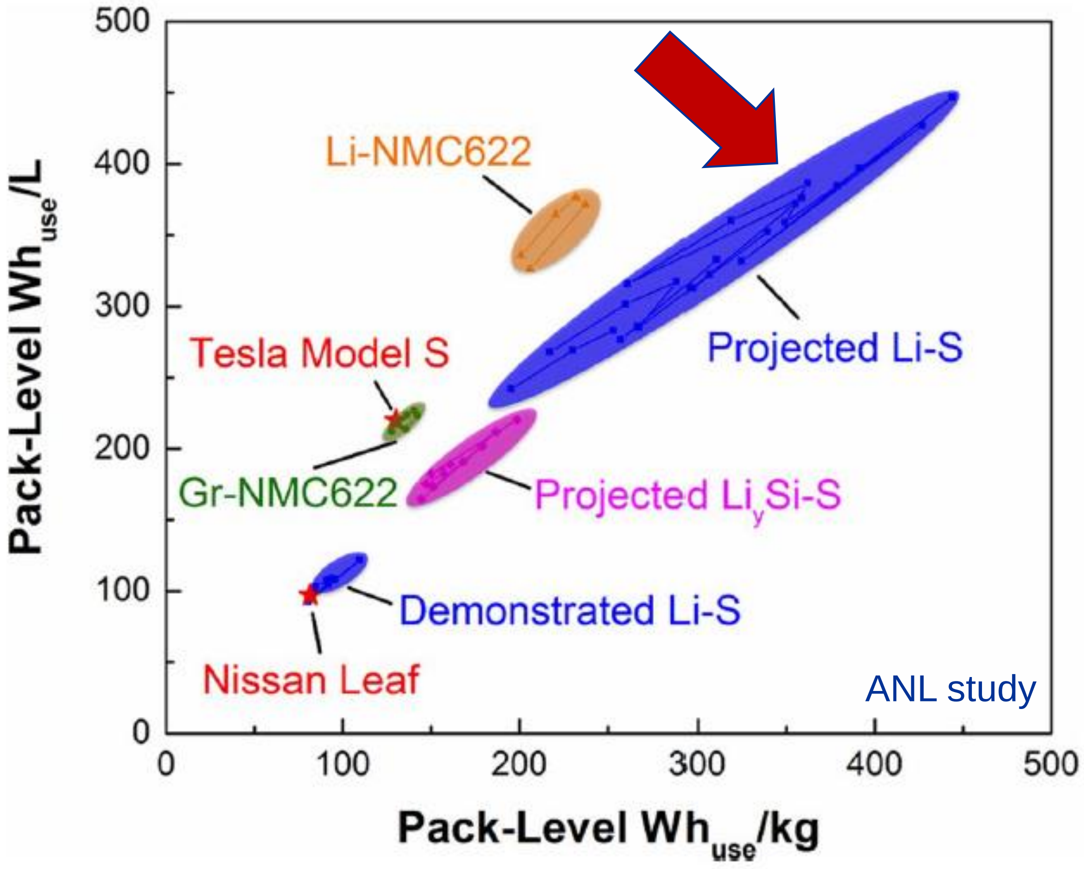


Progress to date:

- 300 – 400 Wh/kg achieved at cell level, low cycle life
- 250 Wh/kg at pack level, low cycle life
- 180 Wh/kg at cell level with high cycle life

