Workshop Summary

Large Scale Grid Storage: Status, Challenges and Perspectives

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NIChE Workshop on Materials for Large-Scale Energy Storage

Sept. 16,17, 2010

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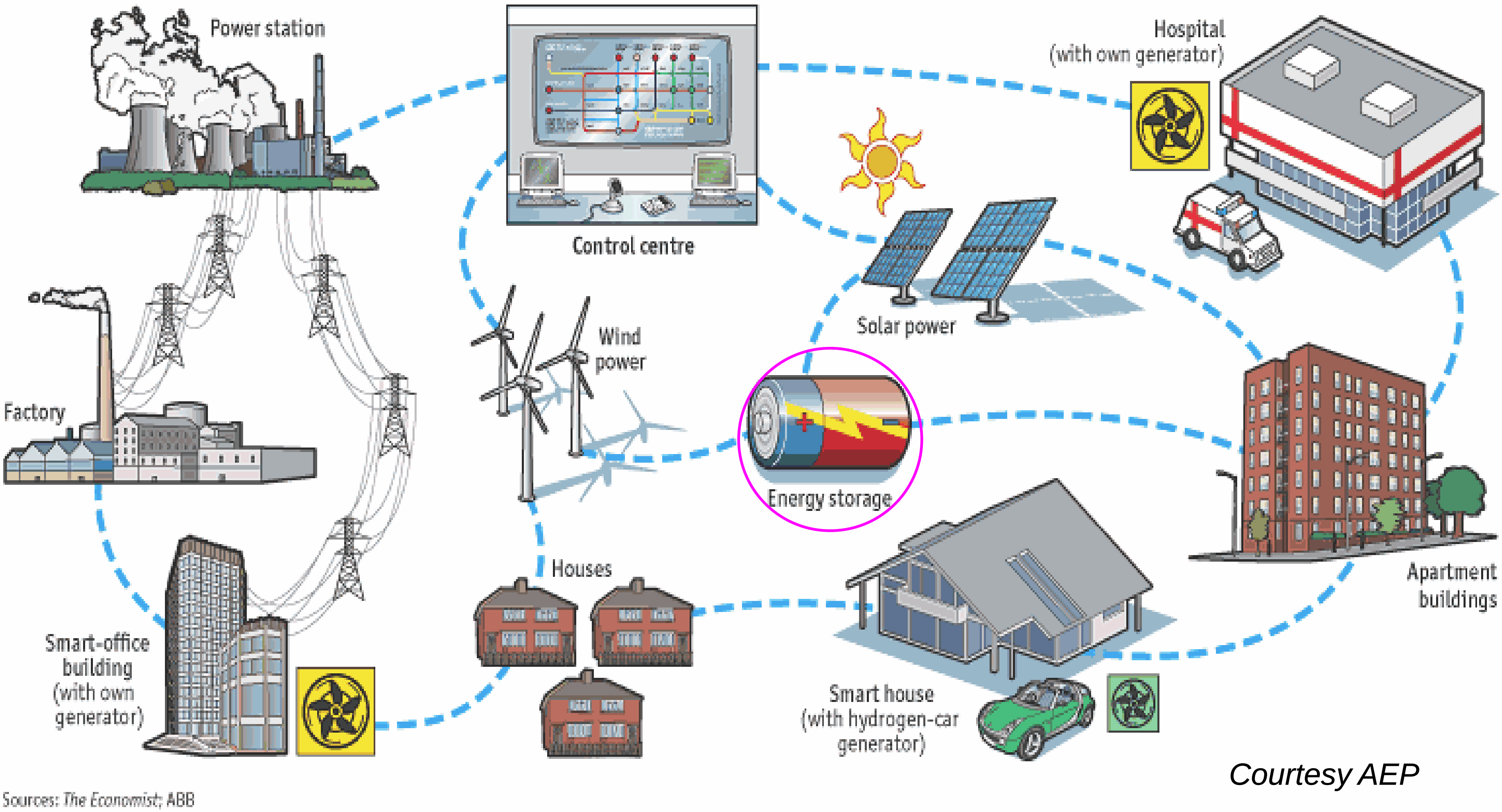
Electrical energy storage- a central component of the future grid



Courtesy AEP

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Application scenarios and power/energy ratings

