SPEAR
POWER SYSTEMS

# It's All About the Batteries

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RevA

*An innovative company of*

Sensata
Technologies

Ecological transformation demands eMobility

Advancing eMobility drives the frontier of energy density without compromise to safety

# Energy Density

Properly ratio of embedded energy (Wh) to volume (l).

Colloquially substituted for specific energy, ratio of energy to mass (kg)

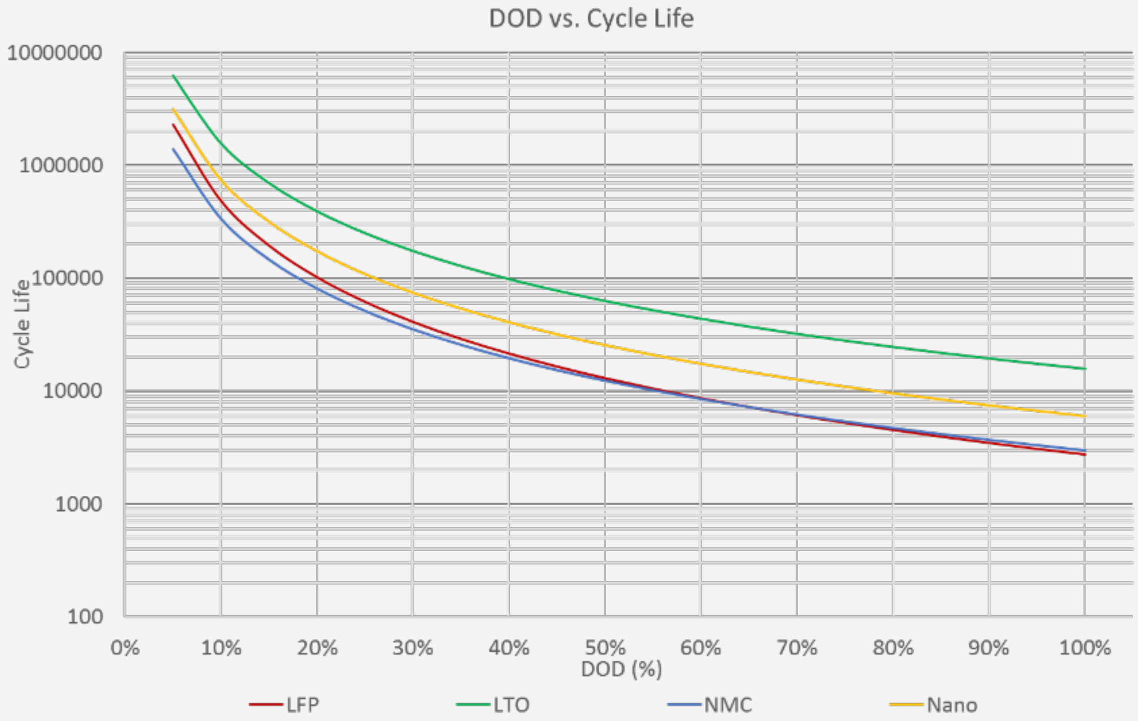
- **Drives range**
  Versus limits of vessel space and capacity, permits electric propulsion versus distance
- **Drives life**
  Life is a byproduct of battery size; larger batteries last longer
- **Drives power**
  Discharge is limited as a function of capacity; larger batteries can discharge more current
- **Drives cost**
  More embedded energy per cell translates to less balance of system per kWh

| | ENERGY DENSITY | SPECIFIC ENERGY |
|---|---|---|
| Cell | 414 Wh/L | 205 Wh/kg |
| Module | 136 Wh/L | 115 Wh/kg |
| String / System | **96 Wh/L** | **111 Wh/kg** |

# Paradox: Life

Efforts to increase energy density compete with aspects that drive the benefits produced

- **Aging concepts**
  Dynamic versus static aging; the role of depth of discharge (DoD) versus cycles. The role of calendar aging
- **Competing properties**
  Cell level: chemistry choice, coating thickness, format. System level: thermal management



# Paradox: Power

Power can be as important to performance as embedded energy. Increasing energy density decreases power density (W/l or W/kg)

- **Benefits of power**
  For multirole batteries drives utility. For propulsion batteries limits charge rate, driving turn time
- **Competing properties**
  Cell level: chemistry selection, coating thickness. System level: thermal management

# Paradox: Cost

Denser batteries lower the system to chemistry ratio, but force trades at cell and system level

- **Cell choices**
  Performance, recycling, security of supply compromises with chemistry, country of origin, industry
- **System influences**
  Higher energy density means more to mitigate, demands more sophisticated system elements

