RANGE: State of the Program Annual Meeting 2016

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Advanced Research Projects Agency - Energy

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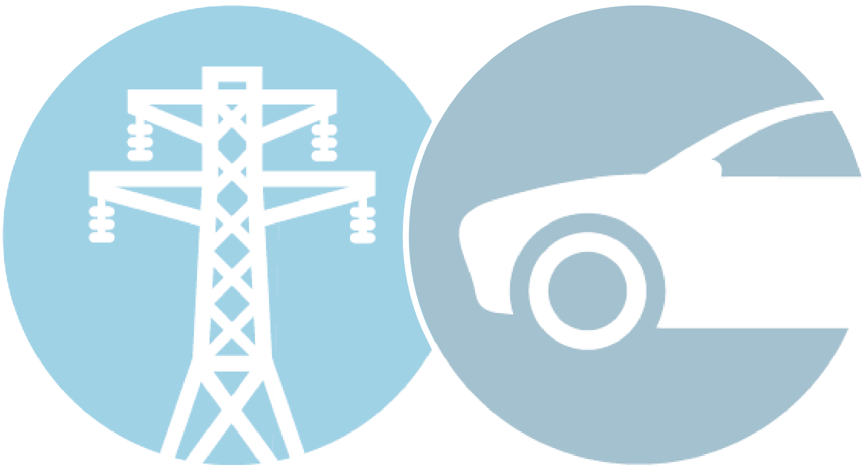
ARPA-E Programs

ARPA-E has funded over 450 projects across 25 focused programs and open funding solicitations



Stationary Energy Technologies

Solar ADEPT	BEETIT	**REBELS**
GRIDS	GENI	DELTA
IMPACCT	FOCUS	MONITOR

Transportation Energy Technologies

BEEST	Electrofuels	**RANGE**
PETRO	MOVE	REMOTE

Stationary & Transportation Energy Technologies

ADEPT	AMPED	SWITCHES
HEATS	REACT	
SBIR/STTR	METALS	

Open

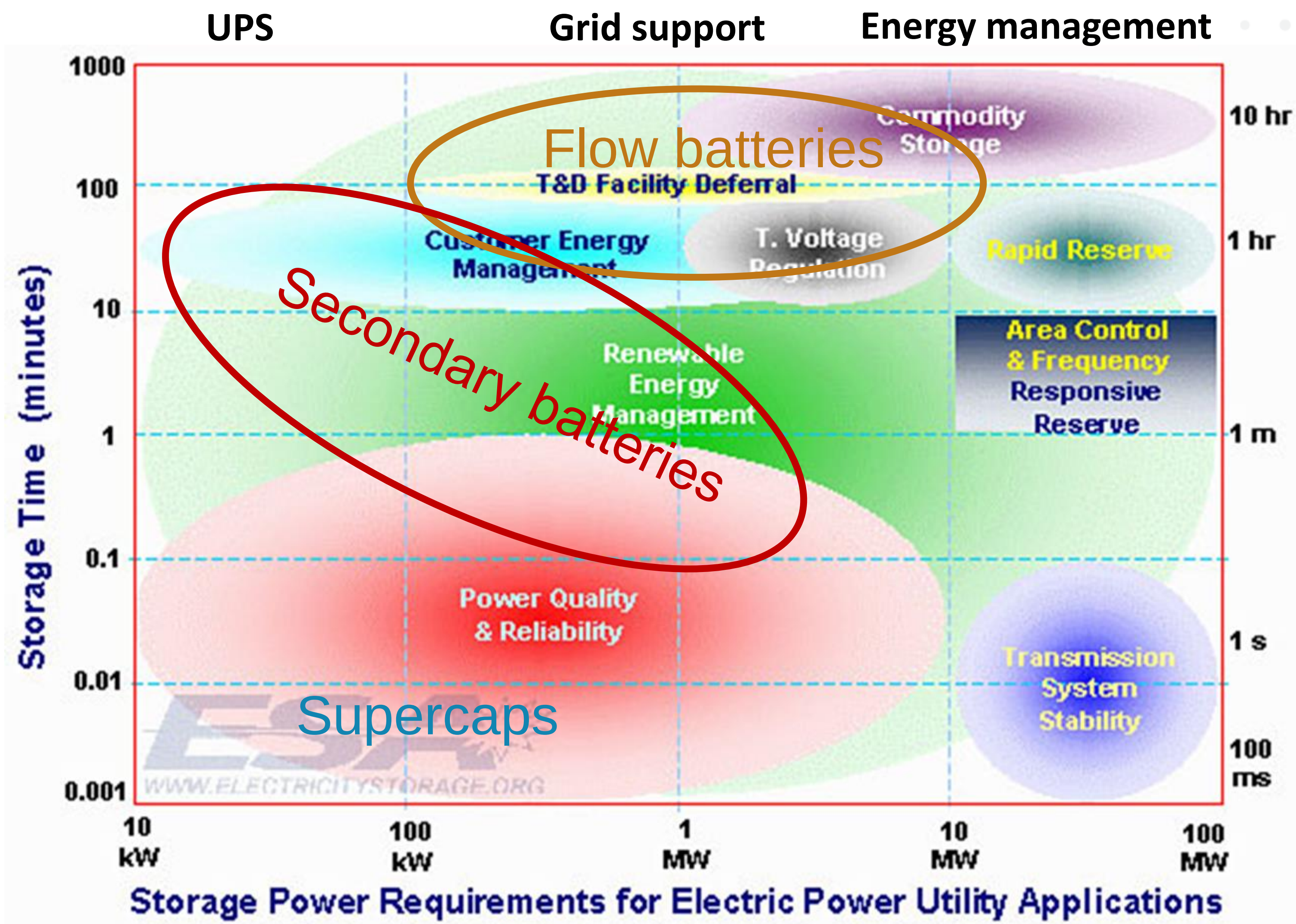
OPEN 2009	**OPEN 2012**	**OPEN 2015 IDEAS**