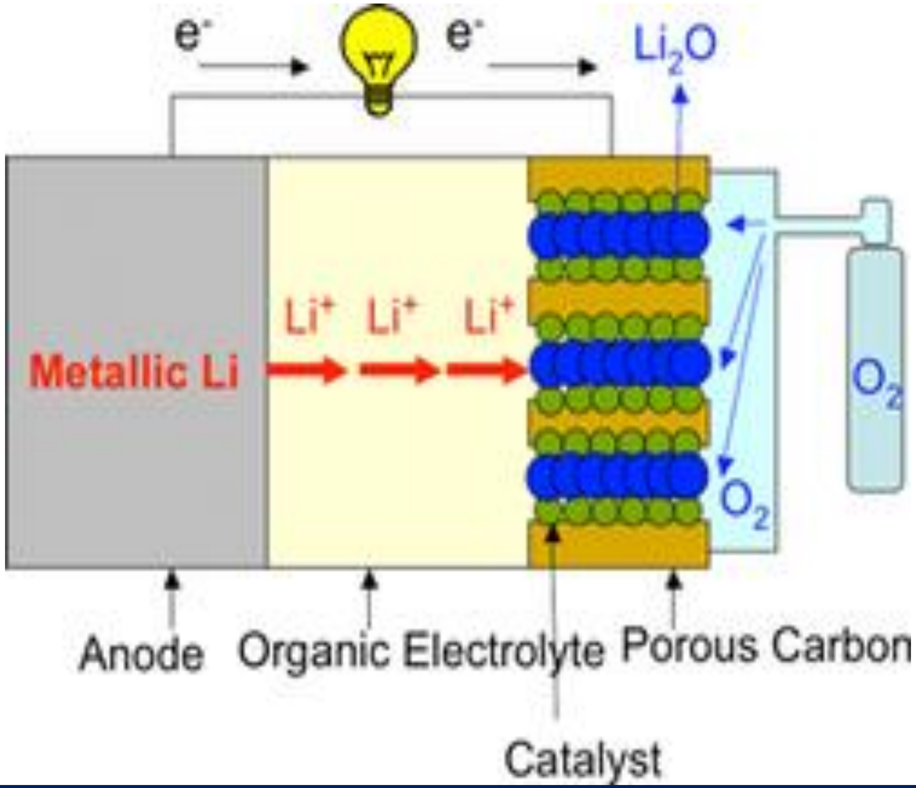
Challenges:

- Limited cycle life (< 300 cycles)
- High self discharge rate
- Reactions not well understood

