Electric Vehicle Battery Thermal Issues and Thermal Management Techniques

John P. Rugh, NREL

Ahmad Pesaran, NREL

Kandler Smith, NREL

NREL/PR-5400-52818

Presented at the

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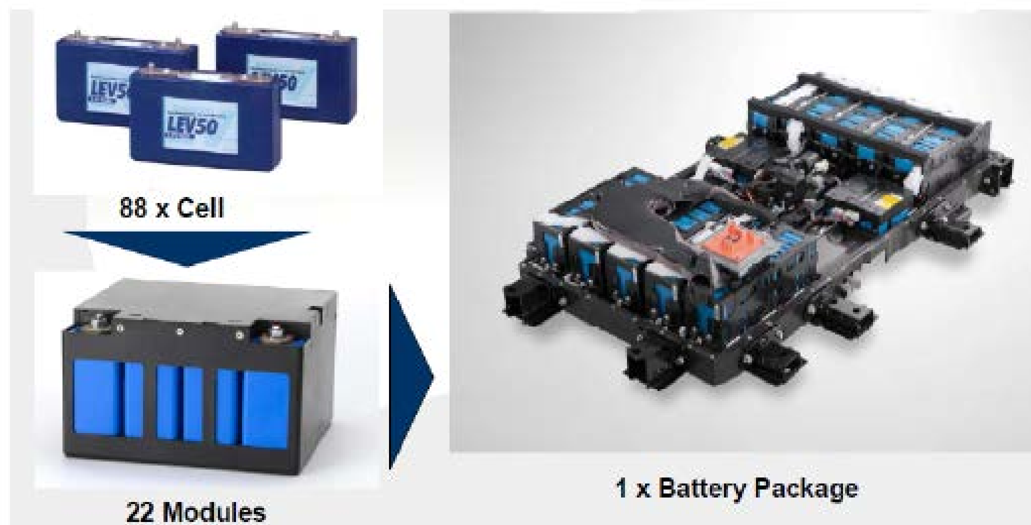
Outline

- Introduction
- Importance of battery temperature
- Review of electric drive vehicle (EDV) battery thermal management options
- Techniques to improve battery life
  - Standby thermal management
  - Preconditioning
- Tradeoff with thermal comfort
- Summary

Battery is The Critical Technology for EDVs

- ✓ Enables hybridization and electrification
- ✓ Provides power to motor for acceleration
- ✓ Provides energy for electric range and other auxiliaries
- ✓ Helps downsizing or eliminating the engine
- ✓ Enables regenerative braking
- × Adds cost, weight, and volume
- × Could decrease reliability and durability
- × Decreased performance with aging
- × Raises safety concerns



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Lithium-ion battery cells, module, and battery pack for the Mitsubishi iMiEV (Courtesy of Mitsubishi)

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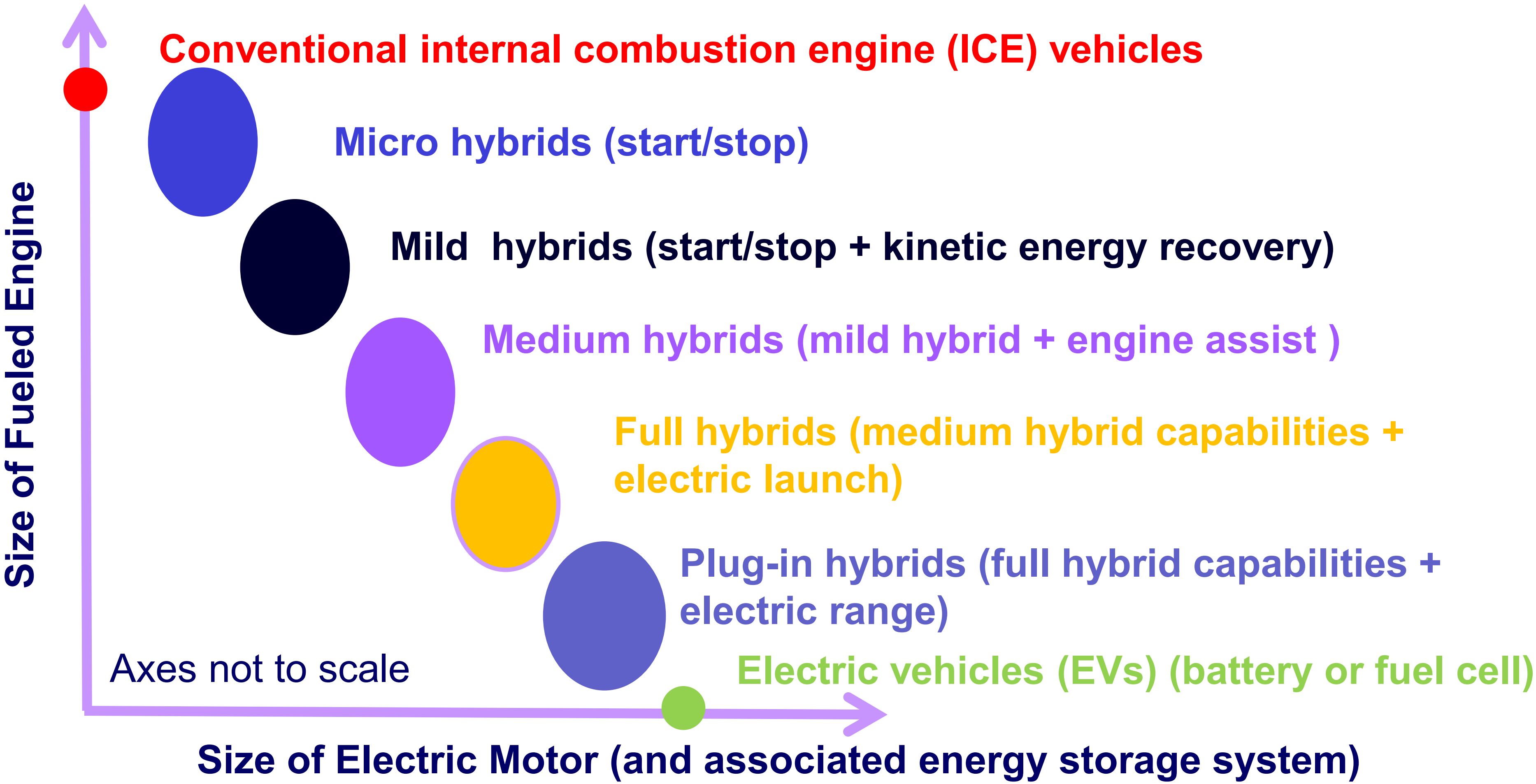
As The Size of The Engine Is Reduced, The Battery Size Increases



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Battery Requirements for Different EDVs

