U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

VTO Battery R&D Program – Prospects for Ultra-High-Energy Density Batteries

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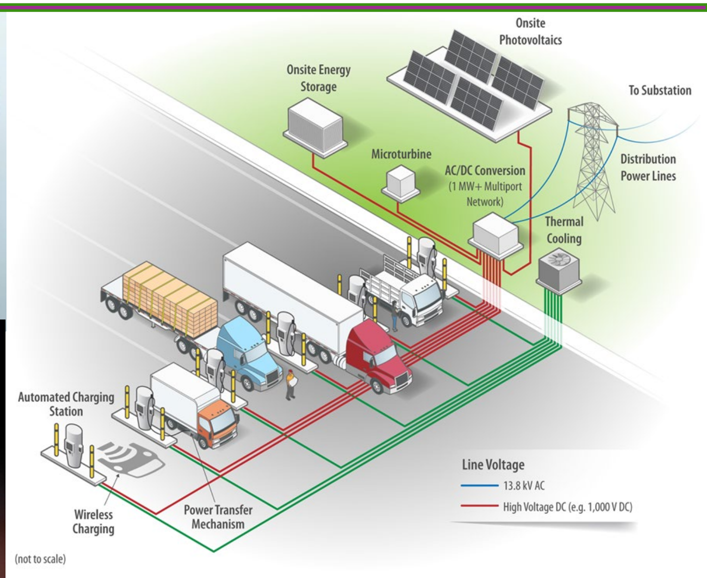
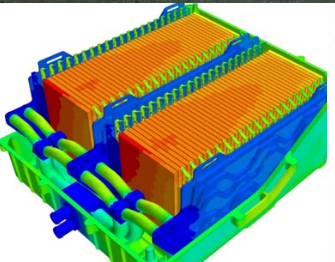
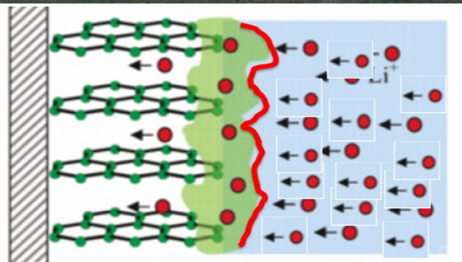
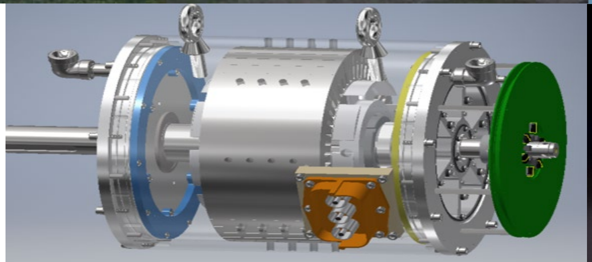








DOE VTO Battery R&D Roadmap (Near, Medium, and Long Term)

Improved Li-ion
Graphite : NMC/LFP

Projected Cell Specific Energy, Cost
300 Wh/kg, $100/kWh

Current cycle life	> 1,000
Calendar life	> 10 years
Mature Manufacturing	Yes
Fast charge	Reduced cycle life
Cost positive recycling	No

R&D Needs
- Improved fast charge
- Low temperature performance
- Low/no cobalt cathodes
- Cost positive recycling

Next-Gen Li-ion
Silicon : NMC/LFP

Projected Cell Specific Energy, Cost
400 Wh/kg, ~$75/kWh

Current cycle life	> 1,000, for ~320 Wh/kg
Calendar life	~3-5 years
Mature Manufacturing	Emerging
Fast charge	Yes
Cost positive recycling	No

R&D Needs
- Improved calendar life
- Abuse tolerance improvement
- Low/no cobalt cathodes
- Cost effective and scalable pre-lithiation

Lithium Metal
Li metal : NMC/LFP/Sulfur

Projected Cell Specific Energy, Cost
500 Wh/kg, ~$50/kWh

Current cycle life	> 200, for ~450 Wh/kg
Calendar life	TBD
Mature Manufacturing	No
Fast charge	Maybe
Cost positive recycling	No

R&D Needs
- Improved cycle and calendar life
- Protected lithium
- Dendrite detection and mitigation
- Cost effective manufacturing