Recntly added programs

ALPHA
ARID
GENSETS
MOSAIC
NODES
TERRA
TRANSNET
IONICS

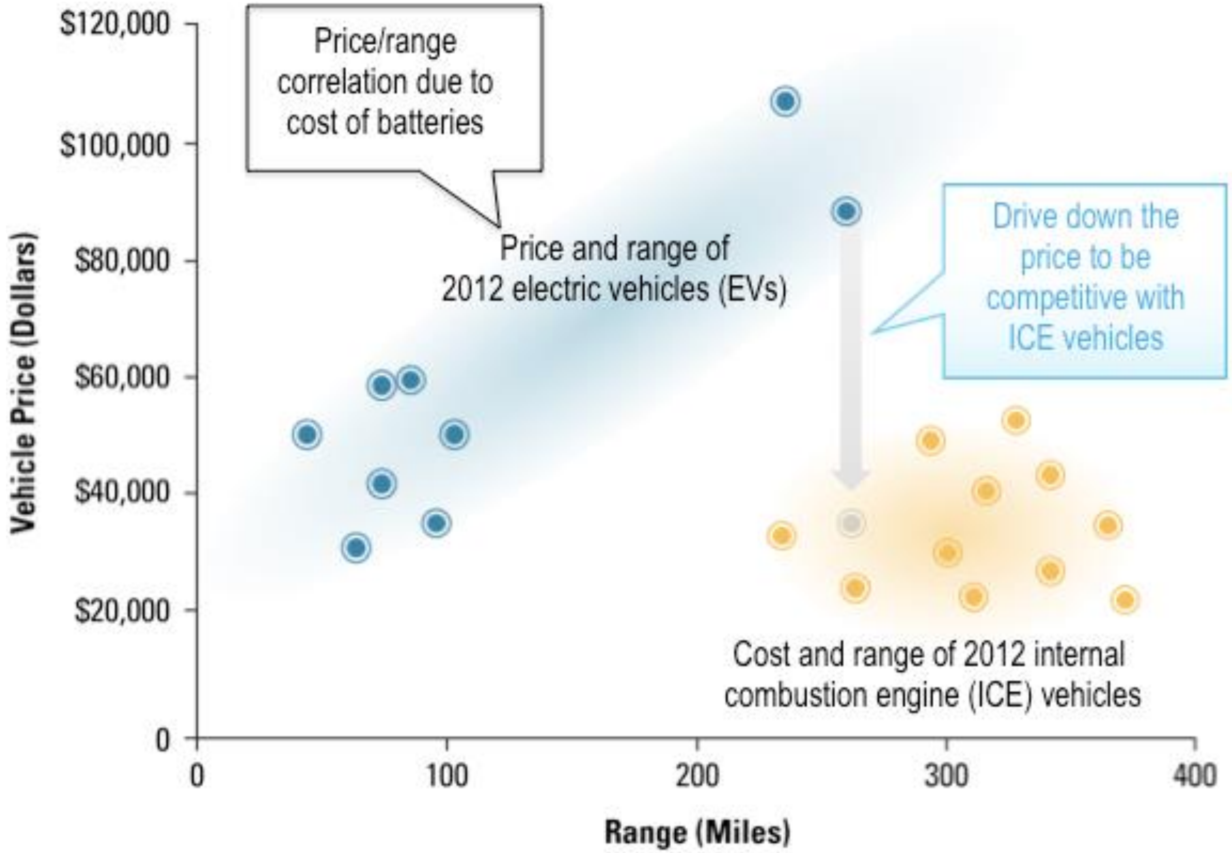
www.arpa-e.energy.gov

Energy Storage Application Space



Data from Sandia Report 2002-1314

Motivation: EVs Competitive with ICE Vehicles in Cost and Range



Battery cost reduction is critical to reduce costs of EVs

A System Perspective to EV Battery Cost Reduction

Vehicle battery cost per mile of range:

$$\$_{battery}/mile = (\$_{battery\text{-}cell} * pack\text{-}overhead)/kWh \times kWh/mile$$

Cost

Performance
Abuse tolerance

Weight

Battery + rest of vehicle

Set program matrix: reduce EV battery system cost to make it competitive with ICE vehicles

Vehicle battery cost per mile of range:

$\$_{battery}$/e-mile
=($\$_{battery\text{-}cell}$*pack-overhead)/kWh x kWh/mile

Conventional Lithium-ion approach

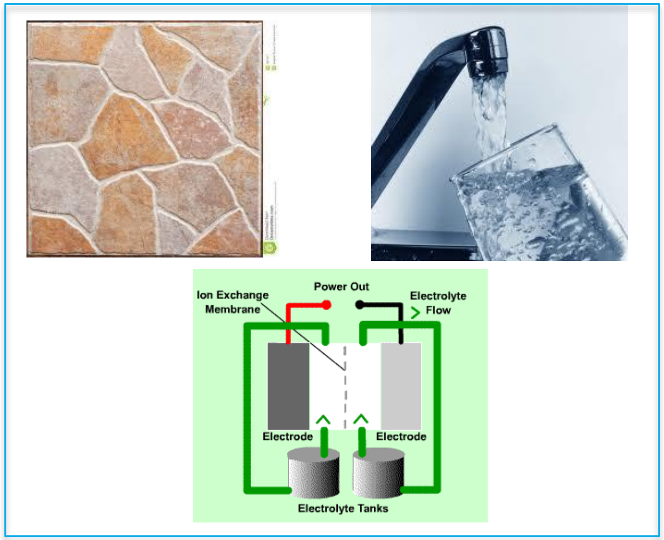
- Higher cell specific energy reduces $\$_{battery\text{-}cell}$
- Lower battery weight also reduces kWh/mile
- *Pack overhead (~2x) is needed to ensure life and safety of batteries*

RANGE approach

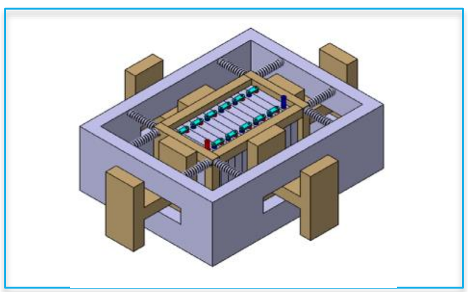
- Safe aqueous chemistries
- Low $\$_{battery\text{-}cell}$ chemistries
- Multifunctional design to reduce kWh/mile
- Low pack overhead due to system robustness