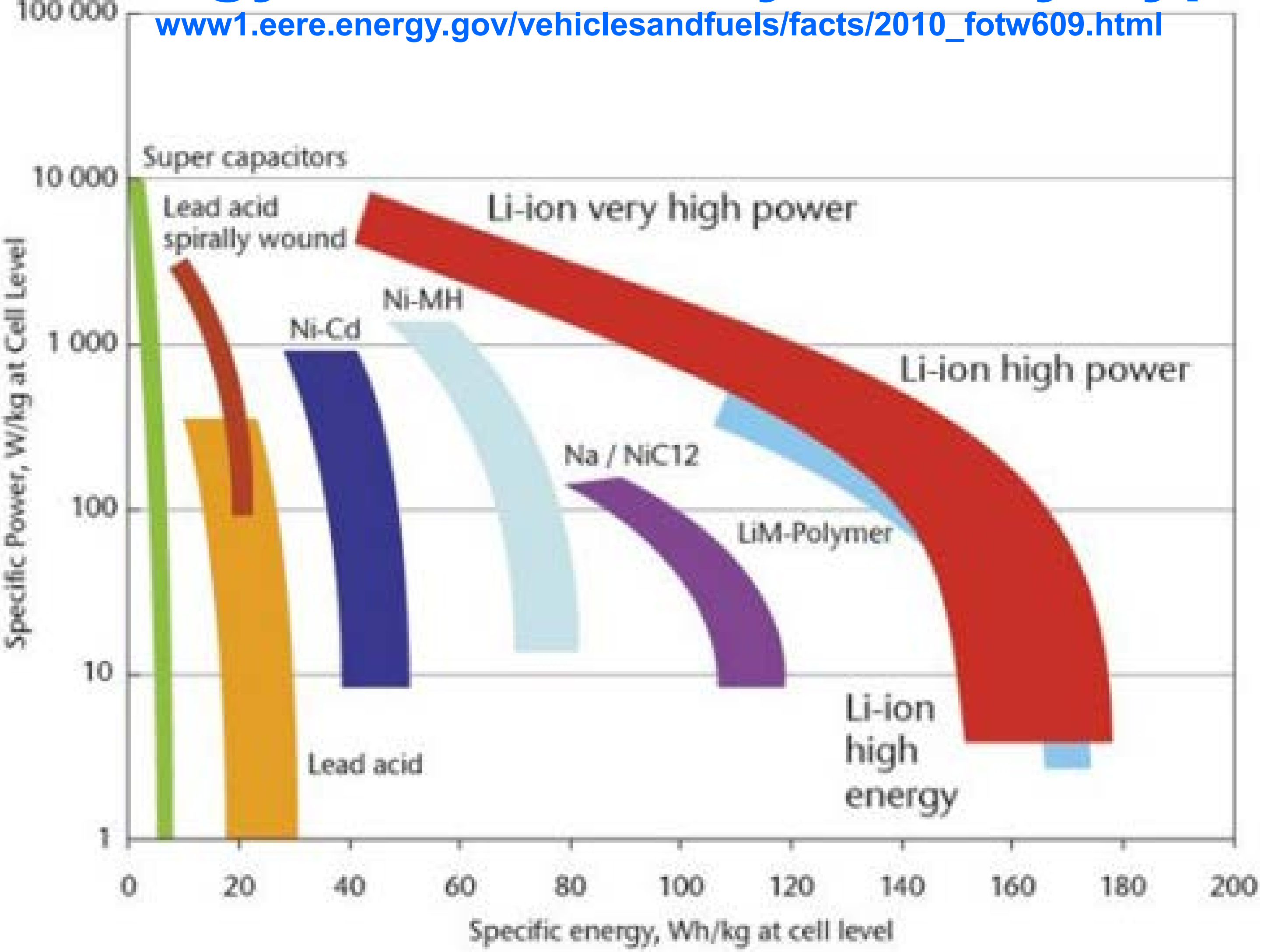
Vehicle	Power (kW)	Energy (kW/h)	Cycles
Micro and Mild Hybrid Electric Vehicles (HEVs)	Very high power	Low energy	Many (400K) shallow charge/discharge cycles (±5% change)
Medium and Full HEVs	High power	Moderate energy	Many (300K) shallow charge/discharge cycles (±10% change)
Plug-in HEVs (PHEVs)	High power	High energy	Many (200K) shallow charge/discharge cycles (±5% change) Many (3-5K)deep discharge cycles (50% change)
Battery EVs	Moderate power	Very high energy	Many (3-5K) deep discharges (70% change)

Calendar life of 10+ years

Safety: the same as ICE vehicles

Energy and Power by Battery Type

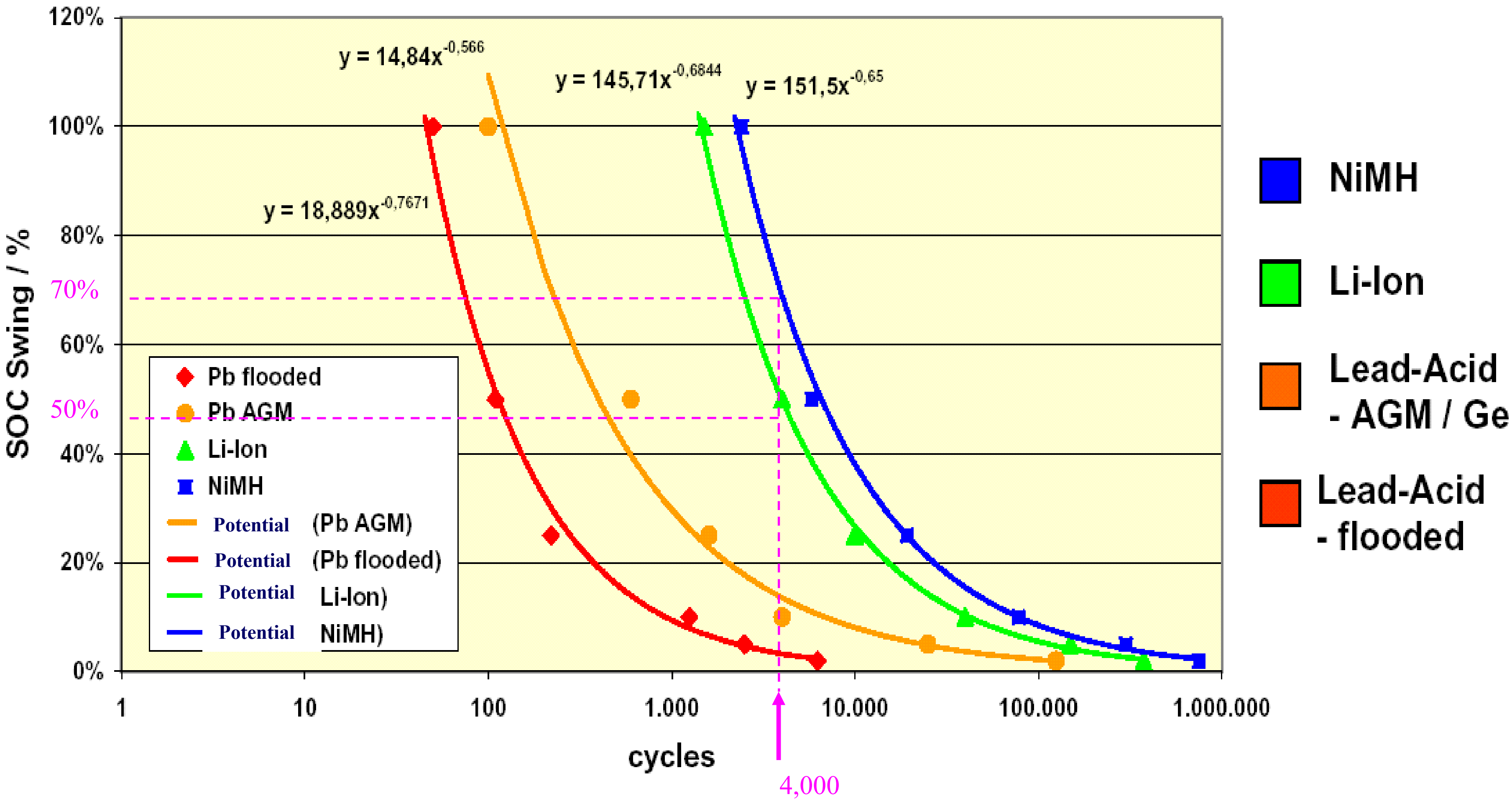
www1.eere.energy.gov/vehiclesandfuels/facts/2010_fotw609.html



Lithium ion technology comes close to meeting most of the required technical and cost targets in the next 10 years.

Battery Cycle Life Depends on State-of-Charge Swing

- PHEV battery likely to deep-cycle each day driven: 15 yrs equates to 4,000–5,000 deep cycles



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Source: Christian Rosenkranz (Johnson Controls) at EVS 20, Long Beach, CA, November 15-19, 2003