Generation site storage

10s MWh ~ 10s GWh

10s MW ~ GW

Transmission-substation

MWh ~ GWh

MW ~ GW

Community storage

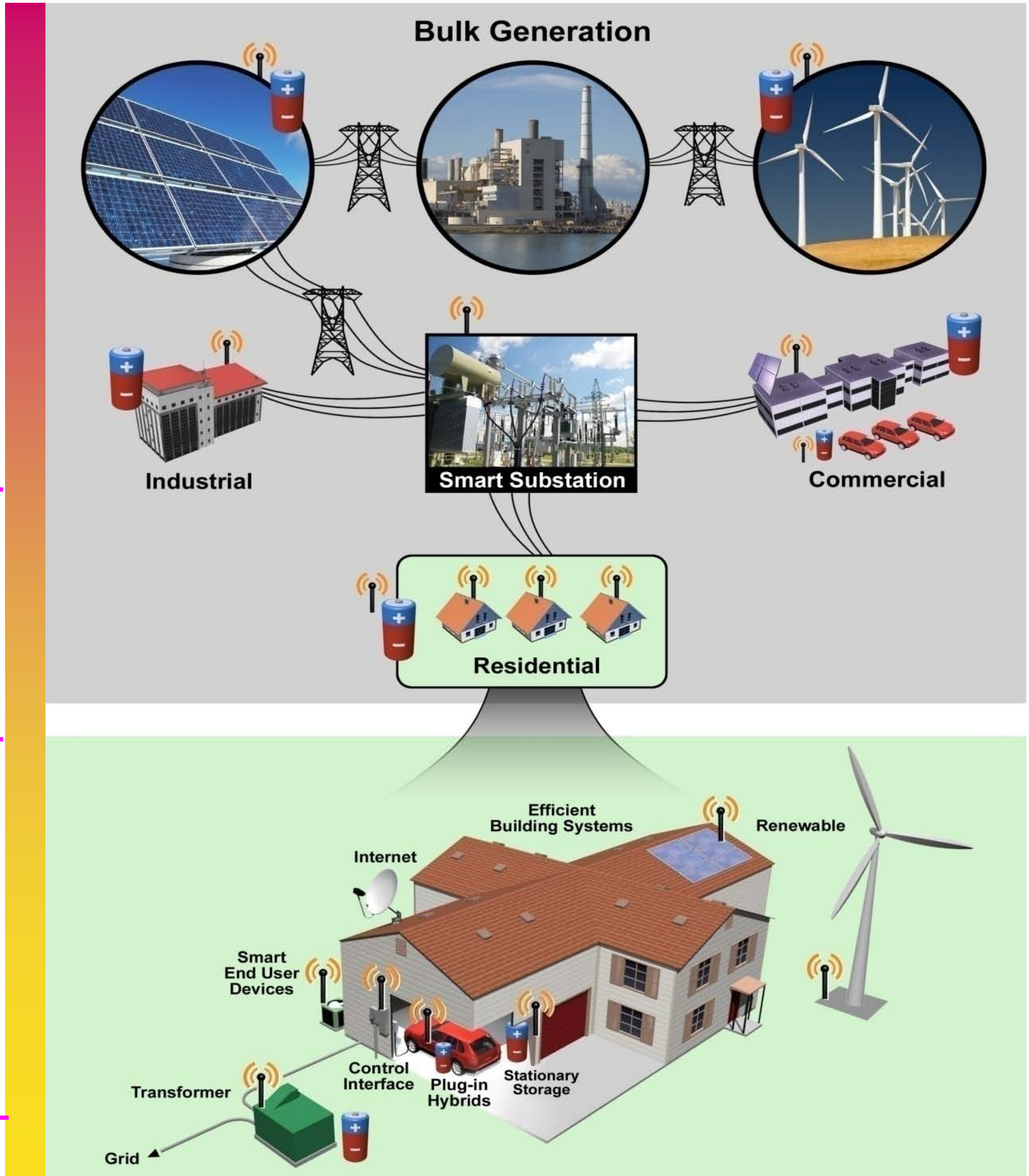
10s kWh ~ 100s kWh

10s kW ~ 100s kW

End user storage

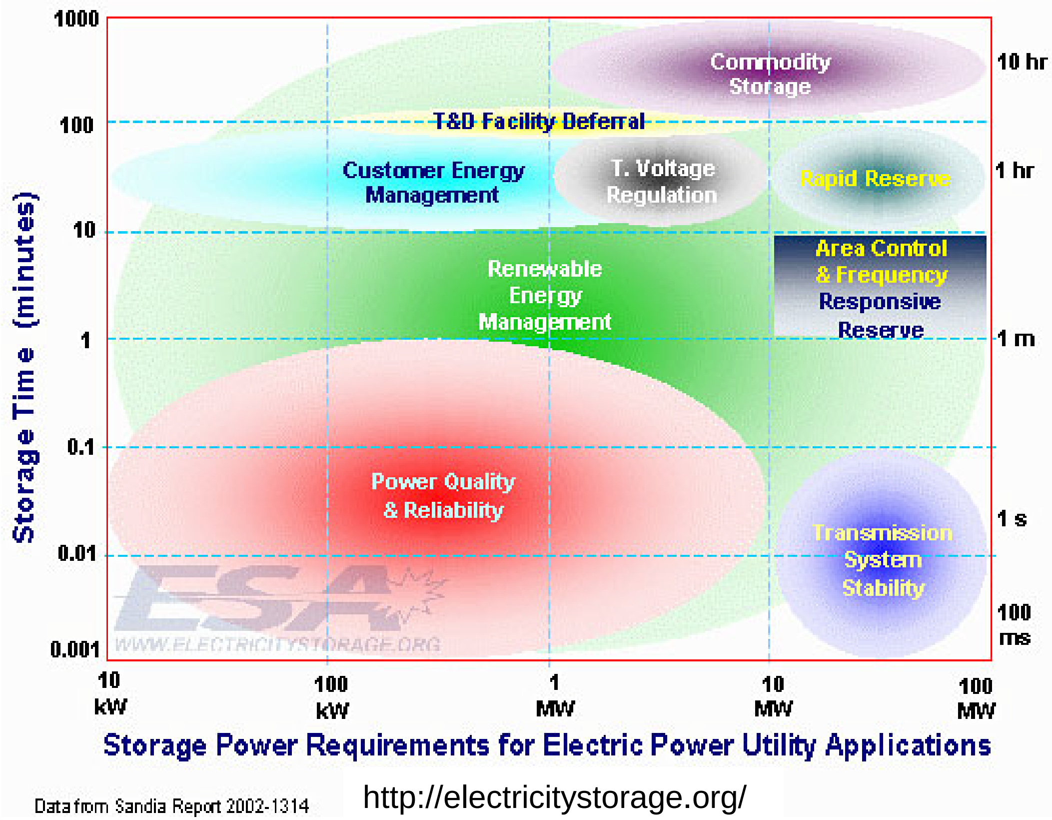
Few kWh~10s kWh

few kW



Performance and economic requirements

- **Energy/power**: depending on applications;
- **Quick response** preferable;
- **Discharge duration**: seconds ~ hours
- **Efficiency**: High, preferable;
- **Life**: >10~15yrs, >5,000 deep cycles, higher for shallow cycles, depending on applications;
- Safety



http://electricitystorage.org/

- **Costs**: low capital cost, life cycle cost, social cost (considering carbon effects)

References:

- *Report of DOE Advanced Materials & Devices Workshop, organized by TMS, Sandia and PNNL for DOE-OE and ARPA-E*
- *EPRI report on grid storage functional requirements, P94.002*

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EES technology options

Electrical energy

Direct Storage in charges

Electrical charges:
Capacitors

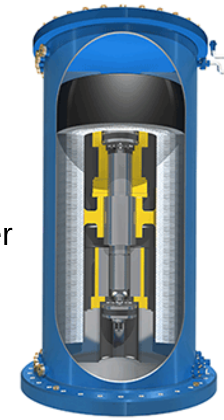
Kinetic energy:
flywheels

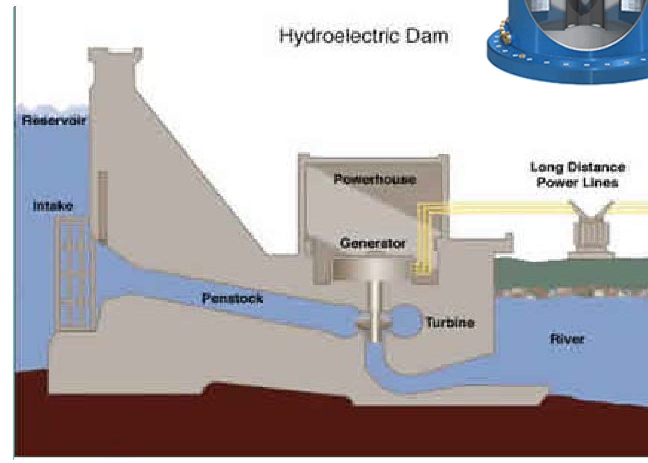
Indirect storage via energy conversion

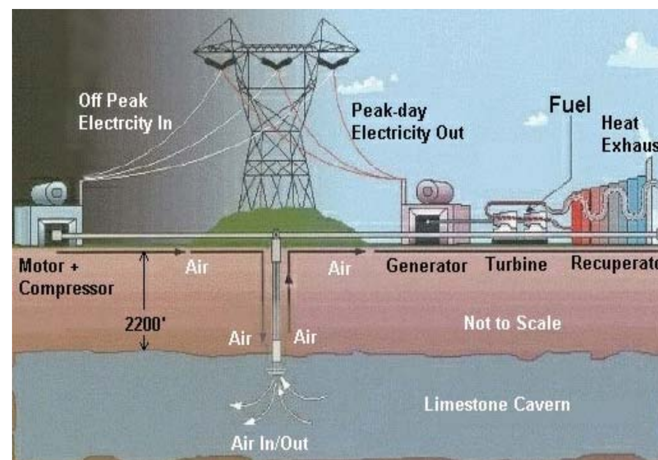
Potential energy:
pump hydro,
compress air