E-mile: electric range in miles

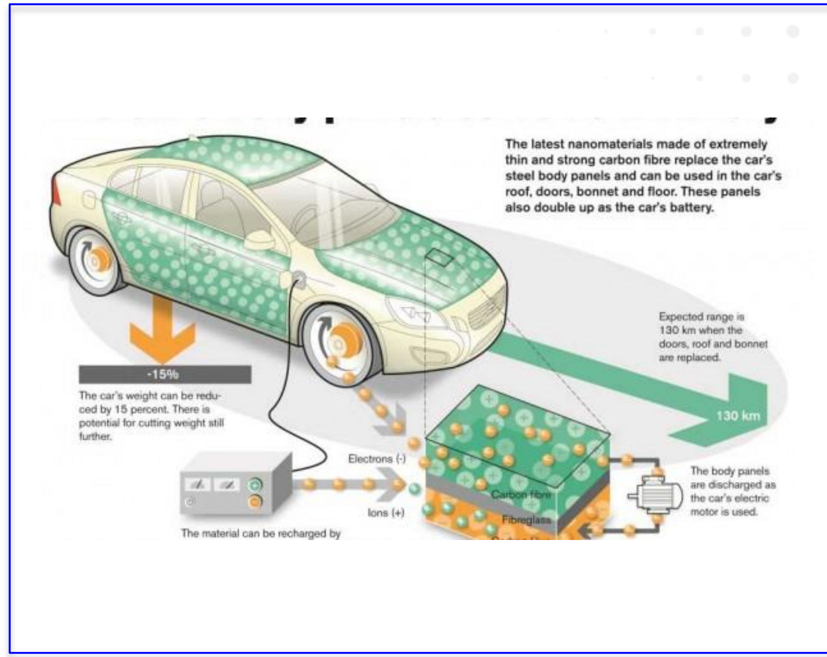
RANGE technical approaches



Hazard reduction



Mechanical design



Multifunctional system

Program considers both chemistry and system design approaches

RANGE Program metrics

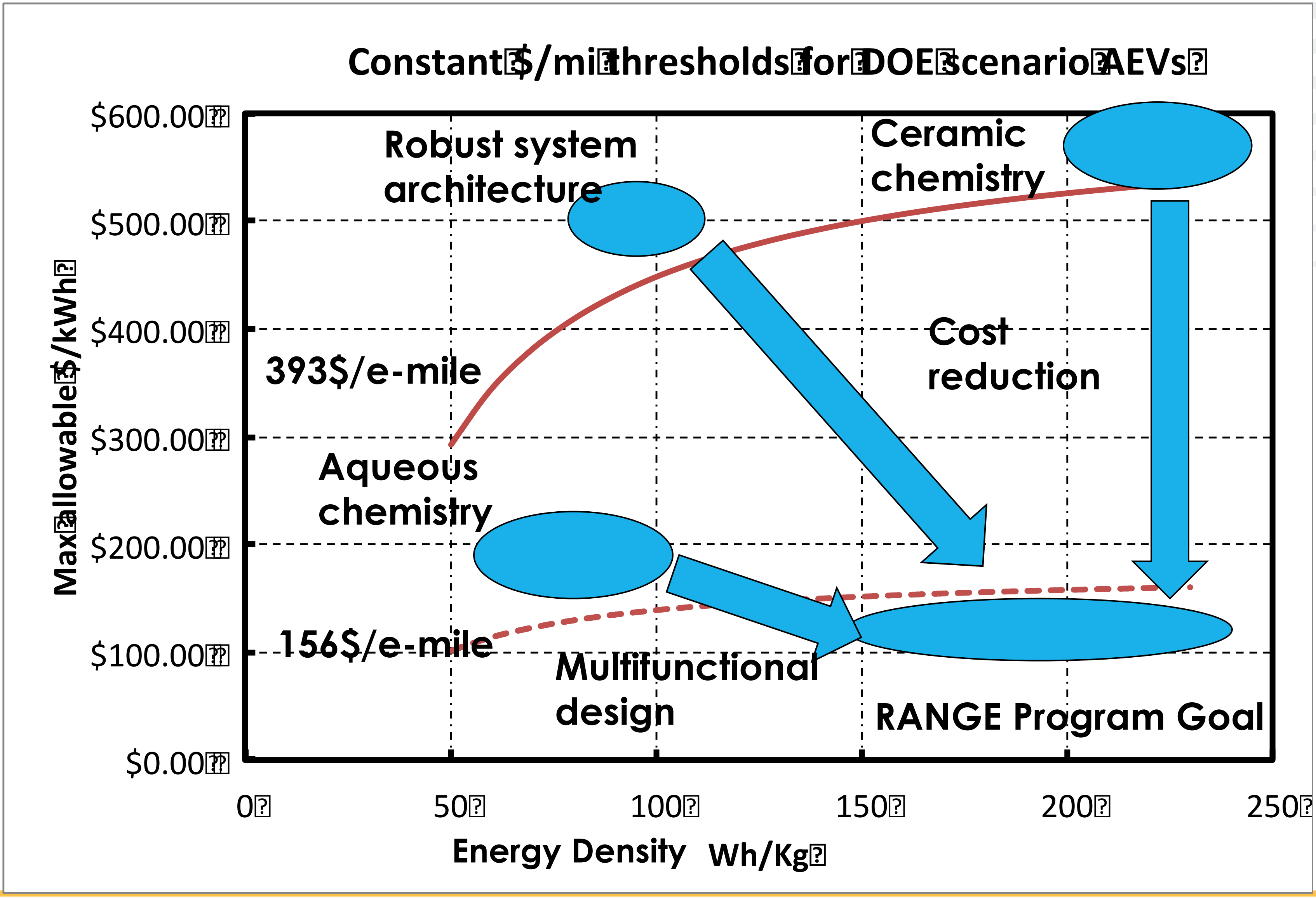
Performance

- Cost <$125/kWh
- Effective specific energy >150 Wh/kg
- Effective energy density >230 Wh/L

Safety

- **Crush test** to 50% of original dimension or at a force of 1000 times of battery mass without maximum temperature exceeding either:
  - The flash point of any volatile component (both original and generated during operation)
  - The melting point of any solid component
- **Pass** USABC battery mechanical abuse tests

