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Automotive Li-ion Battery Cooling Requirements

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Energy Storage R&D: FY 2012

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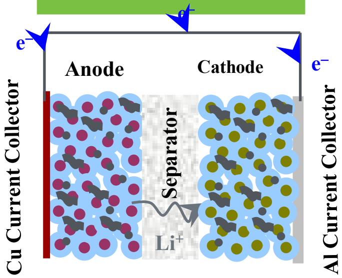
CHARTER: Develop battery technology that will enable large market penetration of electric drive vehicles.

- By *2014*, develop a PHEV battery that can deliver a 40-mile all-electric range and costs $3,400
- By *2020*, develop an EV battery that can store 40 kWh of electricity and costs $5,000

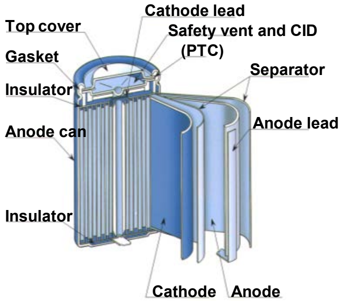
Energy Storage R&D
$81.8 M

Exploratory Technology Research
$22.2 M



New Materials R&D, Diagnostics, Modeling

Applied Battery Research for Transportation
$11.3 M



Next Generation Cell R&D

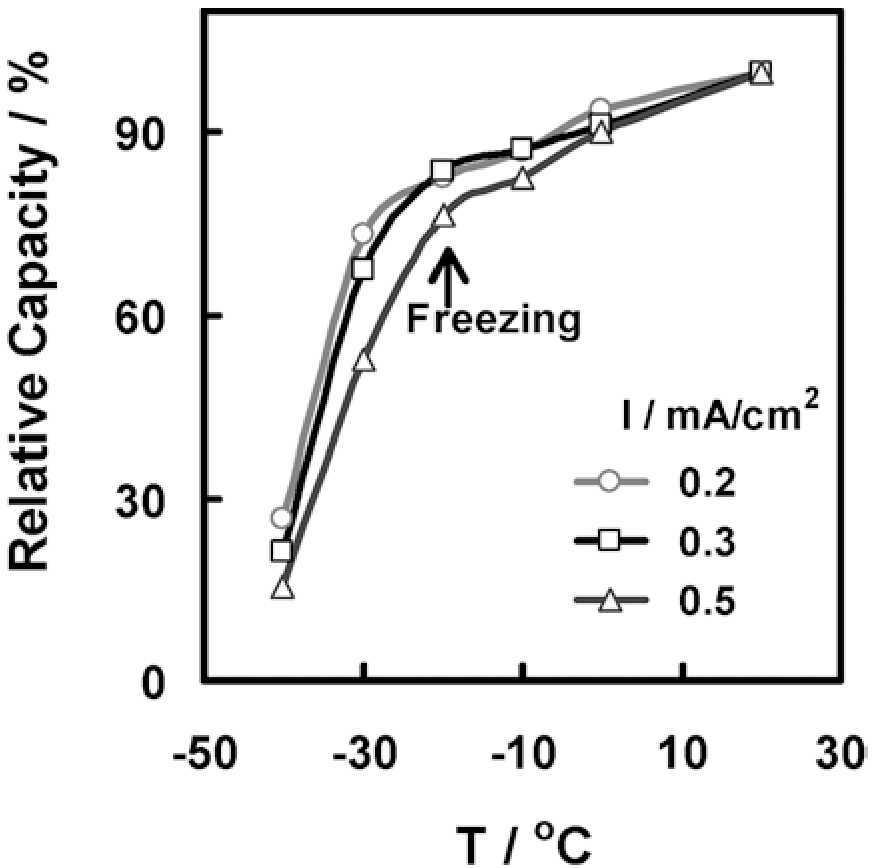
Battery Development
$35.3 M

Battery Development & Cost Reduction

Battery Testing, Analysis & Design
$13 M

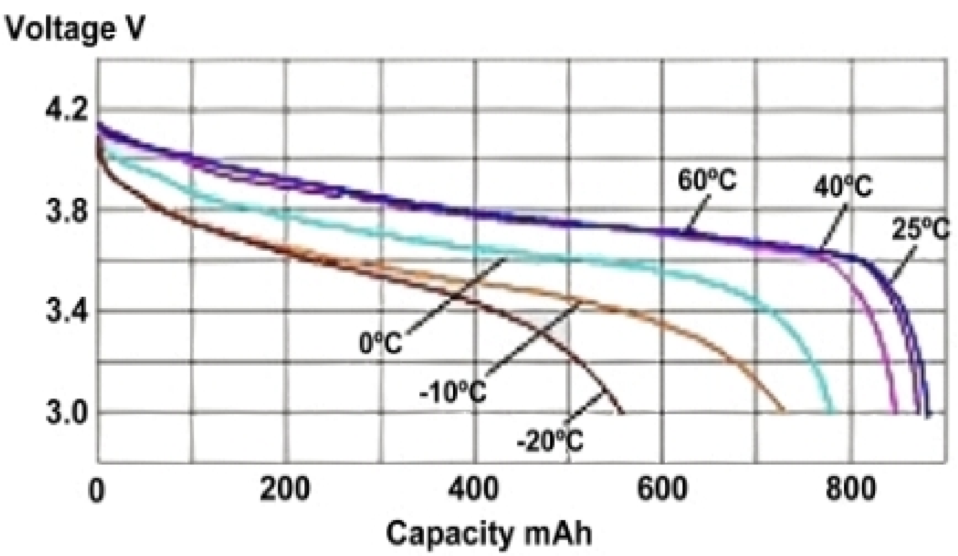
Standardized Testing Life/Cost Projections Design Tools