Chemical energy:
batteries

Beacon power







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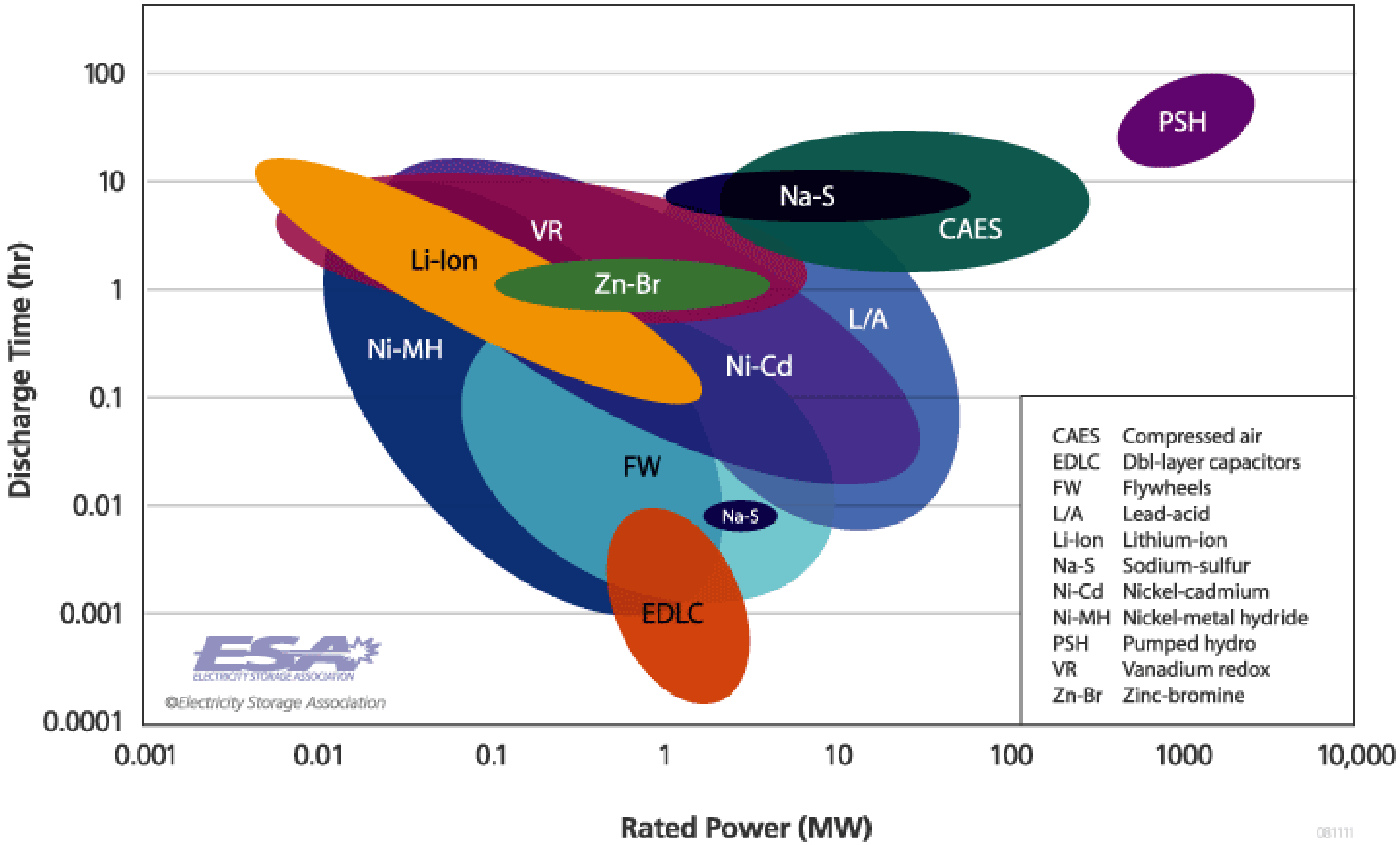
EES via chemical energy-batteries

- Free energy of chemicals converted into electrical energy: without "Carnot" cycles
- Potentially capable of uptake and release of electrical energy according to power and energy demands



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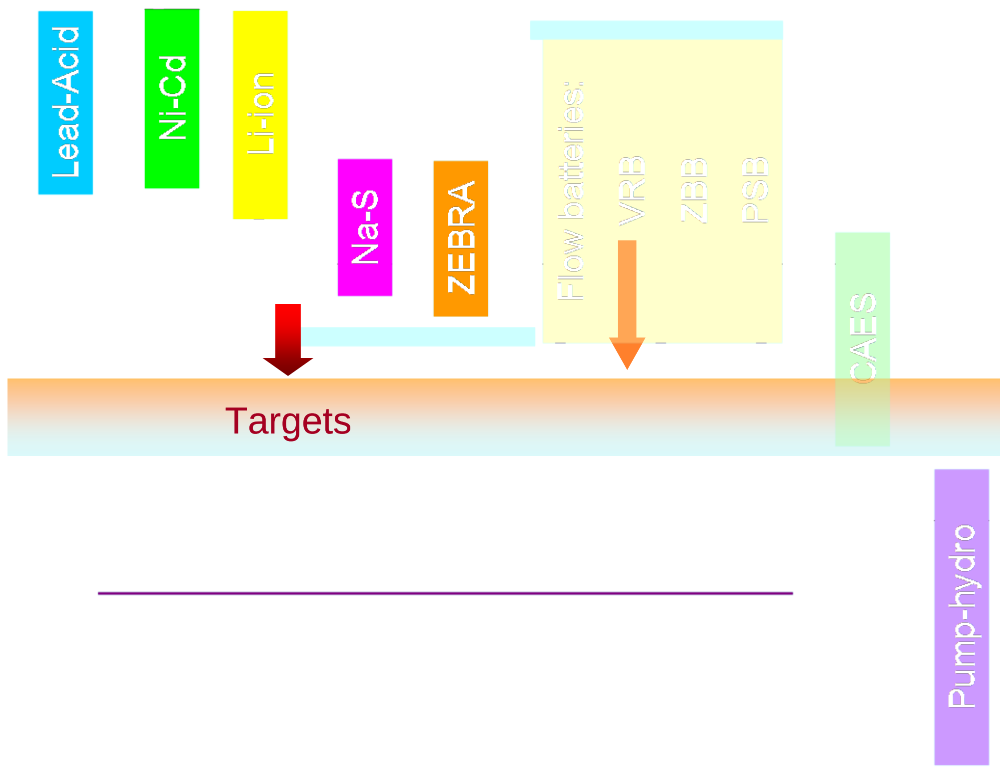
Overall technology challenges

- Cost at least 2~3 x higher for broad market penetration
- Better economy reliant on improved reliability, durability, life and efficiency, along with manufacturing
- Require advancement in science and technology



Life cycle cost: 4¢/kWh/cycle

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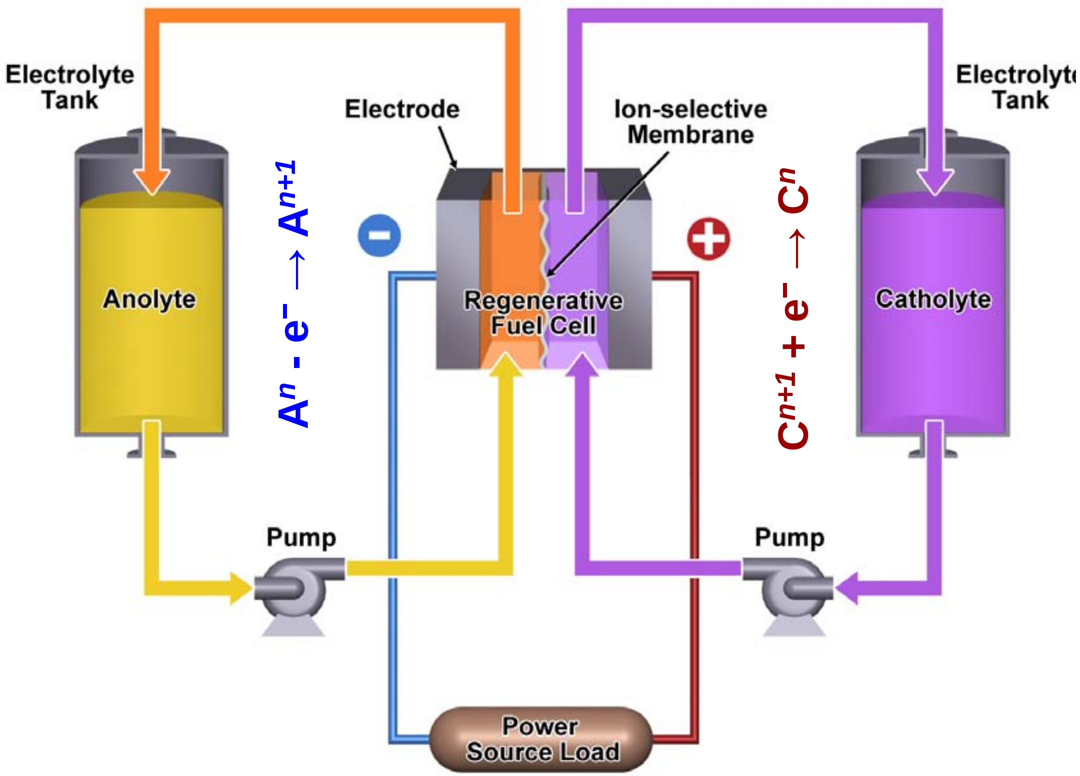
Redox flow batteries (RFB)
or regenerative fuel cells



Why RFBs?