# Paths

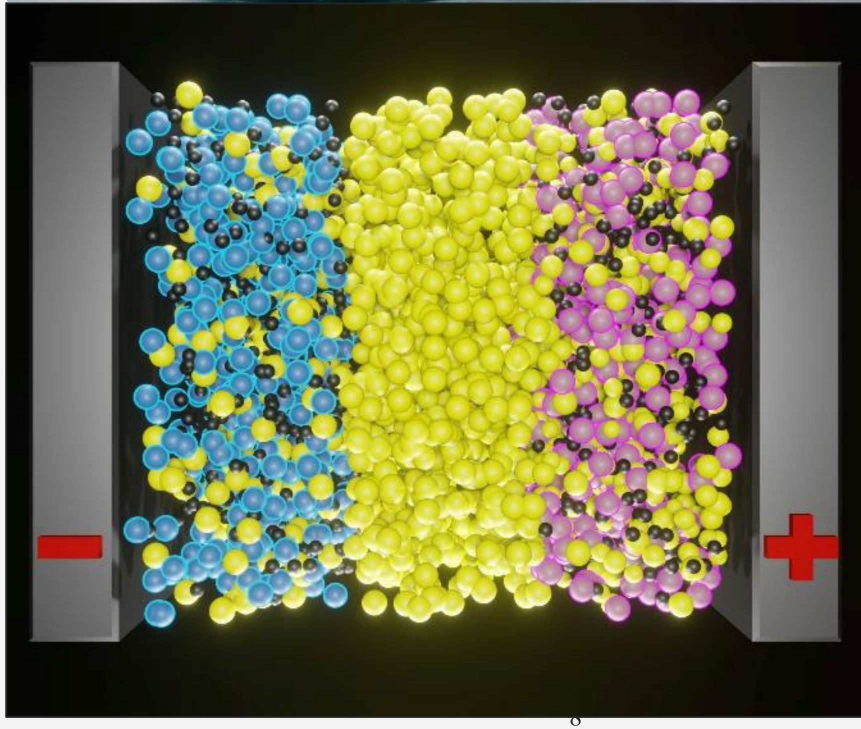
Increasing energy density involves trades. Acceptability of trade is application and market specific

- **Low power big box**
  Often LFP, less thermal management. Can be safe but system must not rely on chemistry. Application sensitive.
- **Advanced chemistry big guns**
  At the limits of NMC, or working trades of LTO. With aggressive thermal management and safety balance of system is the big challenge. Cell supplier sensitive.
- **Swapping approaches**
  Reduces charge and moves toward standardization. Increases stakeholder count. Demands advanced ecosystem beyond single customer. Application specific.

# Forecast

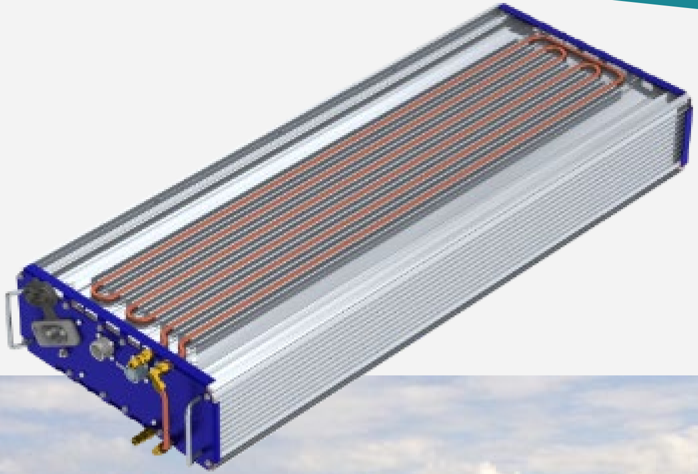
Energy density is the best opportunity for disruptive progress

- **Alternatives**
  Hydrogen offers clear benefits and challenges, will be preferable to batteries in many applications
- **Novel chemistries and architectures**
  Silicon anodes offer limited benefit. Protected anode not meeting with success. Solid state shows most promise but still not tangible nor perfectly safe.
- **Disruptive safety**
  Technologies that reduce system impact of safety can significantly improve packaging ratio



# F'rinstance: Washington State Ferries HEO

| | |
|---|---|
| Trident® Solution | Versa Liquid Cooled |
| Primary Usage | Battery Hybrid Propulsion |
| Embedded Energy | 10 MWh per ship |
| Cooling Method | Liquid |
| Operating Voltage Range | 720 – 1000 VDC |
| Max Discharge Power | 10 MW (1.0 C) |
| Delivery | 5 Vessels 2023-2030 |
| Approvals/Certifications | US Coast Guard |



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