Li- Ion Battery Capacity Decreases with Temperature

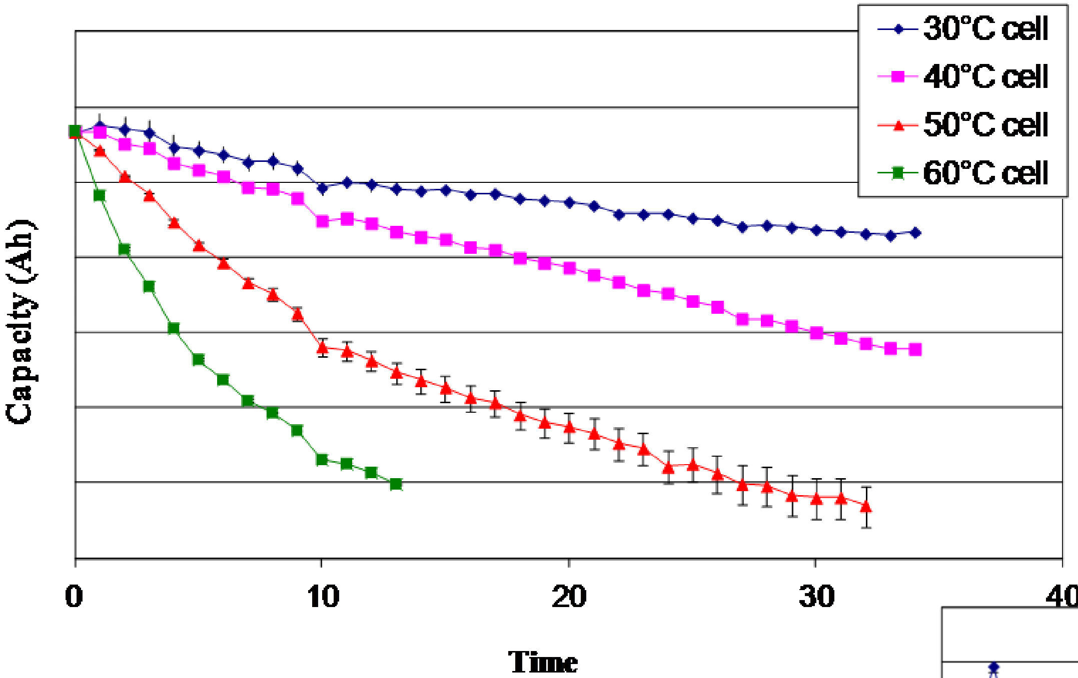


Useful energy from the battery decreases with decrease in temperature

Impacts driving range and performance of vehicle

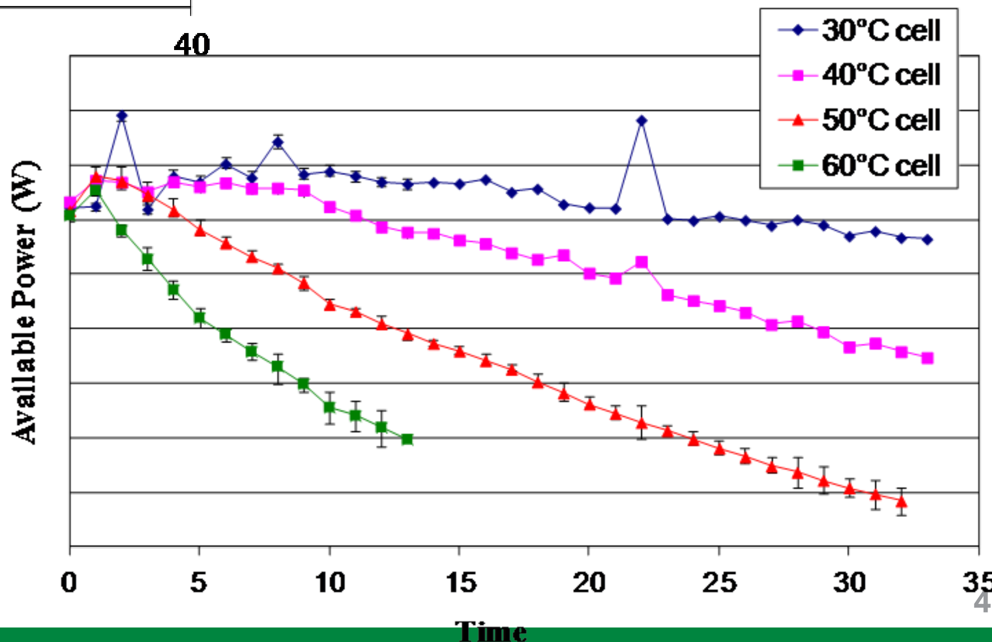


Battery Degrades Faster at Higher Temperatures: Calendar Fade

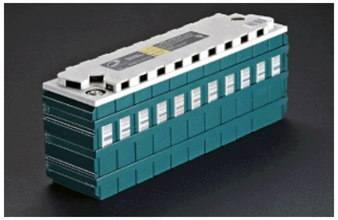


Over time, useful energy from the battery decreases with exposure to elevated temperatures

Impacts driving range and performance of vehicle

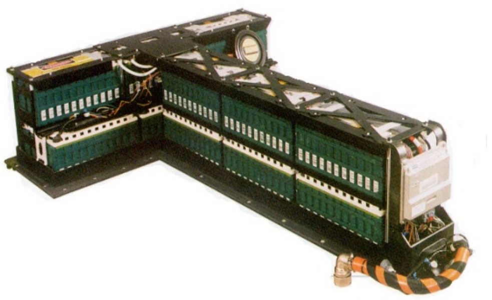


Battery Temperature is Important



Temperature affects battery:

- **Operation of the electrochemical system**
- **Round trip efficiency**
- **Charge acceptance**
- **Power and energy availability**
- **Safety and reliability**
- **Calendar life and life cycle cost**