- ❑ Capable of a large energy/power

  (but not specific energy or density)
- ❑ Separation of energy and power
- ❑ No-mechanical and thermal stress during cycling
- ❑ Active heat management
- ❑ Quick response (milliseconds)
- ❑ Safe
- ❑ Potential low cost
- ❑ …

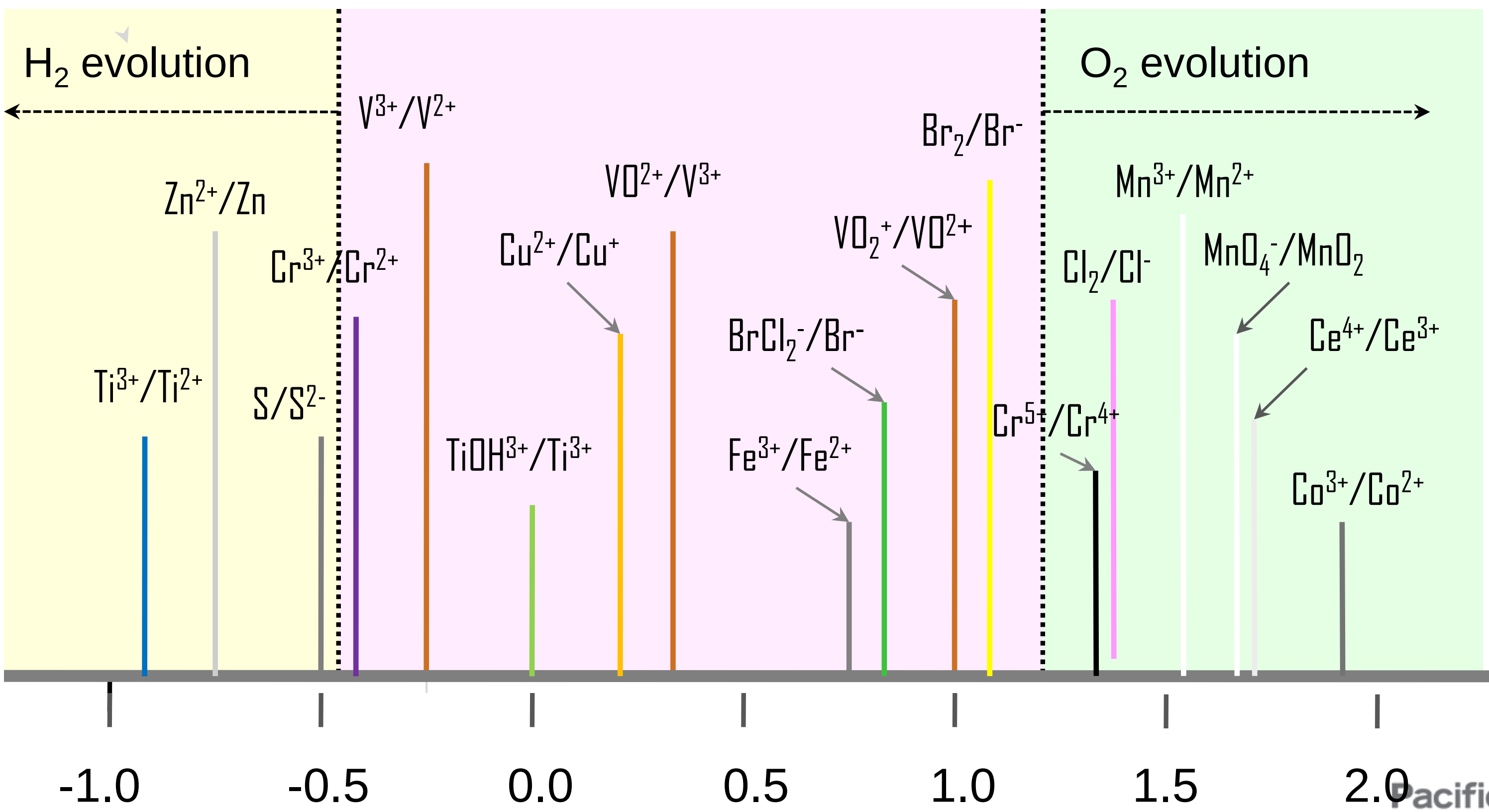
Redox chemistries and exiting technologies

- VRB: V^{2+}/V^{3+} vs. VO_2^{+}/VO^{2+}
- ICB: Fe^{3+}/Fe^{2+} vs. Cr^{3+}/Cr^{2+}
- ZBB: Br^{-}/Br^{2-} vs. Zn^{2+}/Zn
- PSB: Br^{2}/Br^{-} vs. S/S^{2-}

Multi-100 kW or higher demonstrated

Others:
V^{2+}/V^{3+} vs. $Br^{-}/ClBr_2^{-}$;
Ce^{4+}/Ce^{3+} vs. V^{2+}/V^{3+};
Fe^{3+}/Fe^{2+} vs. Br_2/Br^{-};
Mn^{2+}/Mn^{3+} vs. Br_2/Br^{-};
Fe^{3+}/Fe^{2+} vs. Ti^{2+}/Ti^{4+}, …