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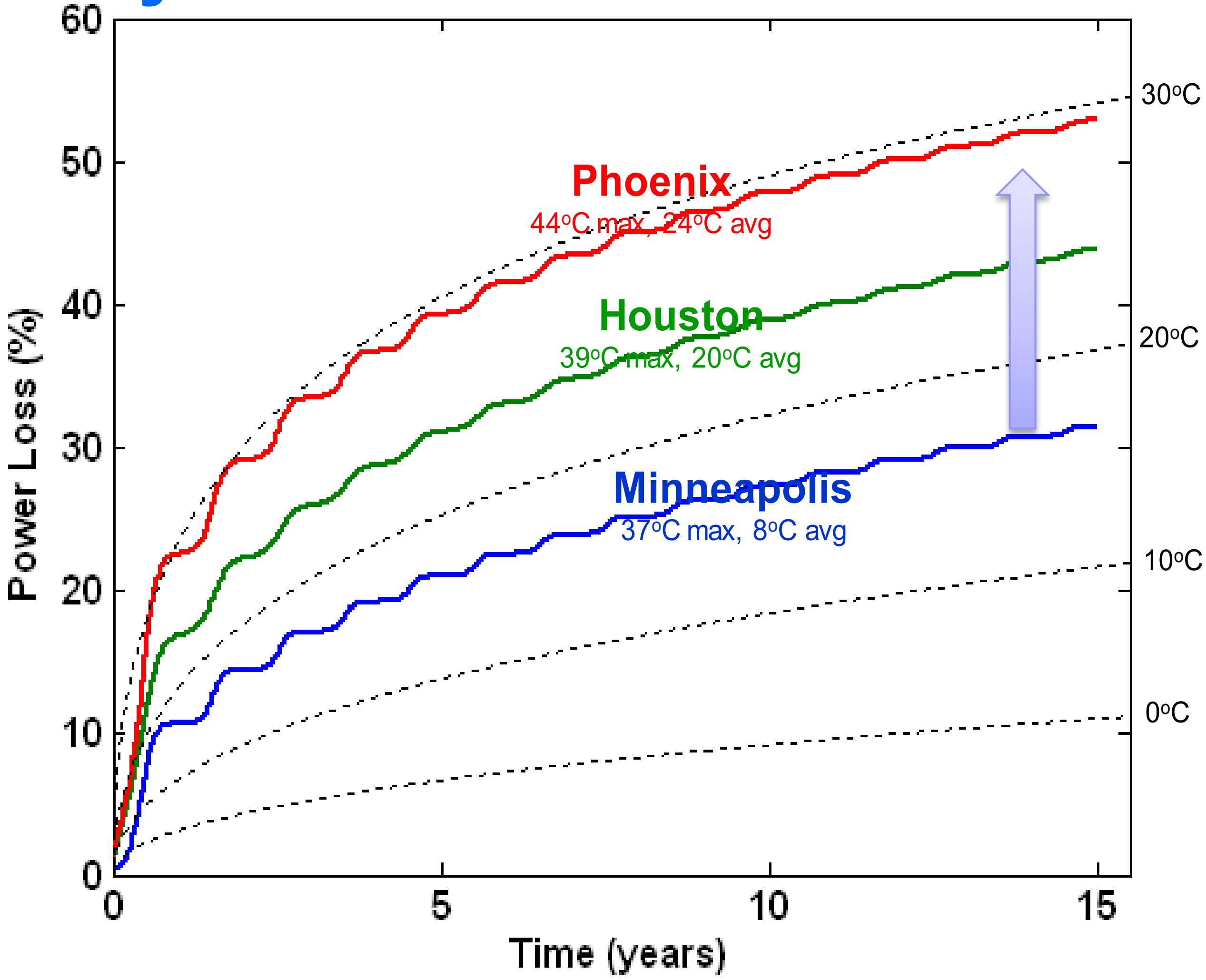
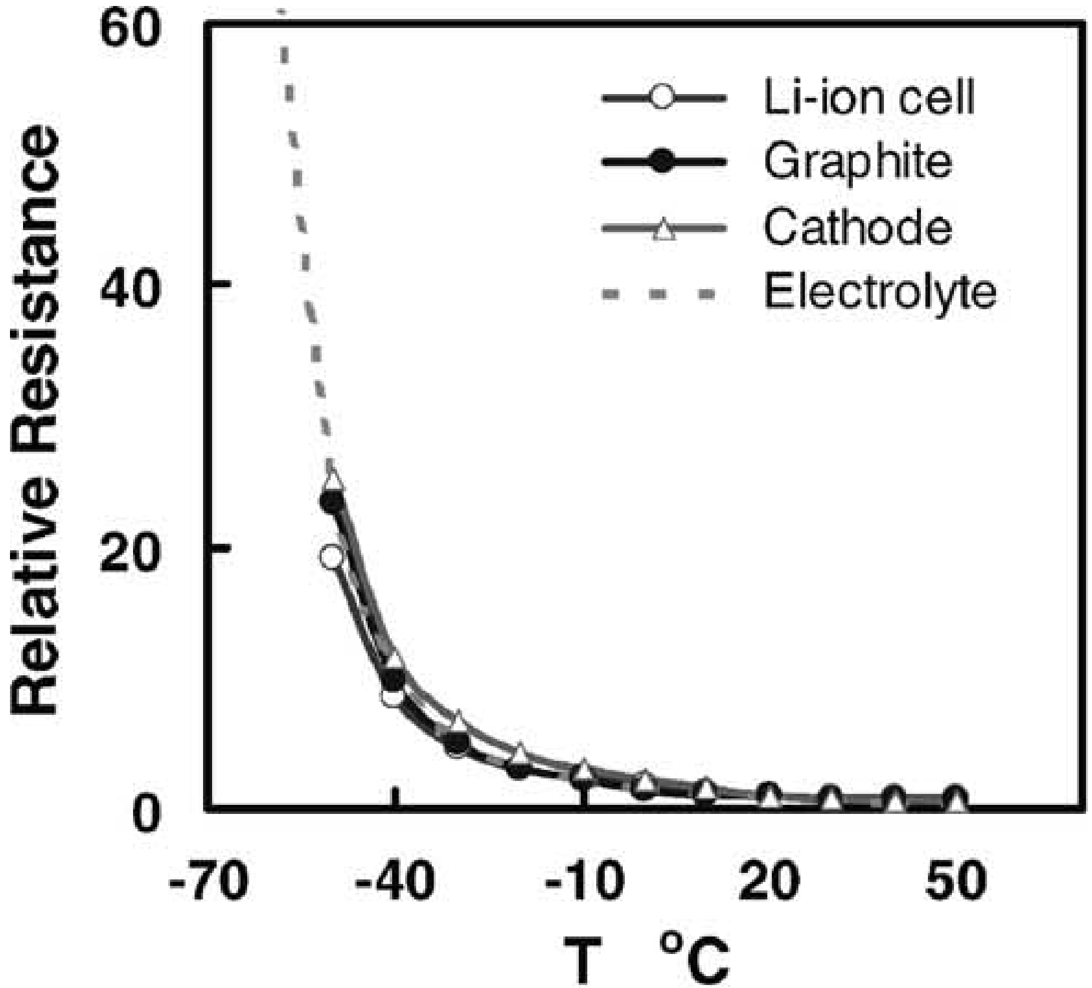
Impact of Geography and Temperature on Battery Life



Li-ion technology must be sized with significant excess power to last 15 years in hot climates

Li-Ion Battery Resistance Increases with Decreasing Temperature



- Power decreases with decrease in temperature
- Impacts power capability of motor and vehicle acceleration

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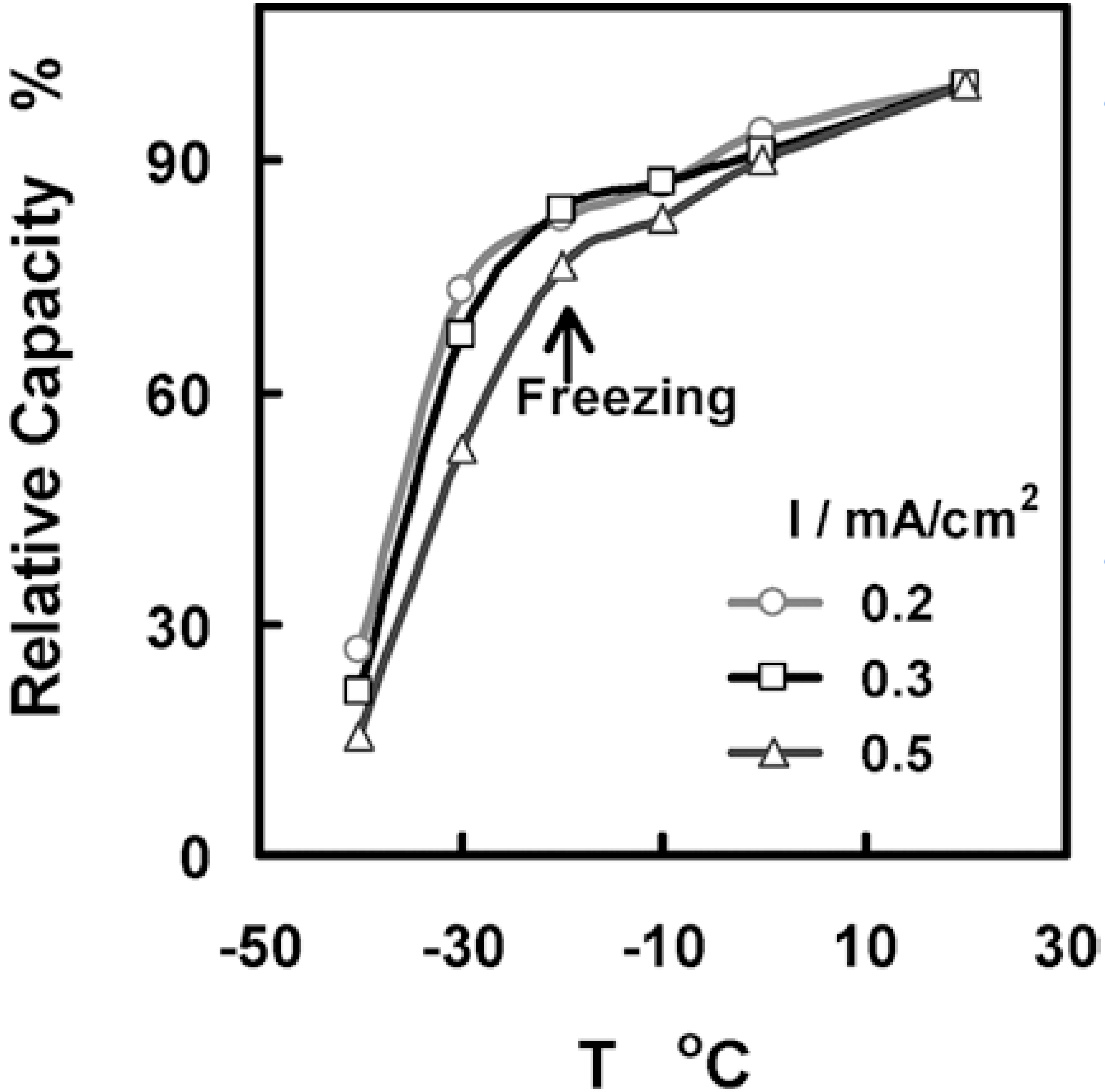
Li-Ion Battery Capacity Decreases with Decreasing Temperature