Paths towards a robust, low cost EV



RANGE Program Portfolio overview

Aqueous

Robust Non-aqueous

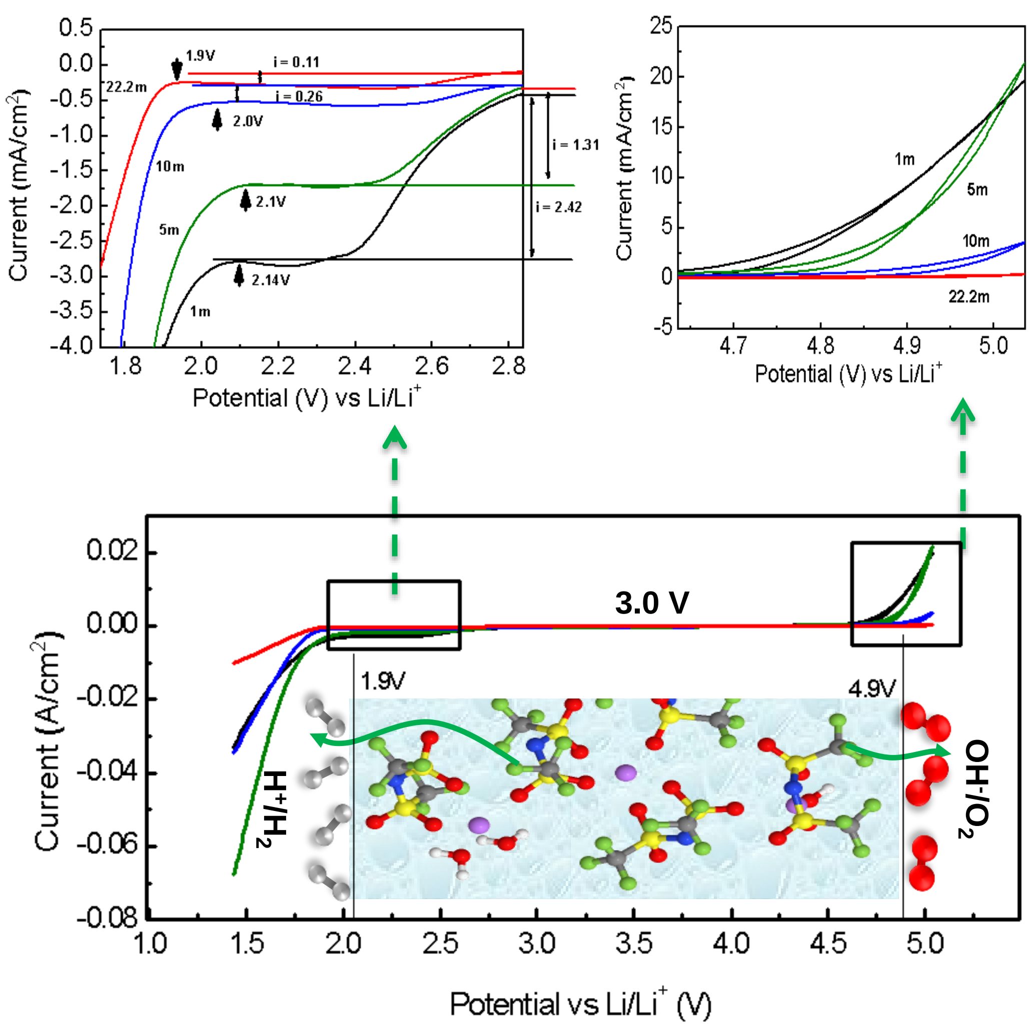
Solid State

Multifunctional

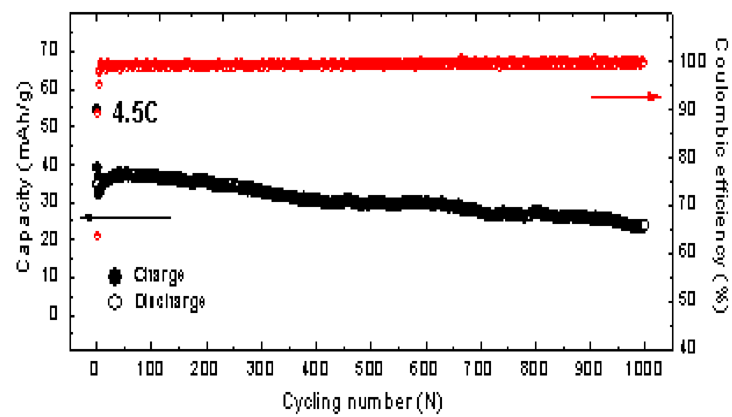
Cloteam, LLC now Cadenza

New on the block: Iowa State University, University of Michigan

Safe chemistry approach example: U Maryland



- Pourbaix-limits (1.23 V) broken to expand electrochemical window to ~3.0V
- SEI successfully formed in aqueous media for the 1st time
- Li-ion conductivity (10 mS cm^{-2} for 22 M water-in-salt electrolyte) is comparable to liquid organic electrolyte
- High voltage (2.0 V), high energy density (~100 Wh/kg) aqueous Li-ion battery demonstrated for the 1st time



High energy density approach example: PolyPlus

Technology Summary

Novel aqueous polysulfide electrolyte

Solid electrolyte to protect lithium metql

Characterize the porous electrode using 3D Xray Computed Tomography and Porosimetry to model and optimize cells

Demonstrate aqueous Li-S battery prototypes that achieve greater than 400 Wh/kg and 650 Wh/l.

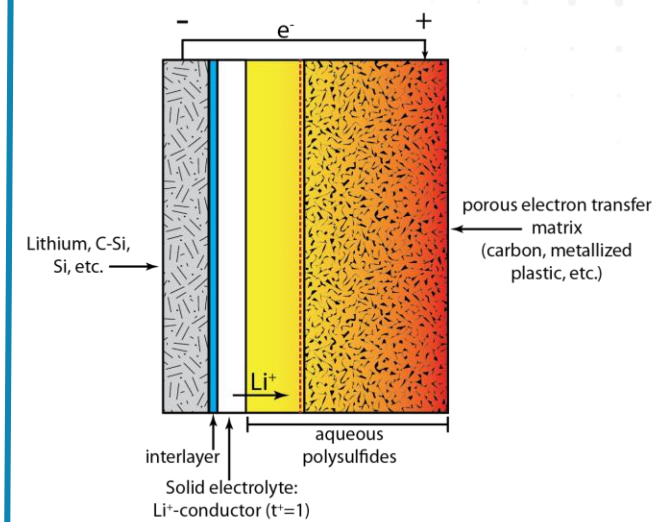
Technology Impact

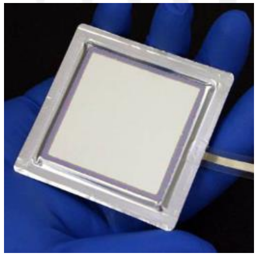
Aqueous lithium-sulfur battery technology offers step-change improvements to EV and grid battery performance at much lower costs