Non-aqueous electrolyte, high V and ED, but high cost

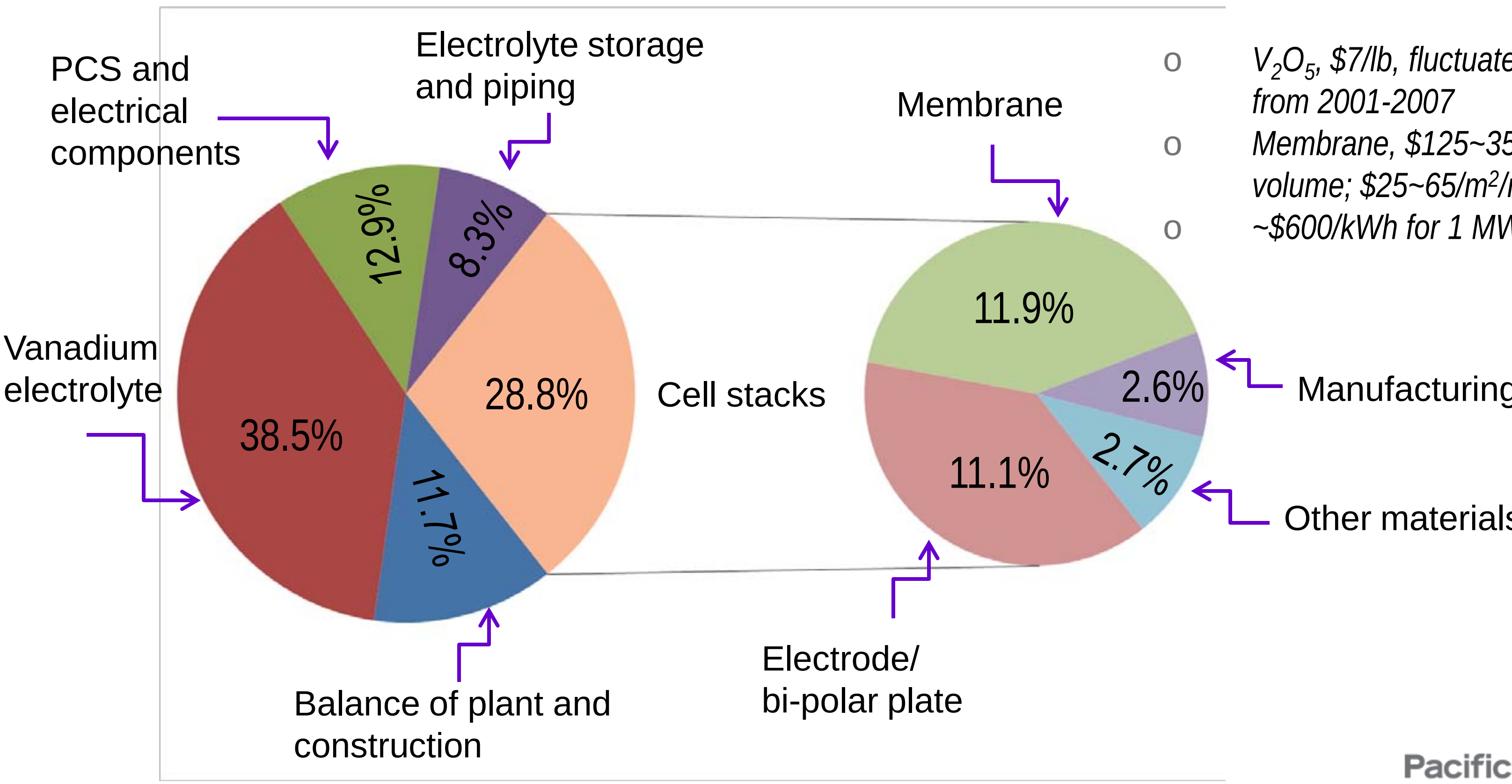


Standard potential (V) of redox couples

Challenges of RFBs: take VRB as example

- Specific energy 15~25 Wh/kg; energy density 20~33 Wh/liter
- Stability of electrolyte, 10~40ºC
- High cost, >\$500/kWh

Capital cost=\$2,300x(kW rating) + \$300x(kWh rating) + \$250,000



- *V_2O_5, \$7/lb, fluctuated \$1.5 ~\$7.0/lb from 2001-2007*
- *Membrane, \$125~350/m²/mil small volume; \$25~65/m²/mil for large volume*
- *~\$600/kWh for 1 MW, 8 hr system*

After EPRI cost analysis, 1 MW/8MWh plant, \$4.9 mil

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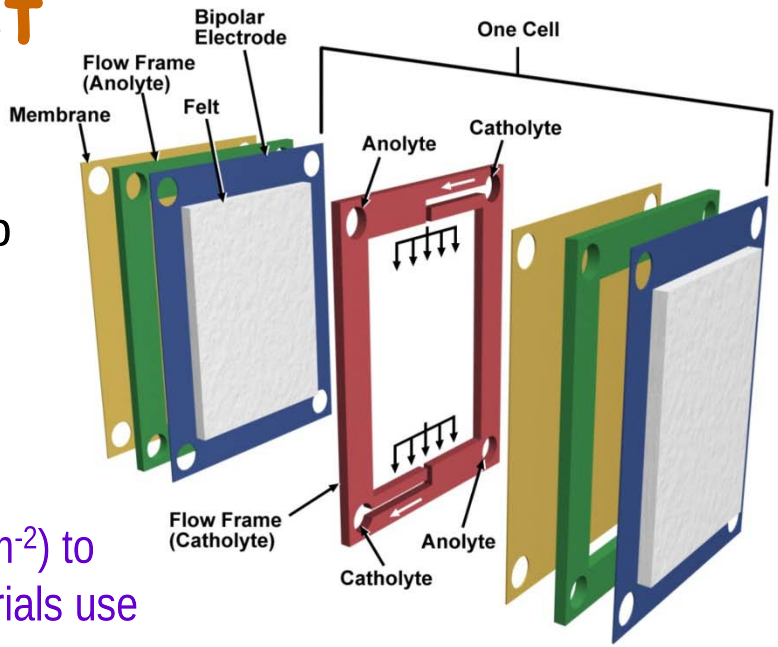
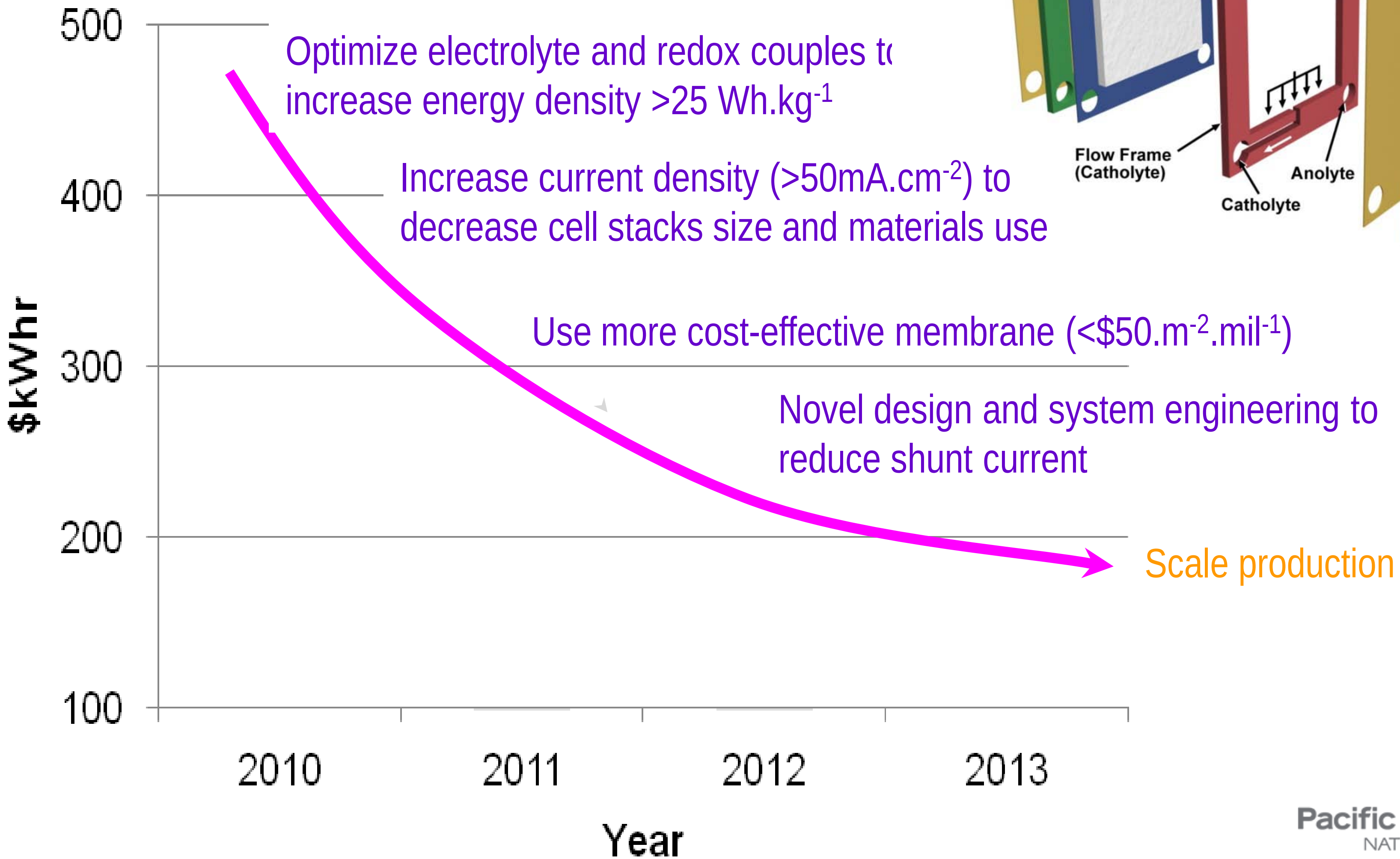
Approaches to reduce cost

- Via use of more cost effective components, improvement in performance parameters and novel system engineering, along with scale-up of production.