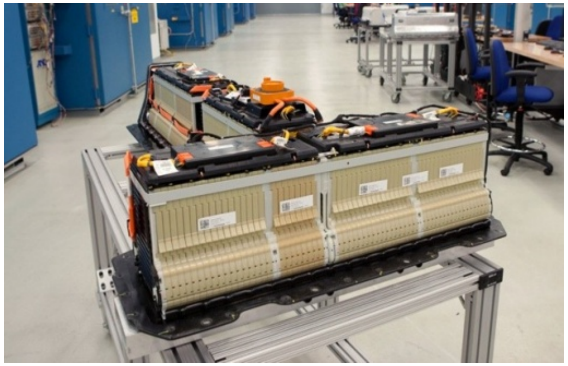


- Useful energy from the battery decreases with decrease in temperature
- Impacts driving range and performance of vehicle

Battery Temperature is Important

Temperature affects battery:

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



Battery temperature affects vehicle performance, reliability, safety, and life-cycle cost

http://autogreenmag.com/tag/chevroletvolt/page/2/

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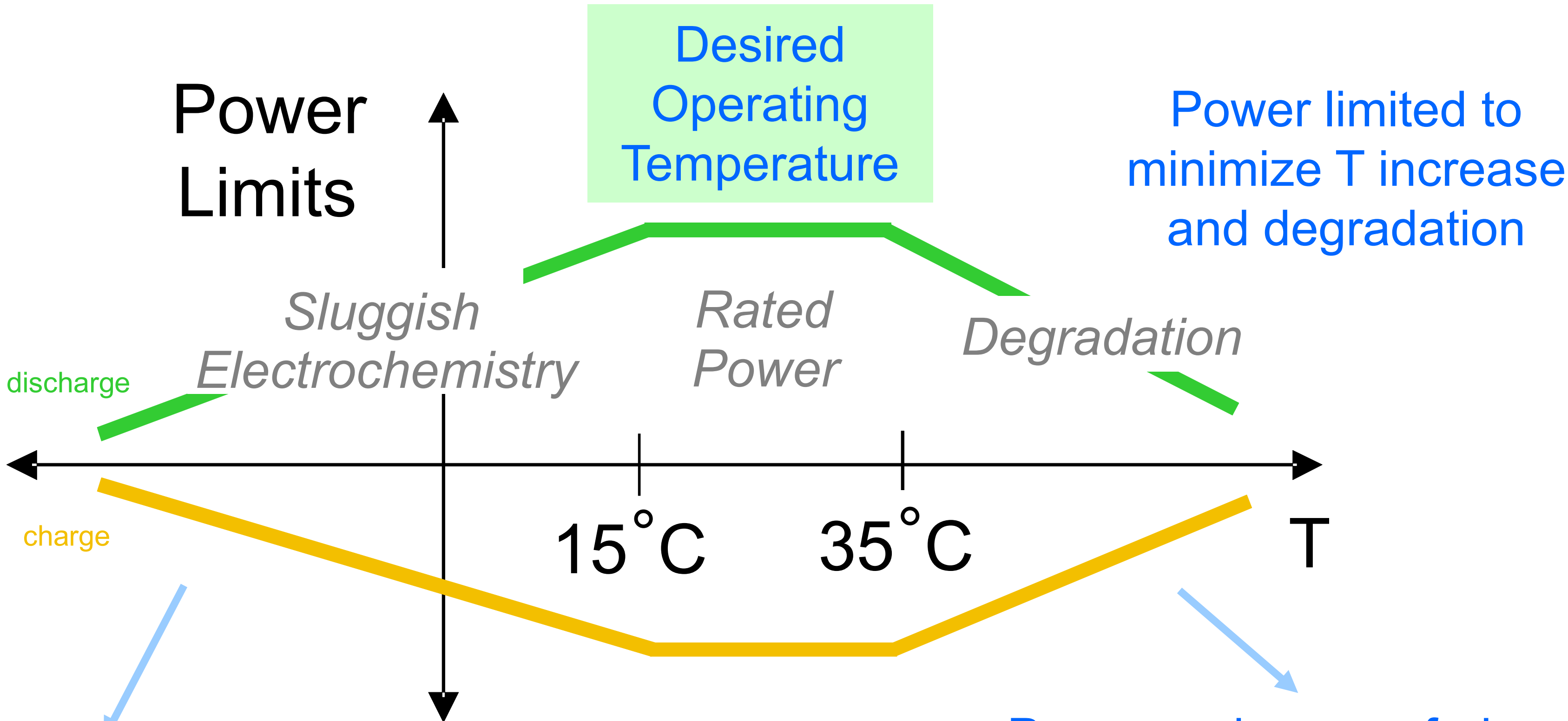
Temperature Impacts Battery Sizing & Life and Thus Cost



Dictates power capability

Also limits the electric driving range

Power and energy fade rates determine the original battery size

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Kandler Smith, NREL Milestone Report, 2008

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Battery High-Temperature Summary

Photo Credit: John Rugh, NREL

- Primary considerations
  - Life
  - Safety
  - Non-uniform aging due to thermal gradients
- Cooling typically required
  - In hot environments (could be 24 hr)
  - During moderate to large current demands during drive
  - During fast charging

Battery Low-Temperature Summary

- Primary considerations
  - Performance
  - Damage due to charging too fast
- Heating typically required
  - In cold environments during charging and discharging

Photo Credit: Mike Simpson, NREL

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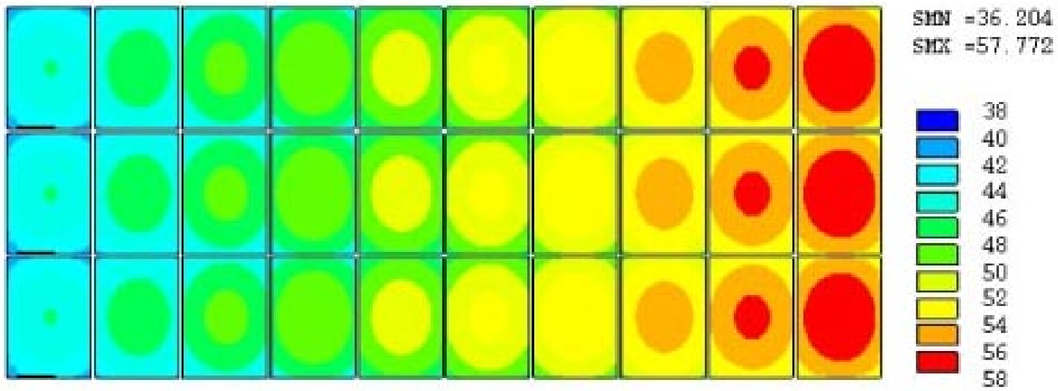
Battery Pack Thermal Management Is Needed