Positions U.S. manufacturers with a dominant position in the global market for advanced batteries

Proposed Targets

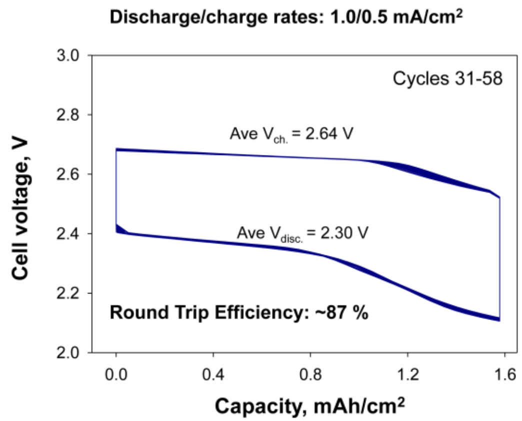
Metric	State of the Art	Proposed
Electrolyte	*Non-aqueous*	*Aqueous*
Safety	*Flammable*	*Non-flammable*
Energy Density	220 Wh/kg	> 400 Wh/kg
Cost	$500/kWh	< $125/kWh

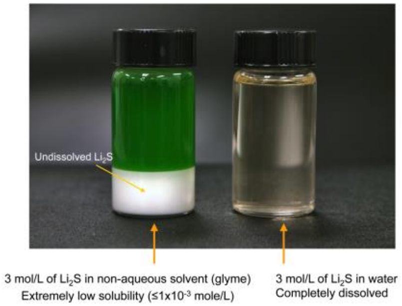




11 Ah water-stable lithium electrode

Cycling of Li-S Cell with 3M Li_2S_4 Aqueous Catholyte





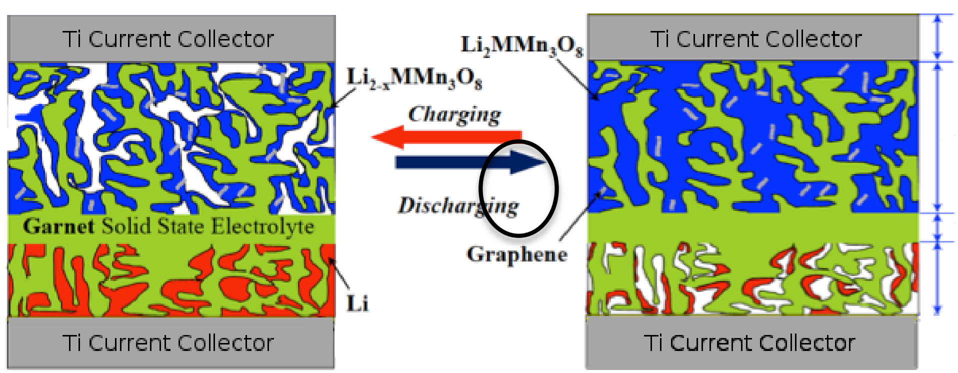
High Performance, Low-Cost Aqueous Lithium/Sulfur Batteries

Steven J. Visco, PolyPlus Battery Company & Johnson Controls

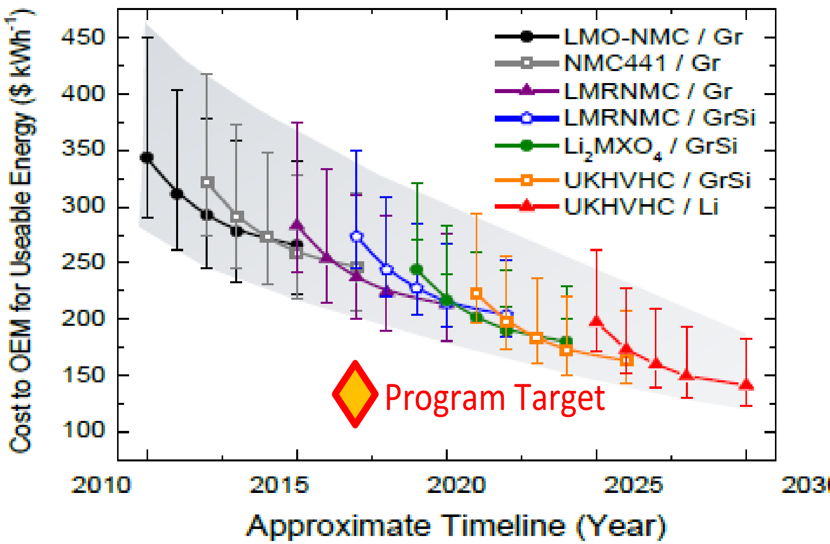
Solid state chemistry approach example: U Maryland