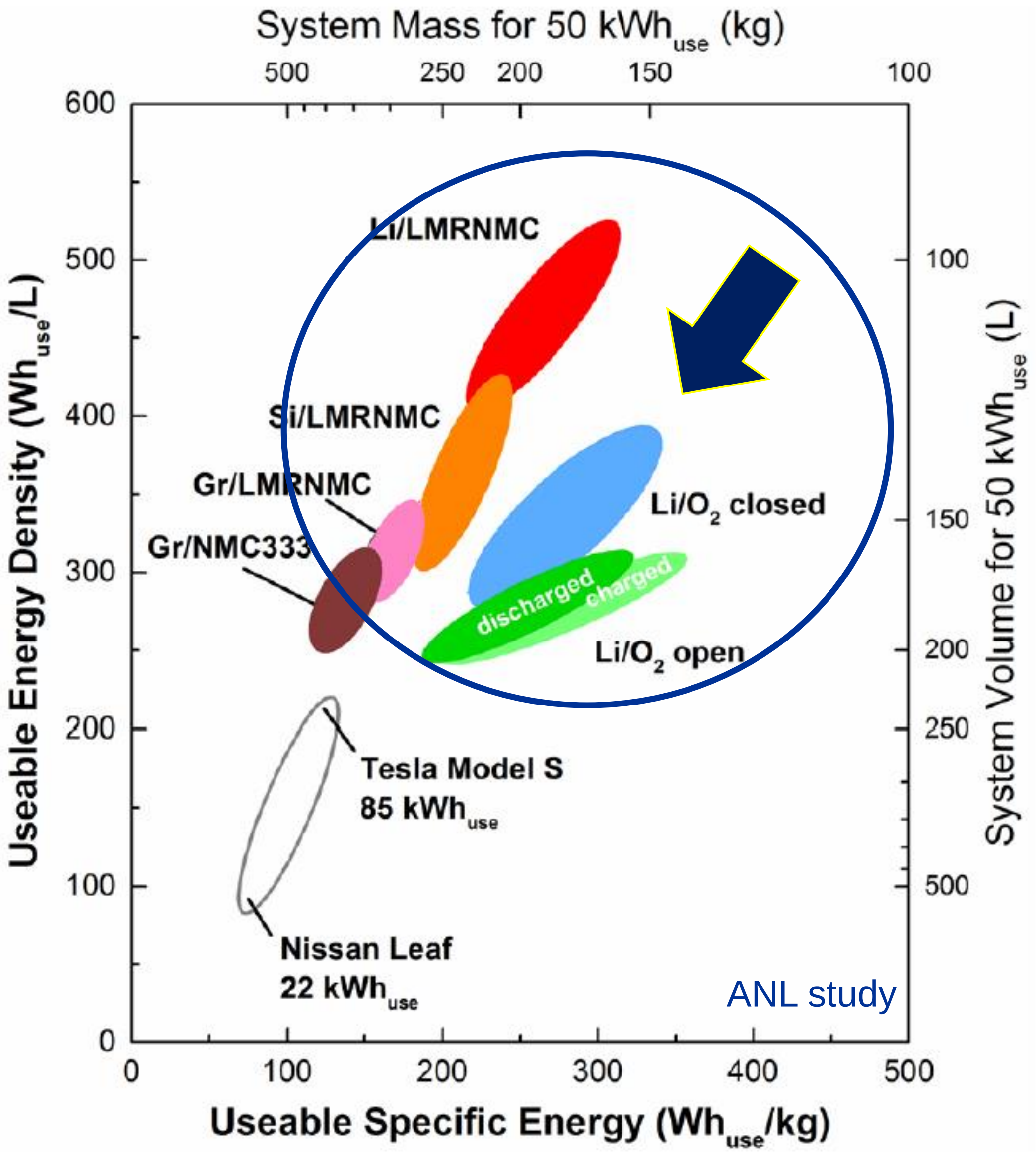


Maximum achievable specific energy at pack level is < 500 Wh/kg

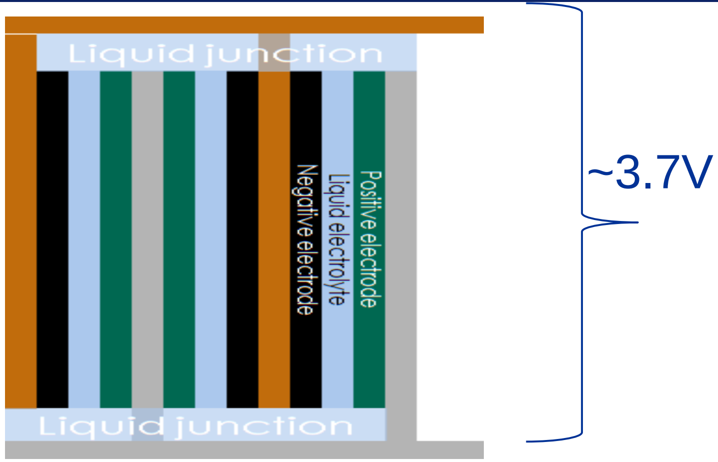
Li – Air Battery



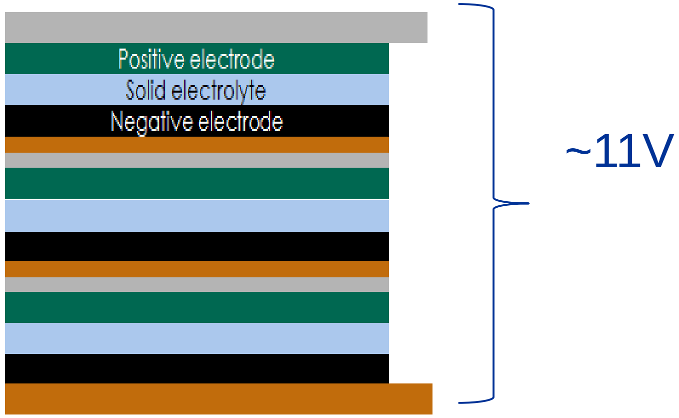
- Limited cycle life
- Complex mechanical system for introduction of oxygen
- Maximum achievable specific energy at pack level no better than Li metal with liquid electrolyte and conventional cathode



Solid State Lithium Metal Battery



Liquid electrolyte forces repeating units to be connected in parallel



Solid electrolyte allows repeating units to be connected in series (increase in packing density)

Current Status:

- Significant world-wide interest (Strong belief that solid state is the future) - Eliminates safety challenges associated with liquids, provides better packing and stack designs
- Significant progress made in development of solid ceramic electrolytes with high ionic conductivity
- Solid state battery with solid state polymer electrolyte – 250 Wh/kg at cell level, potential for 400 Wh/kg at cell level (required 180^{o}C operating temperature)

Challenges:

- **Interfacial instability and lack of understanding of various interfacial phenomena**
- **Mechanical stability**
- **Low cycle life contributed by interfacial and mechanical instability**
- **Commercially scalable process for manufacturing of thin films**
- **Development of full cell**

Significant Promise

Notional Progression of Battery Capability at Cell Level

Li Metal

- **300 - >500 Wh/kg** → **Li metal, all solid state**
- **400 – 500 Wh/kg** → **Li metal anode, sulfur cathode, liquid or solid electrolyte**
- **300 – 400 Wh/kg** →
  - **Li metal anode, advanced cathode (High Ni - NMC or sulfur), Liquid electrolyte**
  - **Li metal anode + high temperature polymer electrolyte**

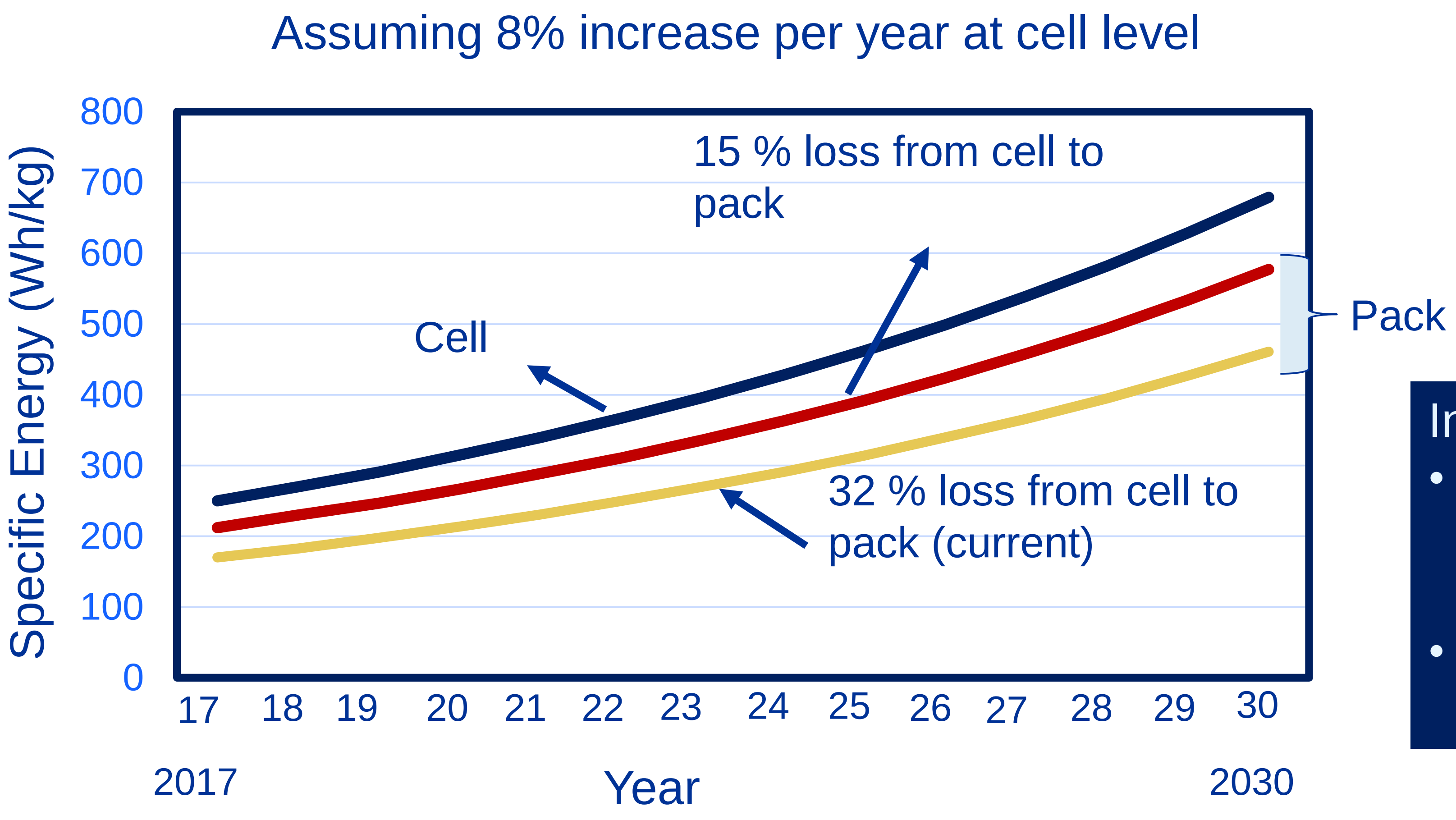
Li ion

- **300 Wh/kg** → **Si anode, advanced cathode (e.g., High Ni), liquid electrolyte**