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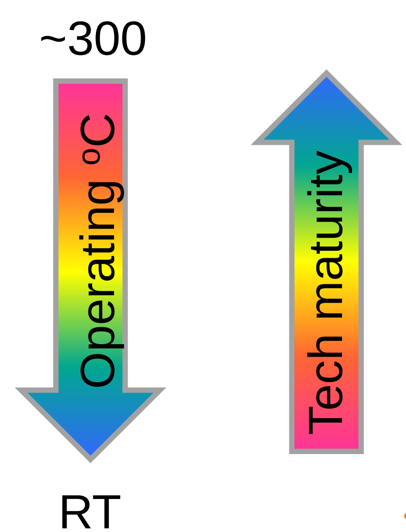
Na-batteries

Electrochemical storage that utilize Na- or Na-containing electrodes and a Na^+ conducting electrolyte, either solid or liquid

Why Na-battery chemistries?

- ❑ Li-resources constrains;
- ❑ Low cost of raw materials

- ❑ Na-beta alumina electrolyte batteries
- ❑ Na-Nasicon electrolyte batteries
- ❑ Na-ion (aqueous or non aqueous electrolyte) batteries



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Na-beta alumina electrolyte batteries (NAB)

NAB are electrochemical devices that store electrical energy via Na^+ transport through conductive solid oxide membrane (typically β''-Al_2O_3) at elevated temperatures.

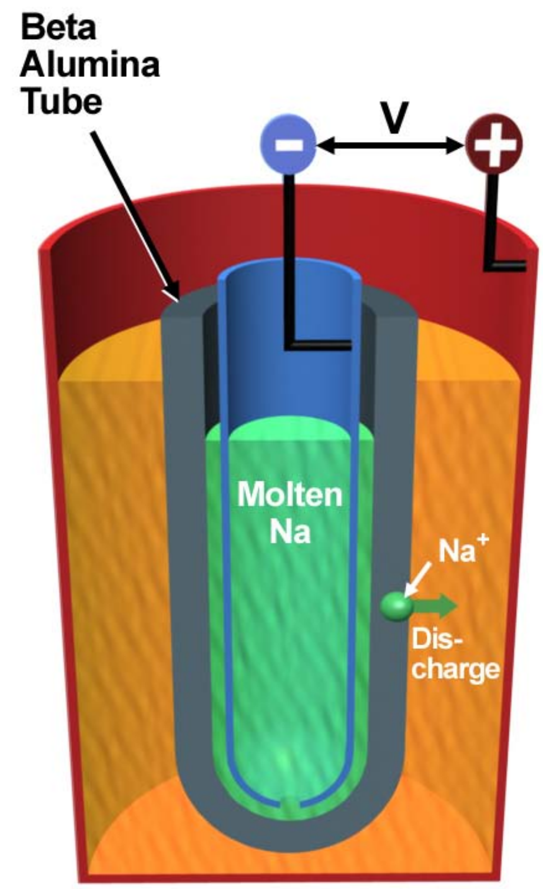
- Sodium-sulfur (SSB)

$$2Na + 4S \underset{d}{\overset{c}{\rightleftarrows}} Na_2S_4 \quad E = \sim 2.0\ V$$

- Sodium-metal chloride (ZEBRA)

$$2NaCl + Ni \underset{d}{\overset{c}{\rightleftarrows}} NiCl_2 + 2Na \quad E = \sim 2.58\ V$$

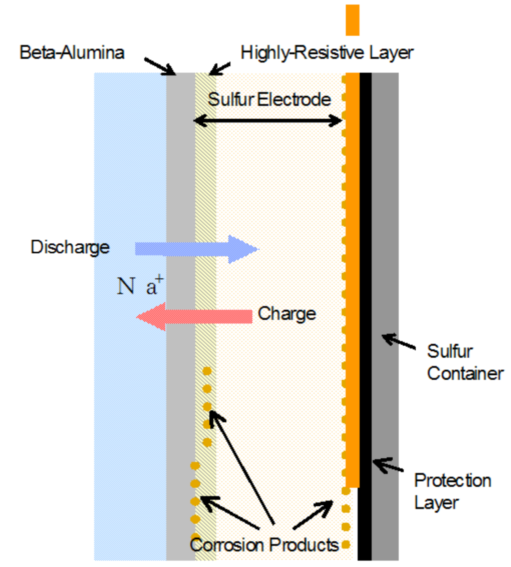
Invented and first investigated by Ford for vehicle applications



- Operated at 300~350°C
- High efficiency, up to >90%
- Capable of hours of discharge duration
- Quick response
- Up to 16MWhs demonstrated, for SSB

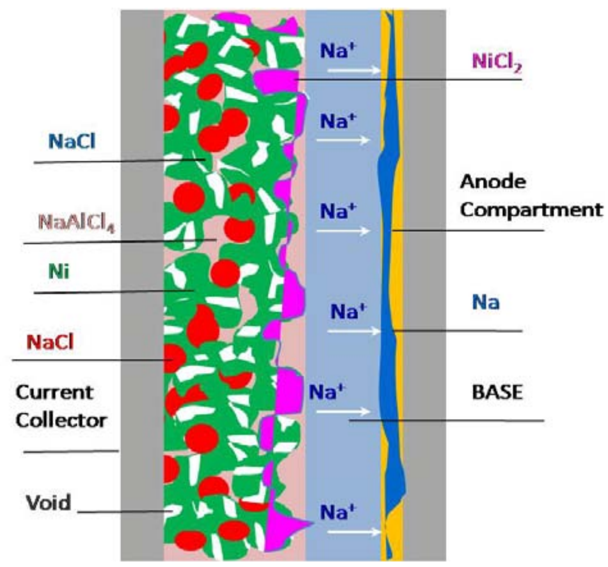
Challenges of NAB

- Na-S, concerned with safety and durability due to the violent Na-S reaction and corrosiveness of S
- NiCl/NaCl cathode (+$NaAlCl_4$) in ZEBRA, improving safety and reliability and making more tolerant to over-charge/discharge.



Schematic of Na-S cell structure during charging

- But further improvement in power and utilization of Ni
- Further reduction in capital cost and life cycle cost