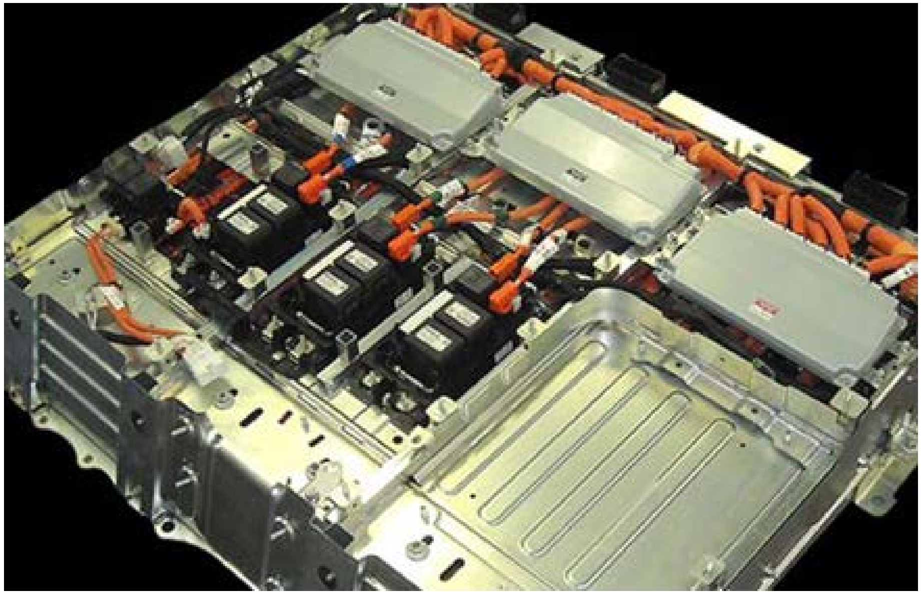
- Regulate pack to operate in the desired temperature range for optimum performance/life
  - 15^{o}C – 35^{o}C



- Reduce uneven temperature distribution
  - Less than 3^{o}C – 4^{o}C
- Eliminate potential hazards related to uncontrolled temperatures – thermal runaway

Battery Thermal Management System Requirements

- Compact
- Lightweight
- Easily packaged
- Reliable
- Serviceable
- Low-cost
- Low parasitic power
- Optimum temperature range
- Small temperature variation



http://www.toyota.com/esq/articles/2010/Lithium_Ion_Battery.html

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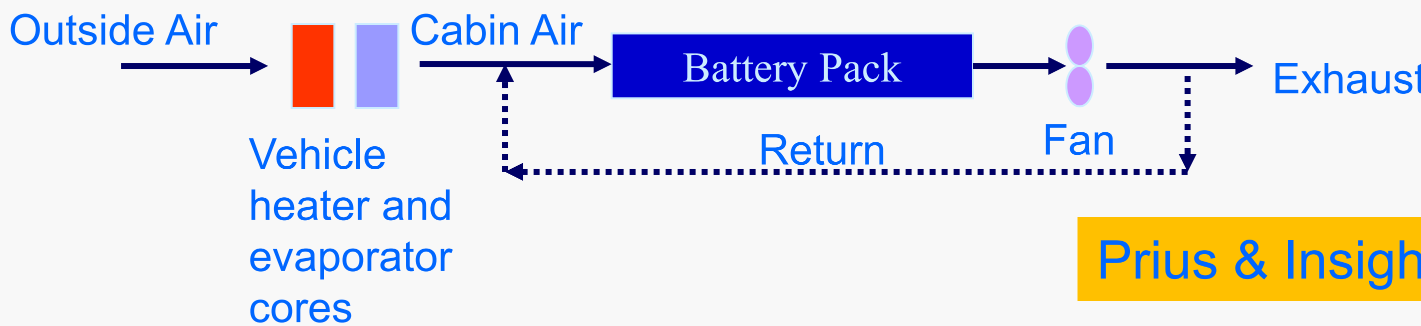
Thermal Control Using Air

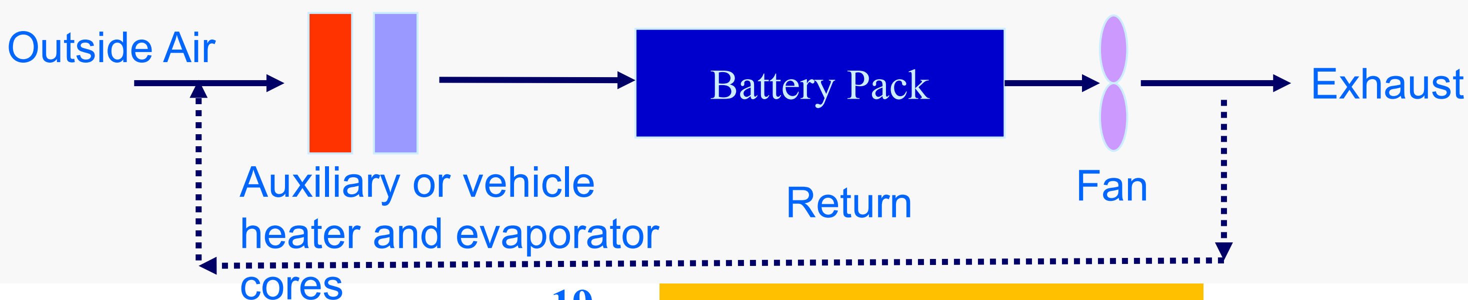
Outside Air Ventilation

Cabin Air Ventilation



Prius & Insight

Heating/cooling of Air to Battery – Outside or Cabin Air



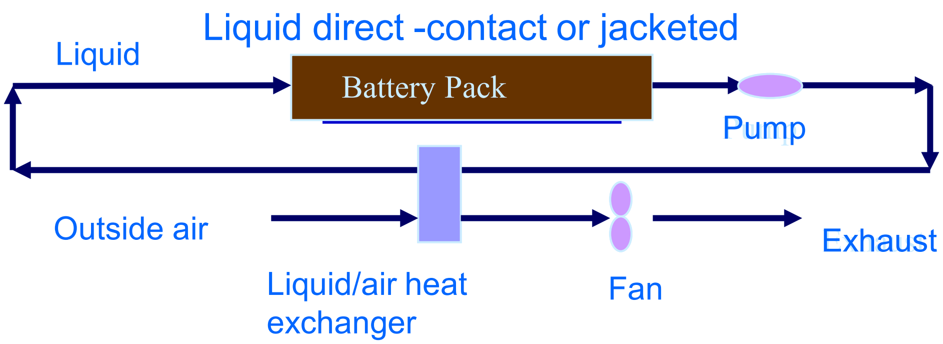
i-MiEV (fast charge)

Battery Heating and Cooling Using Air

Pro	Con
All waste heat eventually has to go to air	Low heat transport capacity
Separate cooling loop not required	More temperature variation in pack
Low mass of air and distribution system	Connected to cabin temperature control
No leakage concern	Potential of venting battery gas into cabin
No electrical short due to fluid concern	High blower power
Simple design	Blower noise
Lower cost	
Easier maintenance	

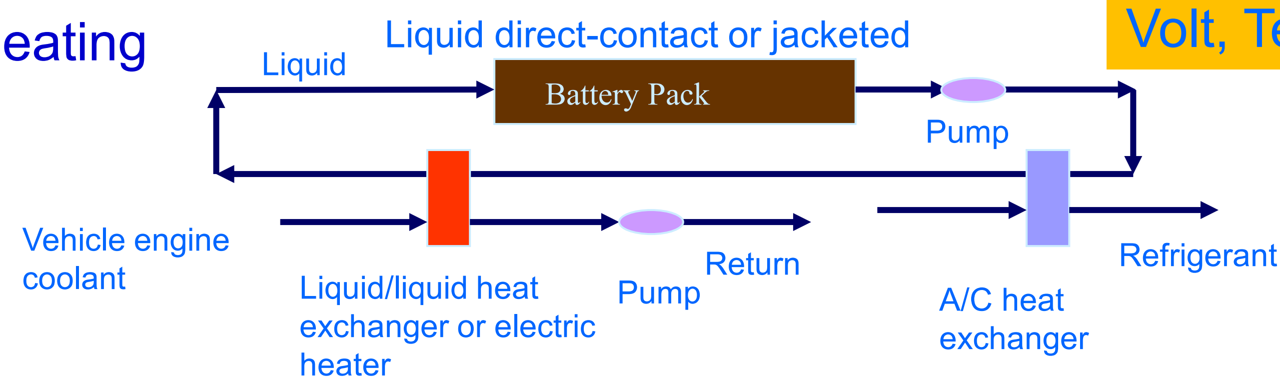
Thermal Control Using Liquid

Ambient cooling



Active dedicated cooling/heating

Volt, Tesla



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Battery Heating and Cooling Using Liquid