SOA – 250 Wh/kg at cell level

Projected Advances in Battery Technology

Rate of increase in specific energy is typically on the order of 5 – 8% per year
Specific energy loss from cell to pack is typically 50 to 60%



Innovation required in:

- New chemistries and materials for cells
- Pack design and integration

Key Takeaways

- **DOE, battery industry, academia, National Labs will drive to 300 Wh/kg at pack level (~400 Wh/kg at cell level) for automotive and industrial applications, but will not be focused on electric aircraft applications**
  - **2022 – 2025 timeframe likely (optimistic ??)**
  - **Need to demonstrate applicability to aircraft through verification of performance, safety, and integration**
- **Beyond the 400 Wh/kg capability at cell level, aeronautics community can focus on developing batteries with 600 Wh/kg specific energy at cell level (400 – 500 Wh/kg at pack level), which is achievable and not impossible**
  - **Not current focus for DOE, battery industry, and national labs**
- **Specific energy on the order of > 700 Wh/kg at pack level is extremely difficult to achieve with the current knowledge, almost impossible at this time**
- **Need detailed system level analysis for different classes of aircraft and different missions**

Aeronautics community lead is necessary to champion development of aircraft materials, cells and packs

Potential Scenario for Electrified Aircraft

		• Potentially achievable in 2022-25 timeframe with non-NASA investment • Need validation for aircraft application	Challenging, but achievable in 2030 timeframe, will need leadership from aeronautics community,	Extremely challenging, may be impossible with current knowledge
Cell level	250 Wh/kg	~400 Wh/kg	~600 Wh/kg	~1000 Wh/kg
Pack level	Current capability, 150 – 170 Wh/kg	300 Wh/kg	400 - 500 Wh/kg	> 750 Wh/kg
	• 2-3 passenger, CTOL, 200 miles, all electric • 2 – 3 passenger, VTOL, 40-50 miles, all electric • 6 – 10 passenger, CTOL, 300 – 600 miles, all electric	• 4 – 10 passenger, VTOL, 60 – 200 miles, all electric • 30 passenger, CTOL, 300 miles, all electric • 50-70 passenger, CTOL, 300 miles, hybrid electric • Light utility helicopter, 100 miles, hybrid electric • Extended range for everything in Box 1	• 50 – 70 passenger, CTOL, > 300 miles, all electric ?? • 100 -150 passenger, CTOL, 300 miles, hybrid electric ?? • VTOL - Multi-mission helicopter, hybrid electric, 100 miles ? • Extended range for everything in Box 2	• 737 type hybrid electric aircraft with at least 900 mile range, CTOL • Extended range for everything in Box 3
	1	2	3	4