Schematic of Na-metal halide Cell structure during charging

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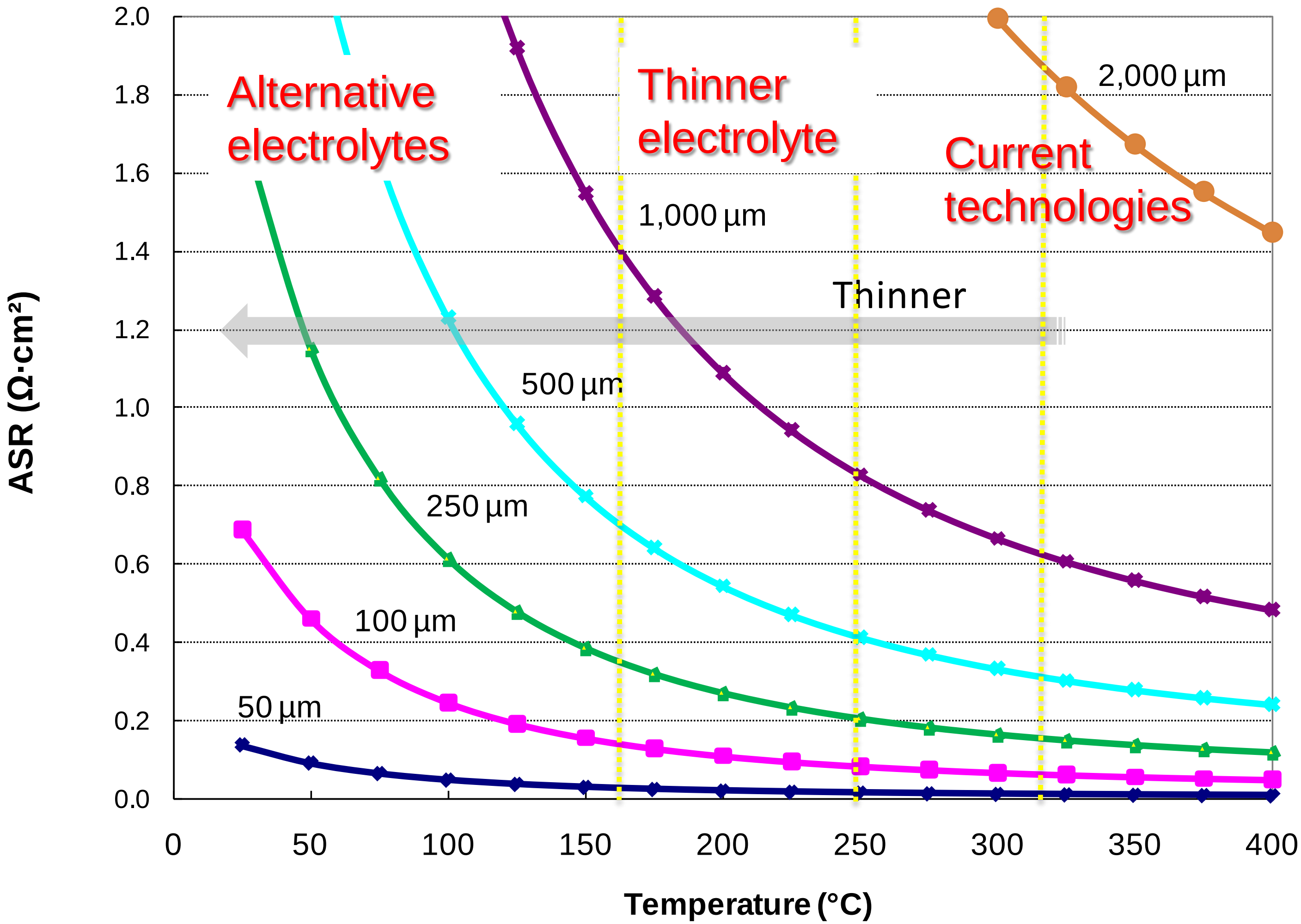
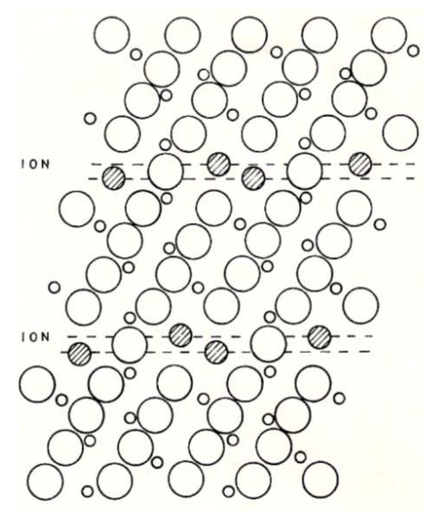
Reduction in operation °C

- Excellent conductivity, 0.3~0.5 s/cm, 300°C
- Thinner, concerning mechanical and structural stability and requiring chemistry changes

Area specific resistance of PNNL's solid electroyte for Na-halide batteries





β''-Al_2O_3

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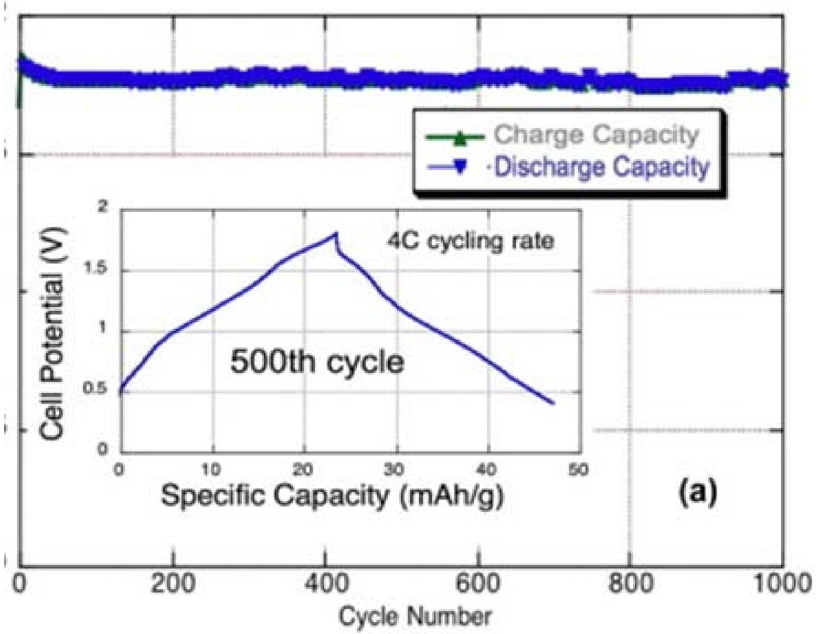
Low temperature Na-batteries

- ❑ Coors Tech (parent of Ceramatec) developed New Na-battery operated at lower temperatures
- ❑ Built upon Nasicon membrane
- ❑ Planar design
- ❑ Operated <98^{o}C

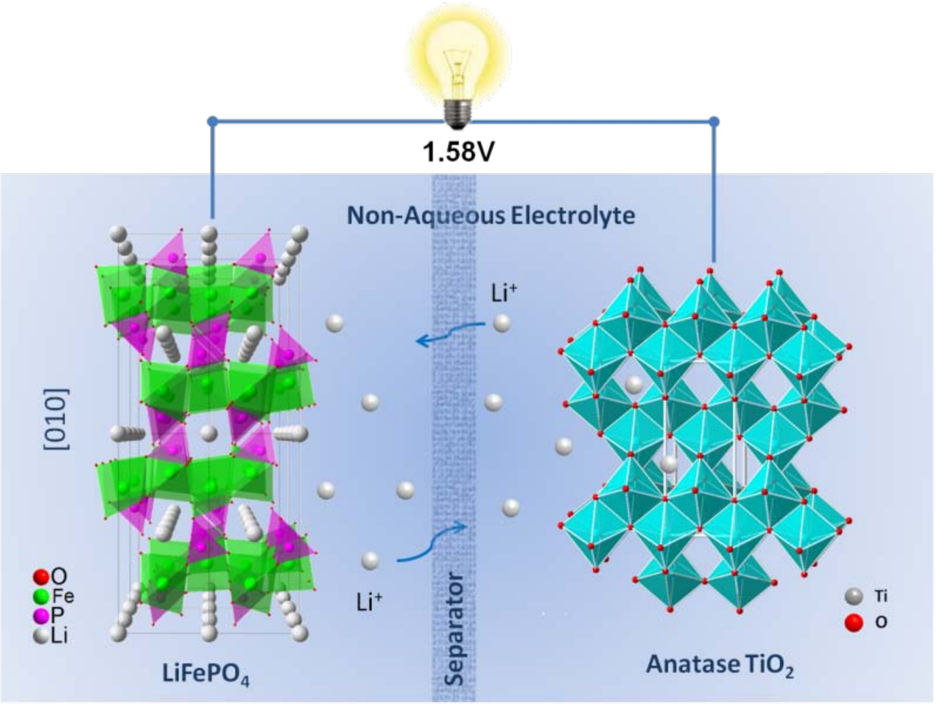
❑ Aquion Energy developing Na-ion battery using aqueous electrolyte