Pro	Con
Pack temperature is more uniform - thermally stable	Additional components
Good heat transport capacity	Weight
Better thermal control	Liquid conductivity – electrical isolation
Lower pumping power	Leakage potential
Lower volume, compact design	Higher maintenance
	Higher viscosity at cold temperatures
	Higher cost

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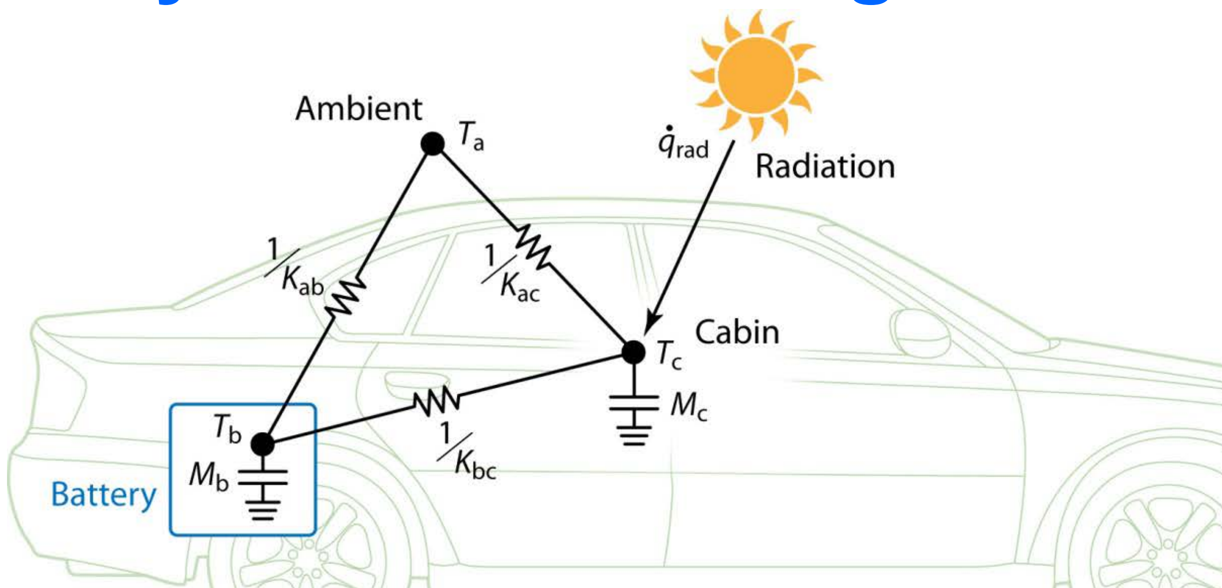
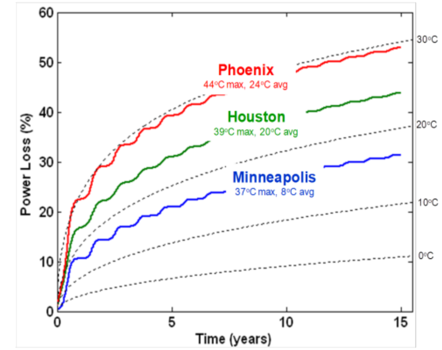
Standby Thermal Cooling in Hot Climates





- Battery life can greatly benefit from cooling the battery during standby, i.e., while vehicle is plugged in to the grid
- Slower battery degradation rate enables smaller, lower cost battery
- NREL study investigated
  - Insulation
  - Insulation and air cooling
  - Insulation and small vapor compression system (VC)
  - Insulation, small VC system, and phase change material (PCM)

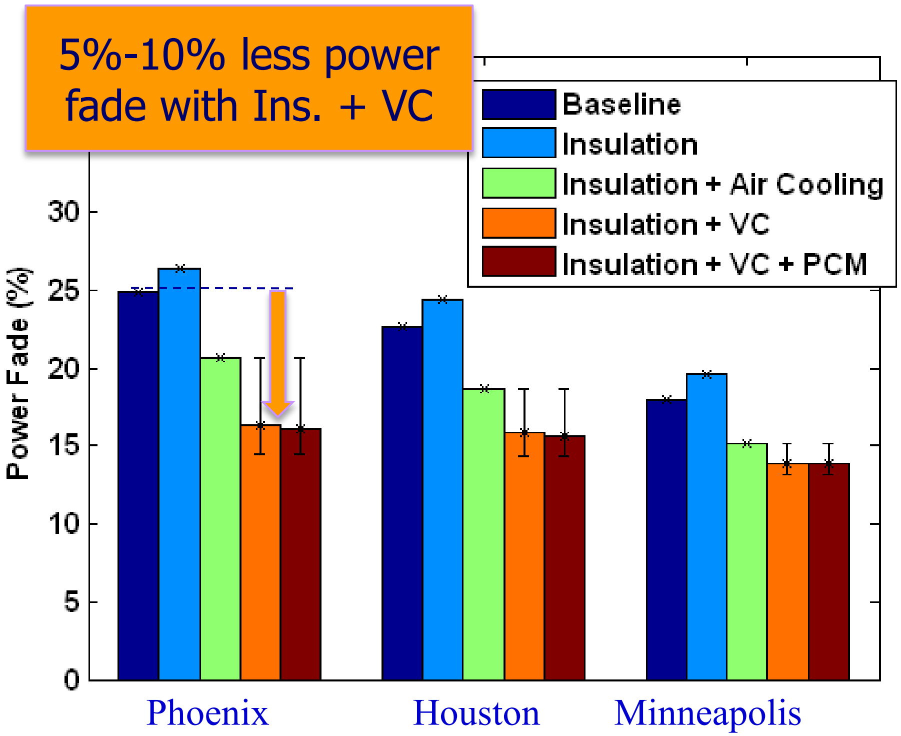
Battery Life for Various Standby Systems

can differ widely depending on cell chemistry, materials, and manufacturer

Saft HP-12LC Cell

(Belt/INL, ECS Mtg. 2008)

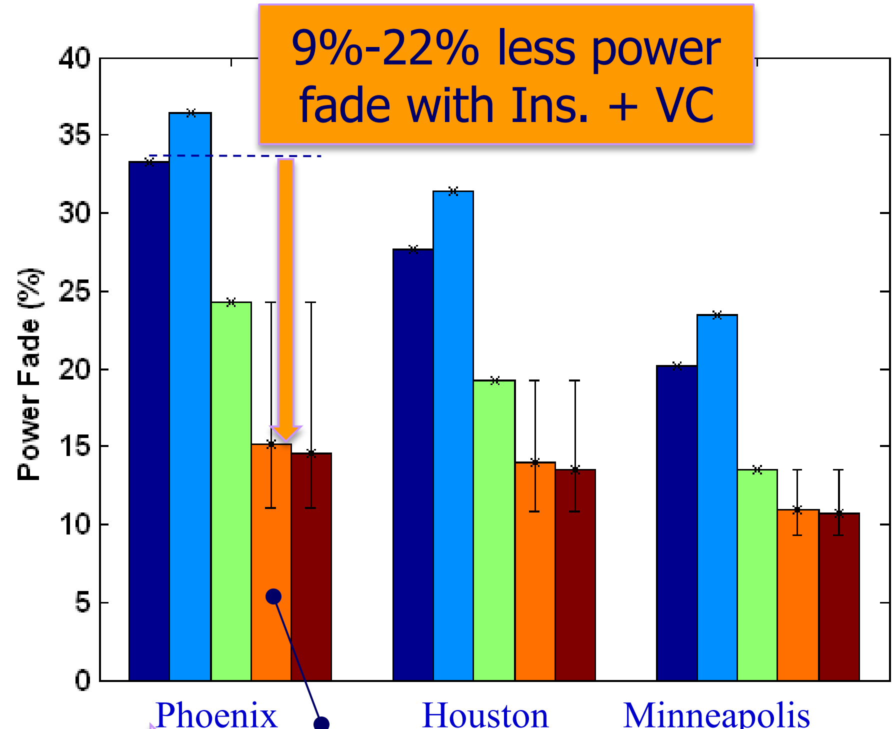
- low fade rate, high cost



DOE/TLVT Cell

(Christopersen/INL, Battaglia/LBL, 2007 Merit Review)