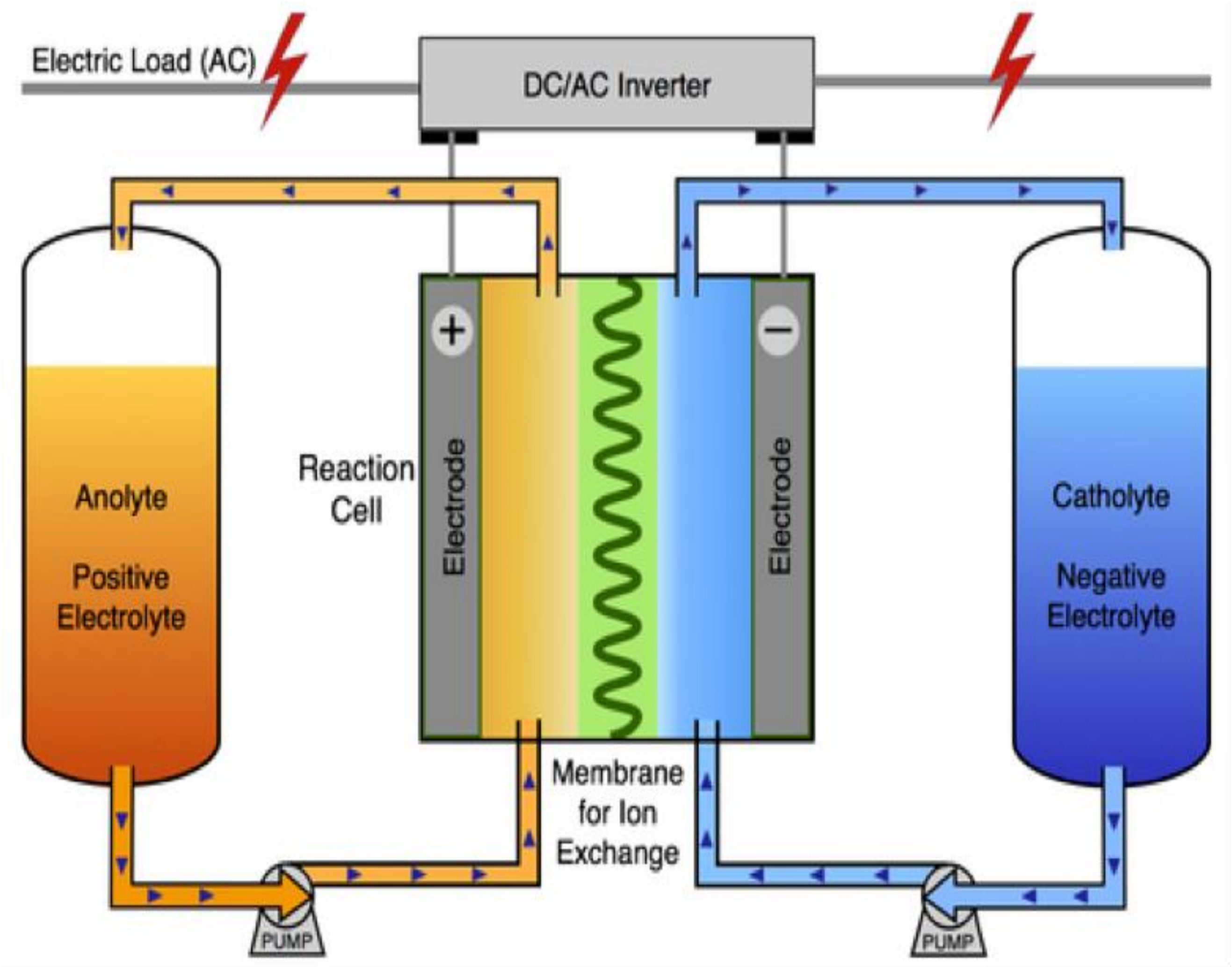
Potential for Innovation in Packing and Integration

- Specific energy loss from cell to pack is typically on the order of 30 – 40 %, could be as high as 50% for some applications - opportunity to increase specific energy at pack level through innovation in packing and integration
- Potential concepts:
  - Lightweight container structure (e.g., cellular, lattice block)
  - Multifunctional structures with load carrying capability for packaging materials
  - Advanced thermal management techniques (e.g., phase change materials if cost is not a factor, high conductivity materials)
  - Integrated thermal management – system approach to cool battery packs
  - Polymer heat exchangers
  - Larger cells
- Innovation in battery health management – improved techniques/models (including move to software-based system) for state-of-charge and state-of-health estimation

Aeronautics community needs to lead innovation in packing and integration specific to aircraft applications

Non-Li Battery System to Watch

- Al – air
- Mg – air
- Zn-air
- Flow batteries



Schematic of Flow Battery

Role of Aeronautics Community in Battery Development

- Accelerate development of 300 Wh/kg battery pack (400 Wh/kg cell) for electrified aircraft application by
  - Developing innovative packing technologies
  - Studying safety of battery system and optimizing battery system for safety
  - Generating performance data under aircraft operating conditions and optimizing battery system for balancing performance and safety
  - Developing and validating battery performance and durability models

- Provide leadership for development of 400 – 500 Wh/kg battery pack (600 Wh/kg cell) system leveraging resources in Dept. of Energy, National Labs, battery industry, and academia

- Conduct system analysis to identify battery requirements for various classes of aircraft and various missions