DOE VTO Battery R&D Roadmap

Na-Ion

Hard Carbon : Layered Oxide

Projected Cell Specific Energy, Cost
100-180 Wh/kg, $75-125/kWh

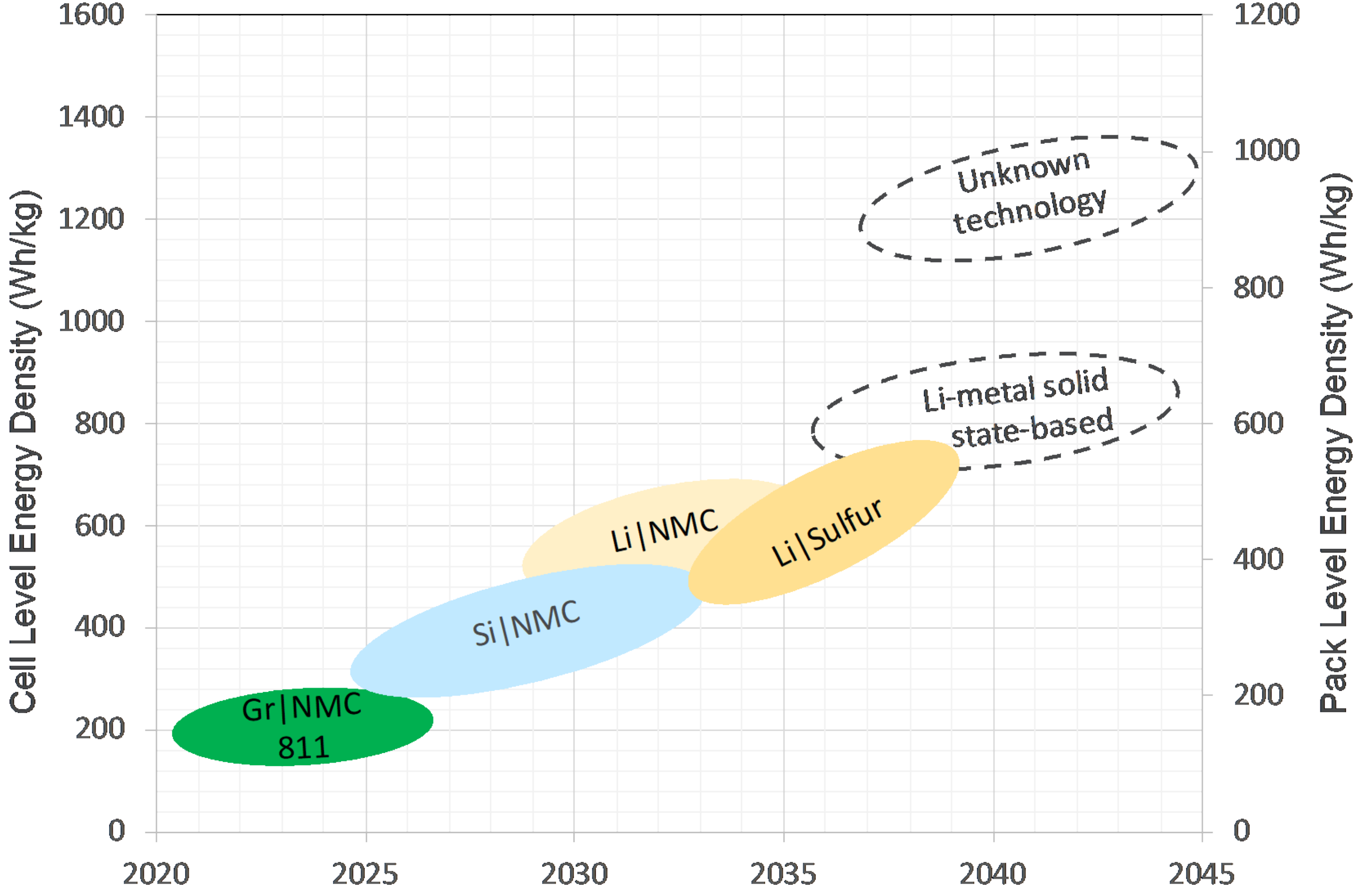
Current cycle life	200-1,000
Calendar life	> 10 years
Energy Density	Too low
Mature Manufacturing	Not yet
Fast charge	Unknown
Cost positive recycling	No

R&D Needs

- Improved energy density
- Low/no cobalt and nickel cathodes

Notional Battery Chemistry Roadmap

Very rough, not prescriptive transportation application based on energy density



From 2023 NASA-DOE Electric Aviation Workshop, credit Venkat Srinivasan, ANL

Fully-electrified rail, marine, aviation
Long-haul heavy-duty, limited passenger aviation, high-energy duty cycle off-road vehicles
UAVs, eVTOLs, medium-duty (e.g., box trucks), heavy-duty (e.g., regional haul, drayage)
Light-duty transportation, medium-duty (e.g., delivery vans)