- moderate fade rate, lower cost

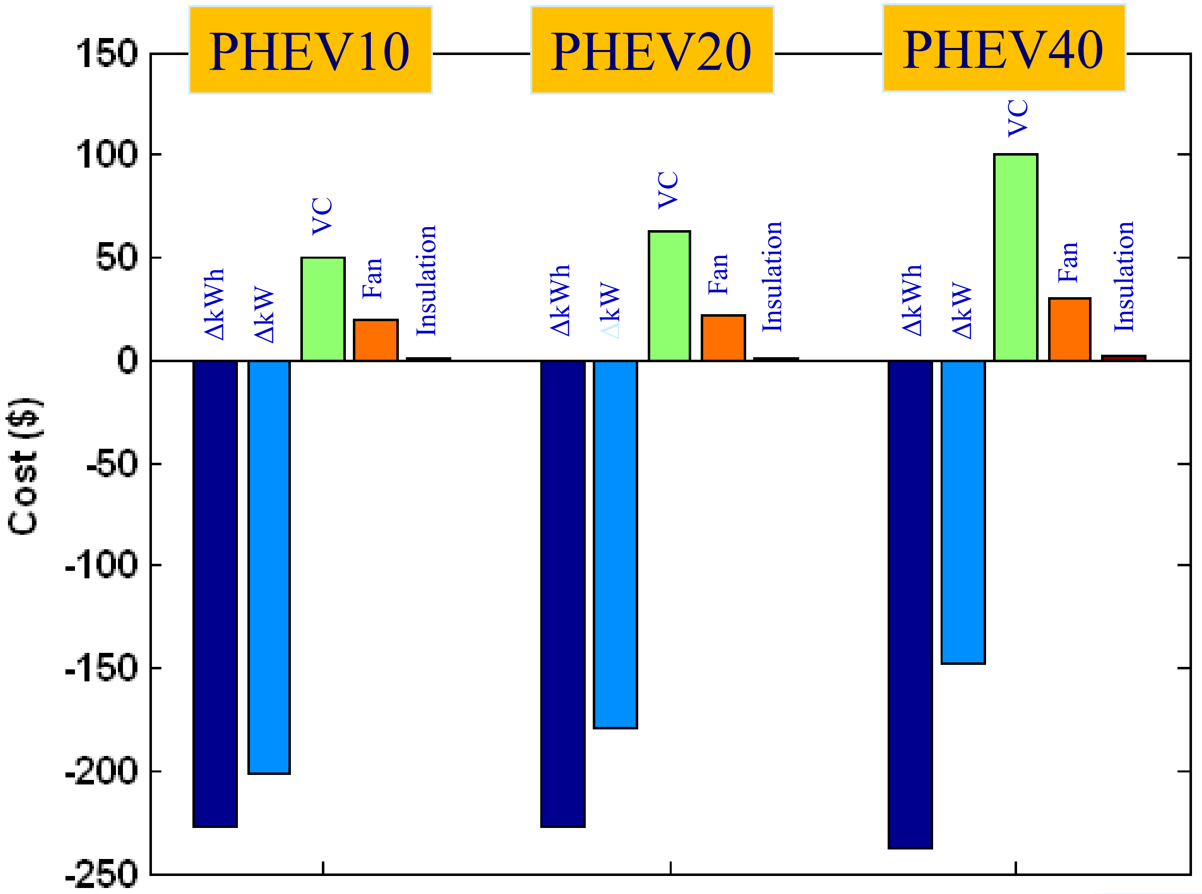


Lower cost cell preferred, provided it can meet life.

Next slide compares Δcosts of DOE/TLVT battery sized for 15 years in Phoenix, w/ and w/o insulation + VC system.

Savings from Downsized Battery Expected to Significantly Outweigh Cost of Added Components

DOE/TLVT cell sized for 15 years; in Phoenix, AZ, charged nightly



Total Savings ($)

	PHEV10	PHEV20	PHEV40
Total savings assuming components represent additional cost	($360)	($320)	($250)

Standby Thermal Management – Passive Techniques to Reduce Battery Temperatures



Photo Credit: John Rugh, NREL

- Installed metalized solar reflective film on the glazings of a Toyota Prius in Phoenix
- Cabin air temperature reduced ~6°C
- Before: Battery daily max temp 1.5°C above ambient
- After: Battery daily max temp 2°C below ambient

Thermal Preconditioning

Issues:

- For conventional vehicle and HEV platforms, A/C use leads to increased fuel consumption
- For PHEV and EV platforms, climate control energy is supplied by the traction battery

→ *Charge depletion (CD) range reduction*

- Batteries degrade rapidly at high temperatures and benefit from active cooling
- Batteries suffer from reduced power and energy at cold temperatures; their performance can be improved by preheating

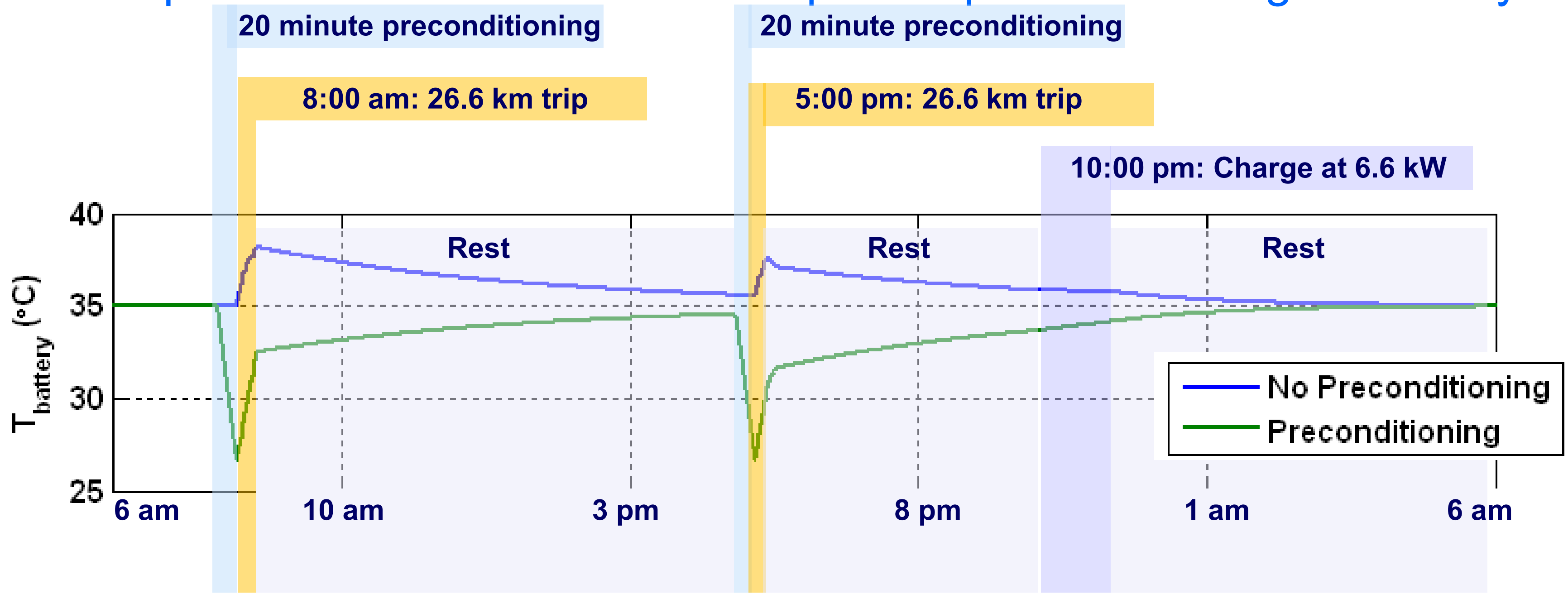
→ *Battery wear and life impacts*

Potential Solution:

- Use grid power to thermally precondition cabin and battery
- Save valuable onboard stored energy for propulsion

Preconditioning, Driving & Charging Patterns Affect Battery Temperature and Duty-Cycle

24-hour profiles created to estimate impact of preconditioning on battery life



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PHEV40s, hwy cycle, 95°F (35°C) ambient.
Battery heat generation rates and SOC extracted from PSAT vehicle simulations of charge-depleting and charge-sustaining operation.