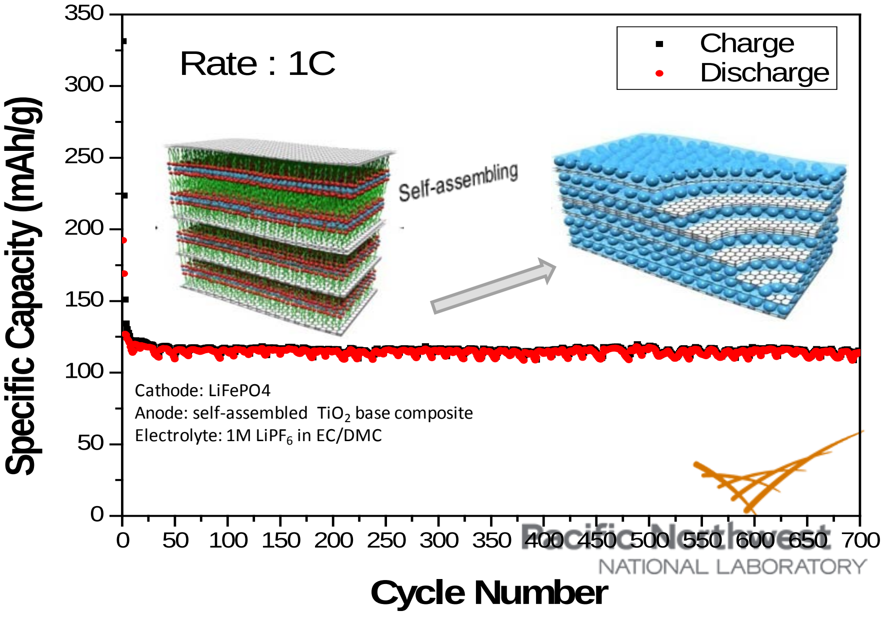
- Operated at RT
- Cathode: $Na_{0.44}MnO_2$
- Aqueous 1 M Na_2SO_4 electrolyte
- Activated carbon anode
- 1.7V, cycled over 1,000 deep cycles (up to 4C) without degradation



Li-ion for stationary applications

- Widely developed for vehicle applications
- High energy/power density; high efficiency (close to 100%)
- Up to MW levels are being demonstrated
- But cost >$1,000/kWh; concerns over, heat management, safety, …
- V2G?
- Long life, low cost Li-ion chemistries

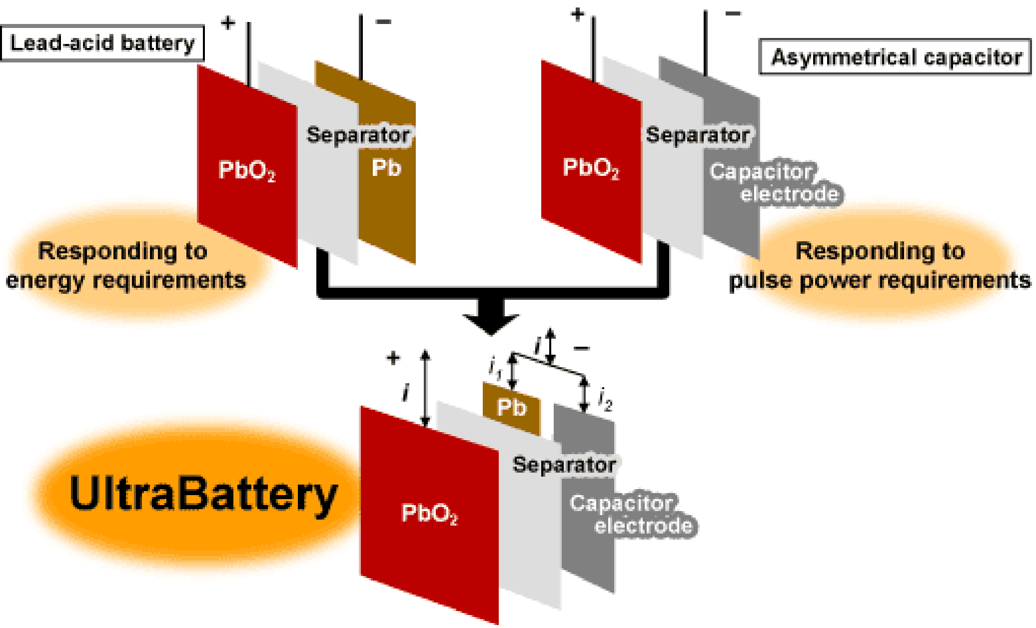




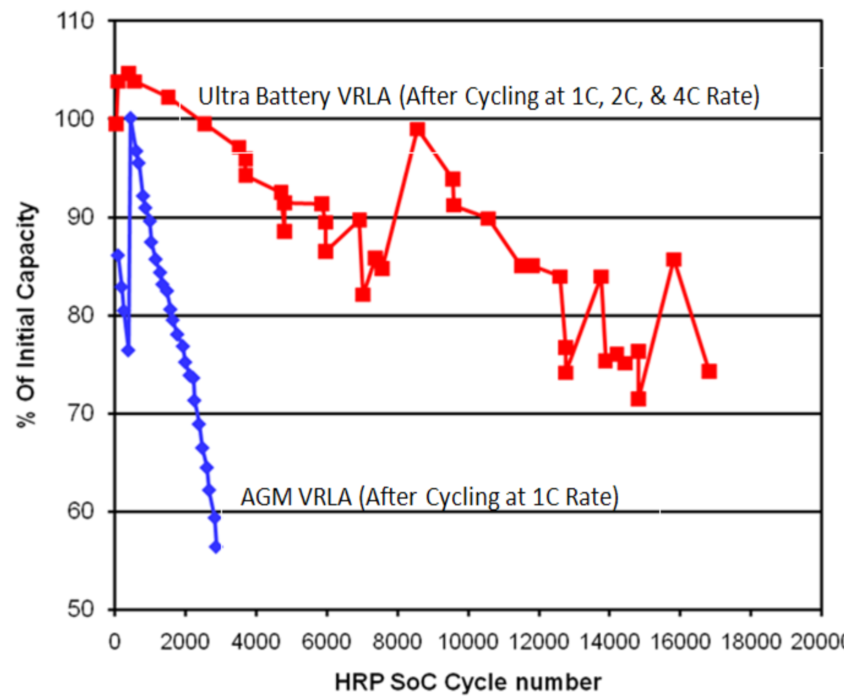
Lead-carbon battery-UltraBattery

- Asymmetric capacitor – hybrid of lead-acid and carbon ultra-capacitor
- Lead electrode in lead-acid replaced by carbon electrodes of capacitor
- Energy stored at anode by double layer and possible H^+ pseudo-capacitance
- Improved cycle life and power

- Demonstration and optimization
- Scientific understanding of carbon effects
- Cost reduction (higher than Pb-acid due to carbon electrodes)



Courtesy The Furukawa Battery Co.



Courtesy SNL

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Emerging technologies

- Invented during 1970's energy crisis, flow batteries, Na-beta batteries, etc.
- Developed in the past two decades, Li-ion, lead-carbon, etc.
- New technologies require efforts from science to technology
  - o Molten metal large scale battery
  - o Zn-MnO_x flow battery
  - o Soluble lead flow battery
  - o Solid state Li-ion battery
  - o …

  } ARPA-E

- "Ultimate" technologies: high energy/power, long life, low cost, safe, scalable, …, addressing the needs of both stationary and mobile?

Conclusion remarks

- There has been increasing awareness on the needs of grid storage
- Government funding plays important roles to advance related science and technologies
- Participation of industries is critical to commercialization and market penetration
- A new around of world-wide competition in grid storage is ongoing
- Invented in the US, but commercialized elsewhere?