Heavy-duty long-haul trucks

- **The Challenge: safe battery storage to enable 500+ mi w/o offsetting cargo, rapid charging, at/below TCO parity with diesel ICE**
- **Class 8 truck segmentation**
  – Sleeper-/daycab, team driving, derating duty cycle: long-haul, regional haul, drayage
  – Distinct needs of North American market
- **Long-haul Class 8 truck daily mileage (source: 2023 VIUS data)**

	Average (mi)	80th percentile	90th percentile	99th percentile
Miles	425	536	636	1,165
Useable Energy (kWh)	765	965	1,145	2,097
Specific Energy (Wh/kg)	334	422	550	1,134
Energy Density (Wh/L)	955	1,205	1,573	3,242

Assumptions:
- Single charge/day (!)
- 1.8 kWh/mi
- 0.35 vol/mass ratio
- 10 y, 2,000+ cycles

Battery Needs for Long-Haul HD Trucks

- **Energy needs:**
  - 1 MWh+ on board
- **Rate capability:**
  - lower than LDVs, but power fade could limit use
- **Charge acceptance:**
  - >2C charge preferable, regen on downhill routes
- **Cycle life:**
  - 2 cycles/day, 300 day/yr, 8 yr life = 4,800 cycles (example)
- **Safety: zero tolerance for thermal propagation events**
- **Cost: TCO basis; many considerations including vocation, resale or repurposing pack or truck**

HD VOLTS - Analyzing Battery Needs for HD Trucks

- Combine real-life duty cycle data, battery modeling, ML tools, TCO analysis
- Duty cycle and charging:

Long Haul operation (16 h/day (600-800 mi/day), a team of drivers)

LH 1	4 h Drive (150-200 mi)	1 h Break (0.7 C)	4 h Drive (150-200 mi)	1 h Break (0.7 C)	4 h Drive (150-200 mi)	1 h Break (0.7 C)	4 h Drive (150-200 mi)	5 h Break (0.4 C)

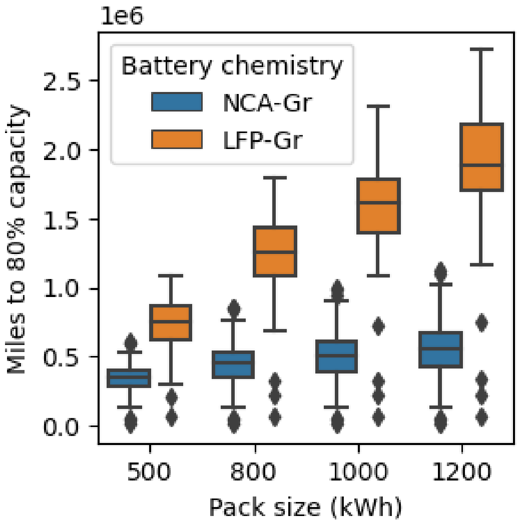
LH 2	4 h Drive (150-200 mi)	2 h Break (0.4 C)	4 h Drive (150-200 mi)	2 h Break (0.4 C)	4 h Drive (150-200 mi)	2 h Break (0.4 C)	4 h Drive (150-200 mi)	2 h Break (0.4C)

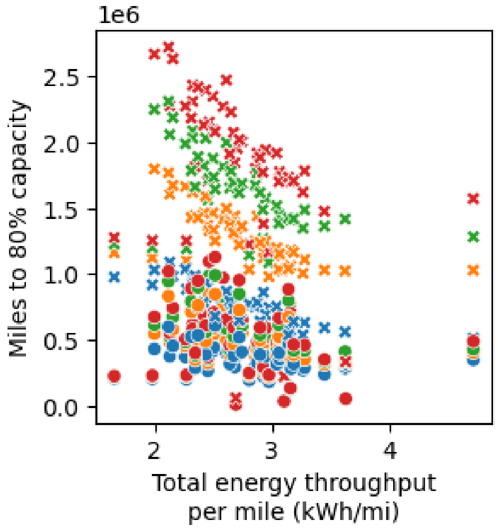
Credit:
Bumjun Park, Tanvir Tanim

Idaho National Laboratory

Scenarios aligned with battery size and regulations associated with drive time

Pack size substantially impacts life. Small packs have higher depth of discharge, more cycles = shorter life.





'Difficult' trips (heavy loads) reduce lifetime due to increased energy throughput per mile.

Credit: Paul Gasper

NREL
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Thank you for your attention

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