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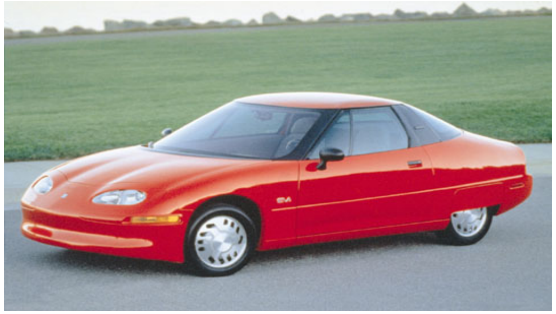
Battery temperature affects vehicle performance, reliability, safety, and life cycle <u>cost</u>



Battery Pack Thermal Management Is Needed

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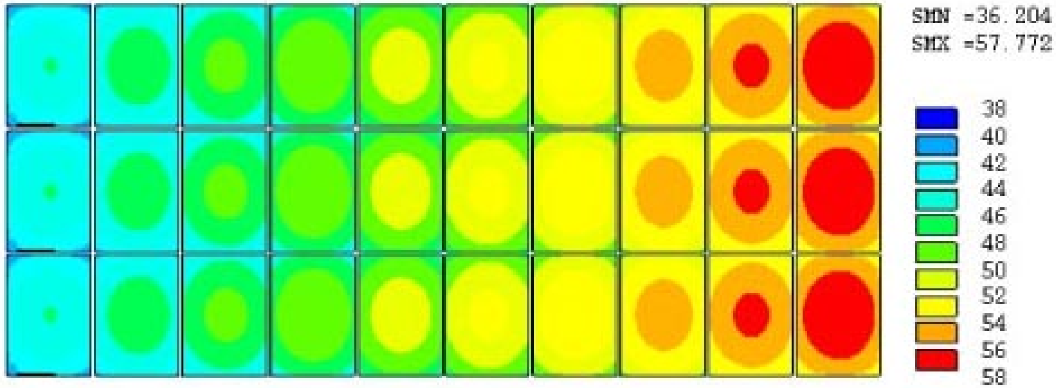
- **Regulate pack to operate in the desired temperature range for optimum performance/life**
  - **20-35° C**



- **Reduce uneven temperature distribution in a pack to avoid unbalanced electrical modules/pack and thus avoid reduced performance**
  - **Less than 3-4° C**
- **Eliminate potential hazards related to uncontrolled temperatures – thermal runaway**