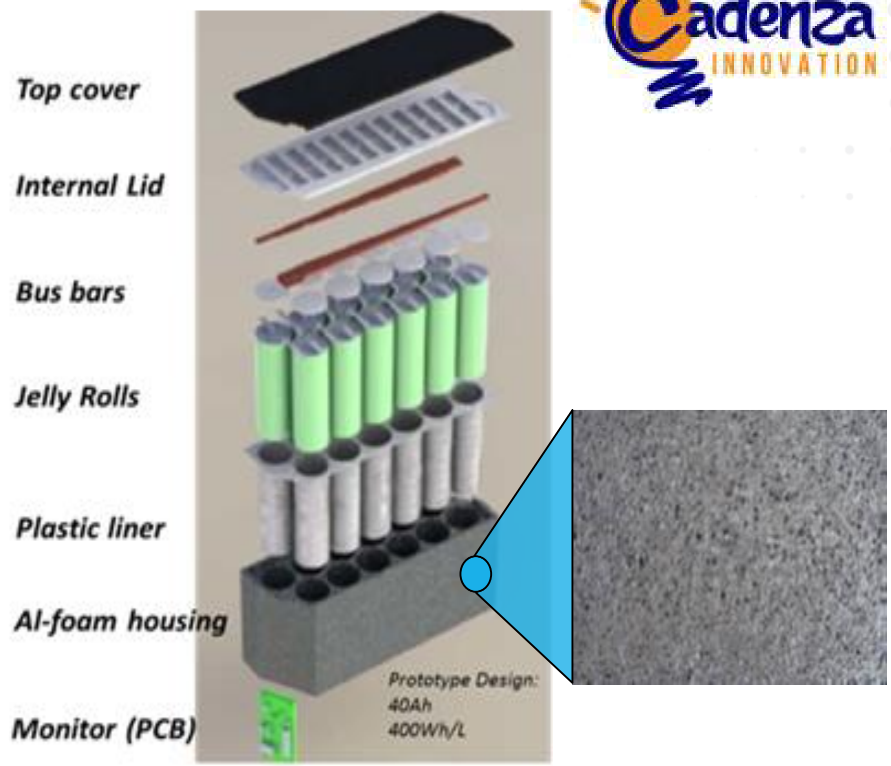
- A dense separating layer and two porous electrodes are made from the same Li+ conducting stable material
- Li metal to cycle with no dimensional change in the anode
- Low ohmic ASR and interfacial impedance

- Safe operations
  - Li dendrite formation blocked
  - No flammable electrolyte
- Design applicable to many chemistries



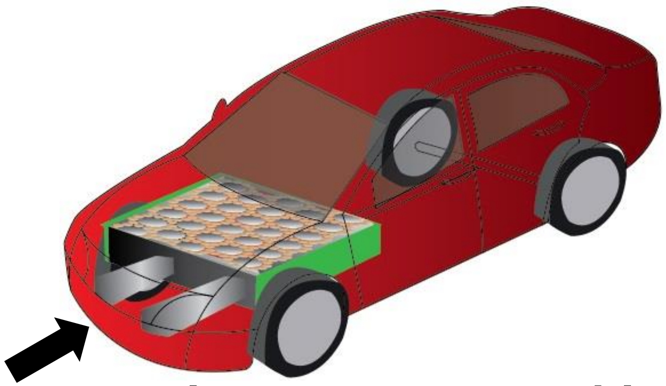
Multifunctional approach example: Cadenza



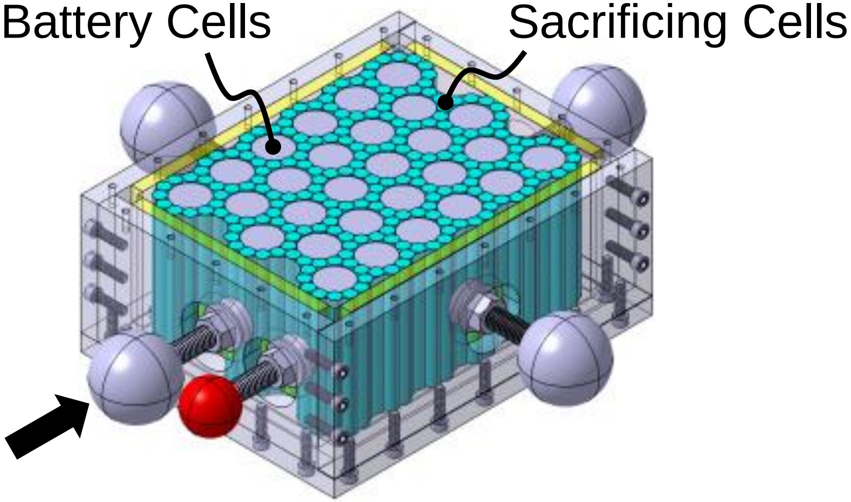


Combination of conventional Li-ion cells and innovative design

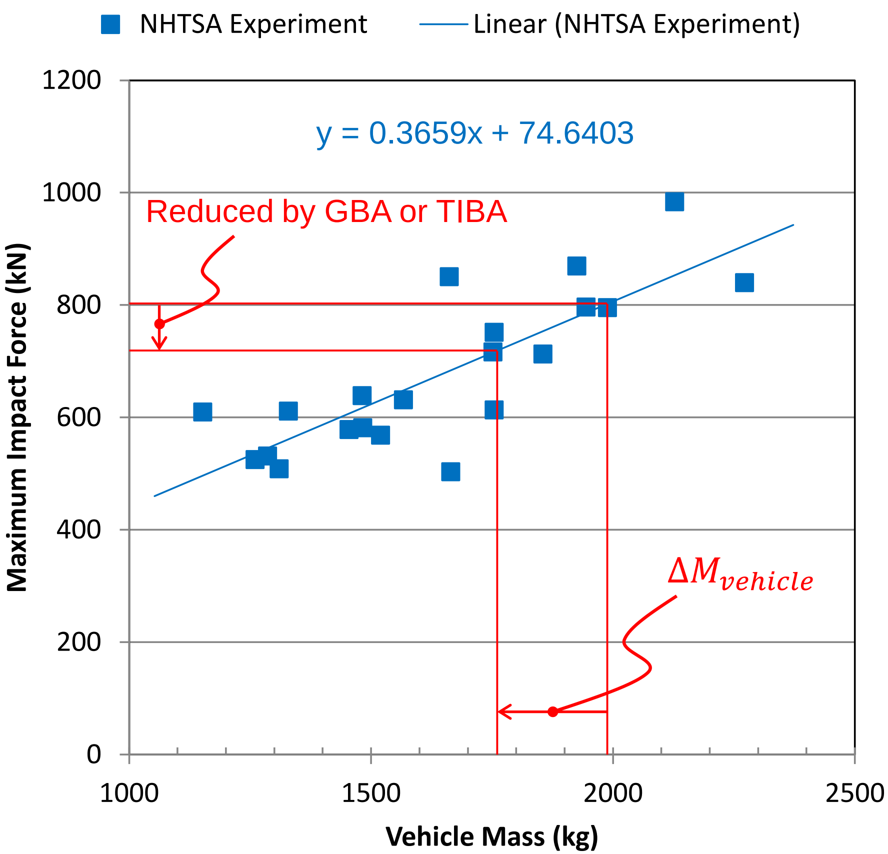
Multifunctional approach example: Purdue



Granular Battery Assembly (GBA) Conceptual Sketch



GBA Scaled-down Prototype



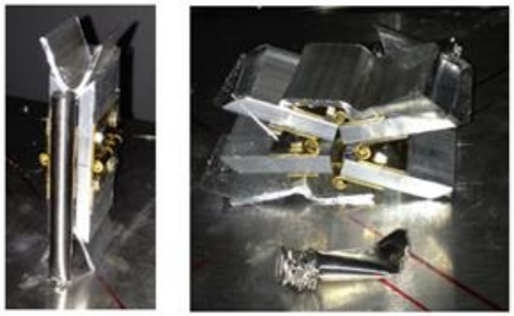
A slight reduction in peak impact force can lead to significant vehicle weight reduction.

Multifunctional approach example: UCSD

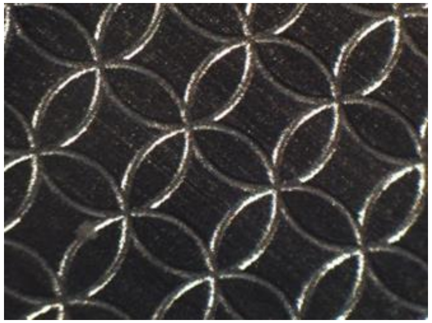
Goal: Increase battery safety and lower cost through multiscale mechanical engineering designs.

Progress:

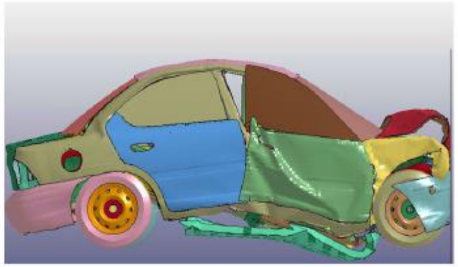
- Cell package designs can be crushed to 50% size with no thermal runaway.
- Current collector patterning allow cells to disconnect without thermal runaway after crushing. New electrode coatings allow cells to function safely after nail puncture
- Computer models show that an 80 kWh battery pack can absorb the same impact as an engine, and save 50kg weight from the car



Deformable battery packs



Disintegrable current collectors



Crash simulated confirmed weight savings

RANGE Program Progress Summary

- **RANGE has developed an array of inherently robust battery materials and architectures that will impact vehicle and grid storage:**

  - Vehicle level modeling/design demonstrated system level benefit of > 10% vehicle weight saving

  - Cells can carry load and tolerates intrusion
  - Robust cycling of lithium metal anode

- **RANGE has jump started the field of high energy density aqueous battery:**
  - Expanding the stability window of aqueous electrolyte to enable high voltage batteries
  - Developing a set of low-cost electrode chemistries (metal oxides, organic redox materials)

- **Program has laid the foundation for multifunctional vehicle design:**
  - On track to achieve a demonstration on an EV