Life Trade Off Analysis

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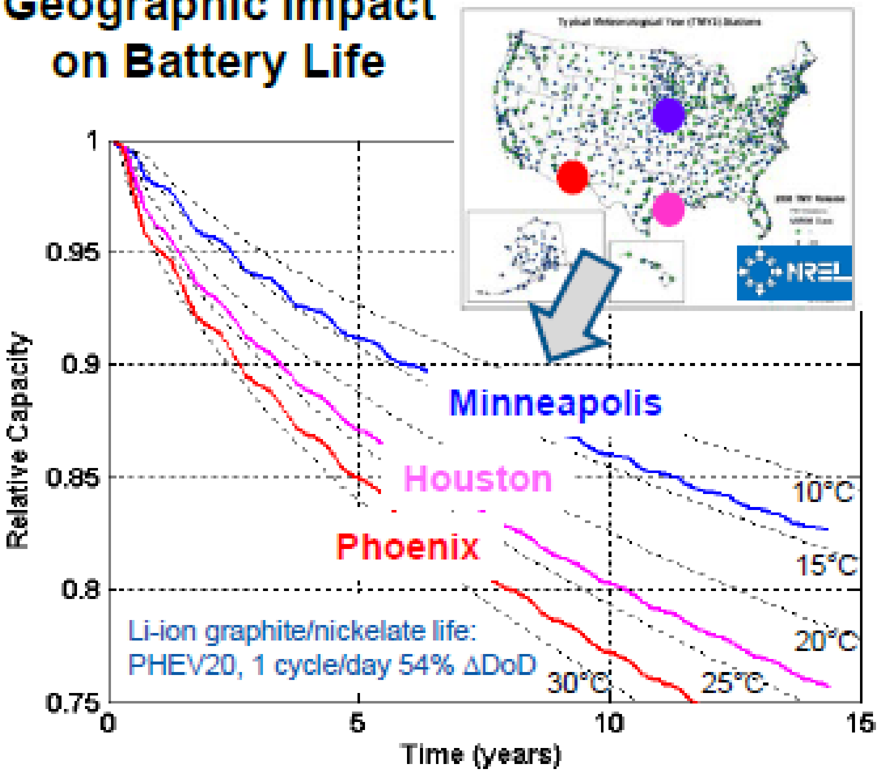
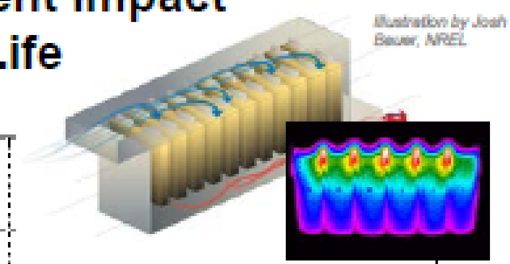
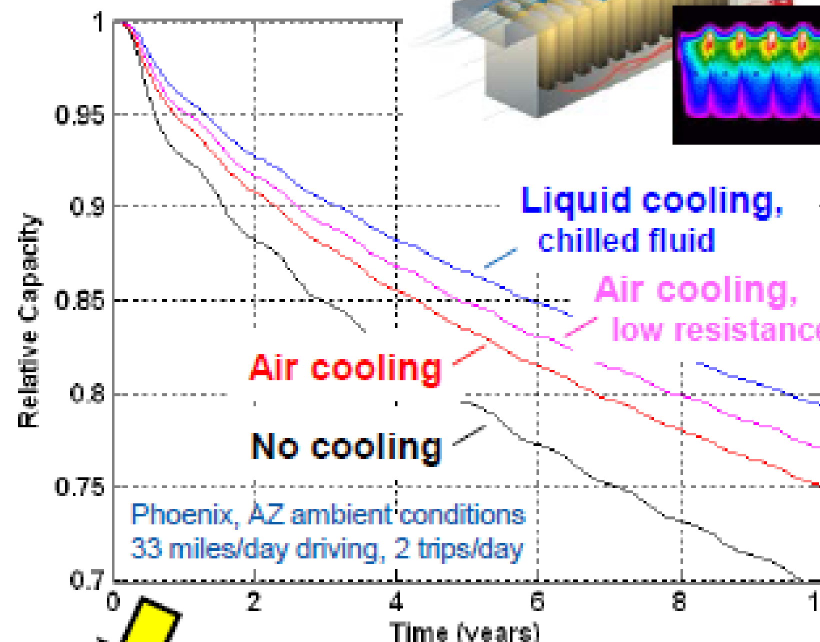
Life expectation in various thermal environments

Geographic Impact on Battery Life



Thermal Management Impact on Battery Life





Compared with no cooling, the liquid-cooled battery can use 12% fewer cells and still achieve a 10-year life in Phoenix. Air cooling using low-resistance cells also seems appealing from a thermal / life perspective; however, this battery has the highest cell costs of the four options shown due to the cost of its high excess power.

Thermal Management Requirements for EV

- EV-100 with 24 kWh energy and 100 kW peak power
- Average efficiency of battery pack at most demanding drive cycle: 95%
- Average power draw for most demanding drive cycle: 40 kW
- Average heat loss in the pack: 40kW*0.05= 2.0 kW
- Energy density of cells 150Wh/kg : battery mass: 24kWh/0.15kWh = 160 kg
- Temp rise/Sec: Q/m Cp = 2000/160/900 = 0.0139 °C/Sec
- Adiabatic T rise In 10 minutes = 8.33 °C
- Need 1-2 kW cooling systems for peak
- Heat transfer rejection rate needed: 10-100 $W/m^2/°C$

Battery Heat capacity= 900 J/kg/C