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Thermal Preconditioning can Regain CD Range as well as Improve Thermal Comfort

EDV Platform (Climate Control)	Fuel Consumption Impact*	CD Range Impact*
PHEV15 (heat)	-1.4%	+19.2%
PHEV15 (AC)	-0.6%	+5.2%
PHEV40 (heat)	-2.7%	+5.7%
PHEV40 (AC)	-1.5%	+4.3%
EV (heat)	NA	+3.9%
EV (AC)	NA	+1.7%

*Compared to no thermal preconditioning

Thermal Preconditioning Can Also Improve Battery Life

EDV Platform (Climate Control)	Capacity Loss Reduction*
PHEV15(A/C)	+2.1%
PHEV40 (A/C)	+4.1%
EV (A/C)	+7.1%

*Compared to no thermal preconditioning

- Battery capacity loss over time is driven by ambient temperature
- Thermal preconditioning has a small benefit in reducing battery capacity loss (2%–7%), primarily by reducing pack temperature (2%–6%) in the high ambient temperature (35°C/95°F) scenario

Thermal Preconditioning Considerations

- Timing
  - avoid cooling or heating too early
  - does the heating/cooling coincide with peak demand on the grid?
- Can the charge circuit provide power for simultaneous heating/cooling and charging?
- When not plugged in, is it worth using onboard stored energy for preconditioning?
  - Trade stored energy (range) for battery life

Systems Approach - Options for Improving Electric Range with Climate Control

- Incorporate thermal preconditioning strategies
- Reduced heat transfer into/out of the cabin
- Use efficient HVAC equipment
- Reduce cooling capacity or heat load
  - Zonal climate control
  - Focus on occupant comfort
- HVAC controls
  - Eco mode (temporarily minimize energy use)
  - Eliminate inefficient HVAC control practices

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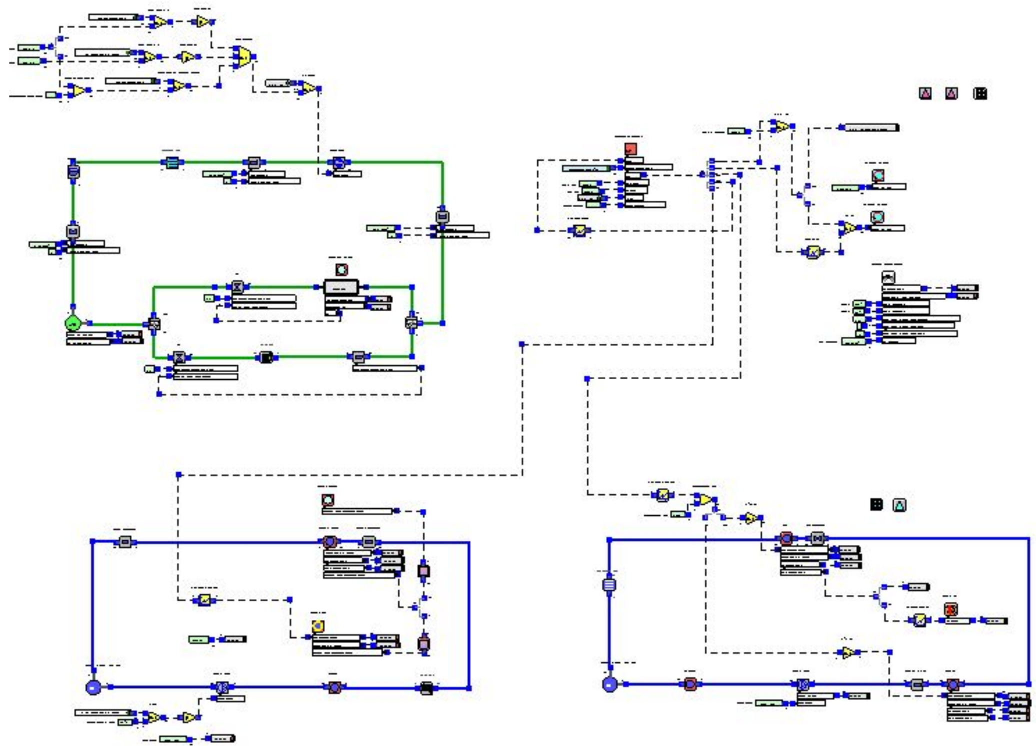
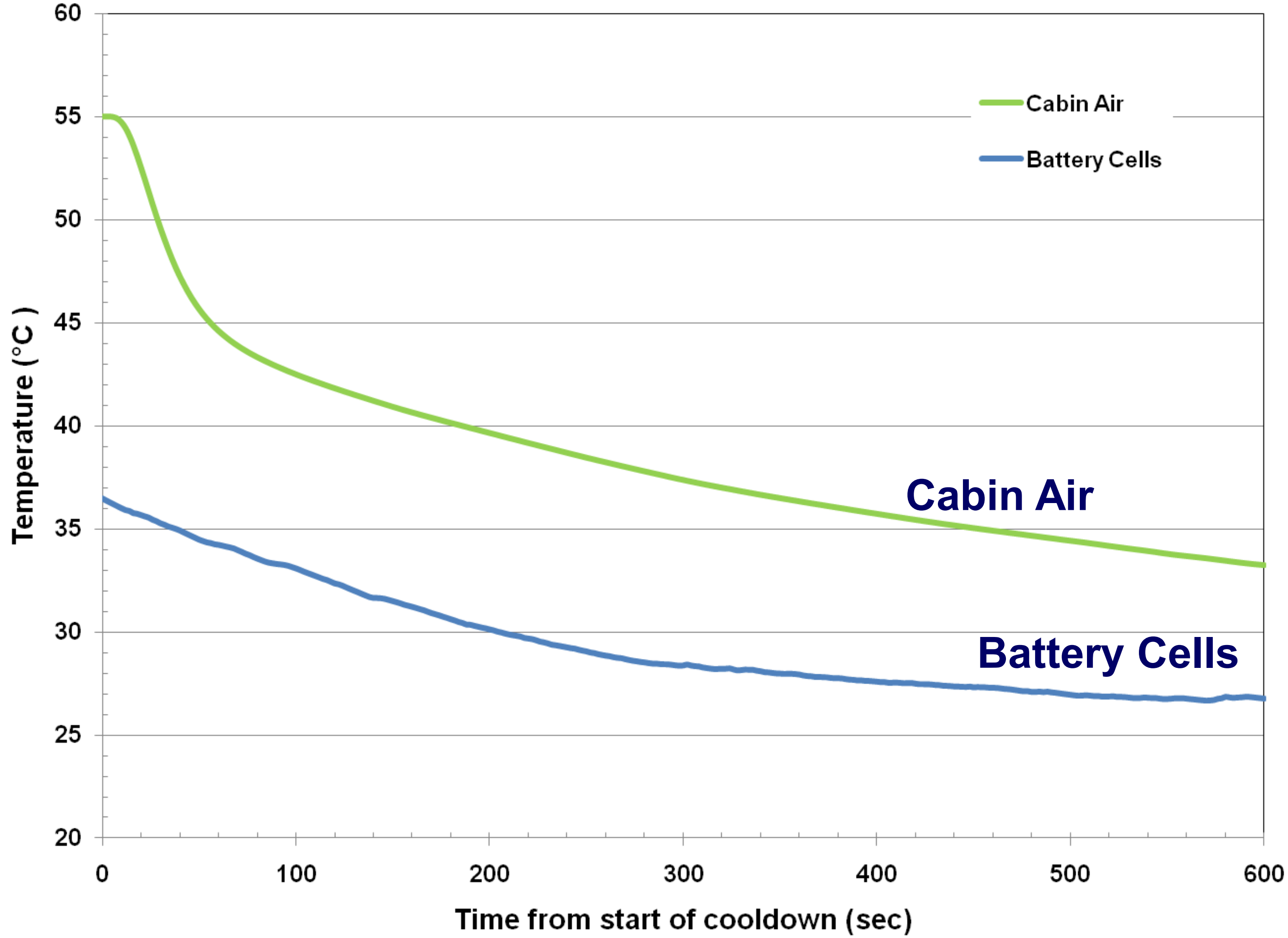
Tradeoff of Battery Cooling with Thermal Comfort

- NREL Integrated Vehicle Thermal Management task
- KULI thermal model
  - A/C and cabin
  - Battery cooling loop
  - Motor and power electronics cooling loop
- Nissan Leaf size EV
- Environment
  - 35 °C
  - 40% RH
- 0% recirc
- US06 drive cycle
- Cooldown simulation from a hot soak



Source: David Howell, DOE Vehicle Technologies Annual Merit Review

After 10 Minutes, the Battery Cools to Control Setpoint While the Cabin is Still Warm



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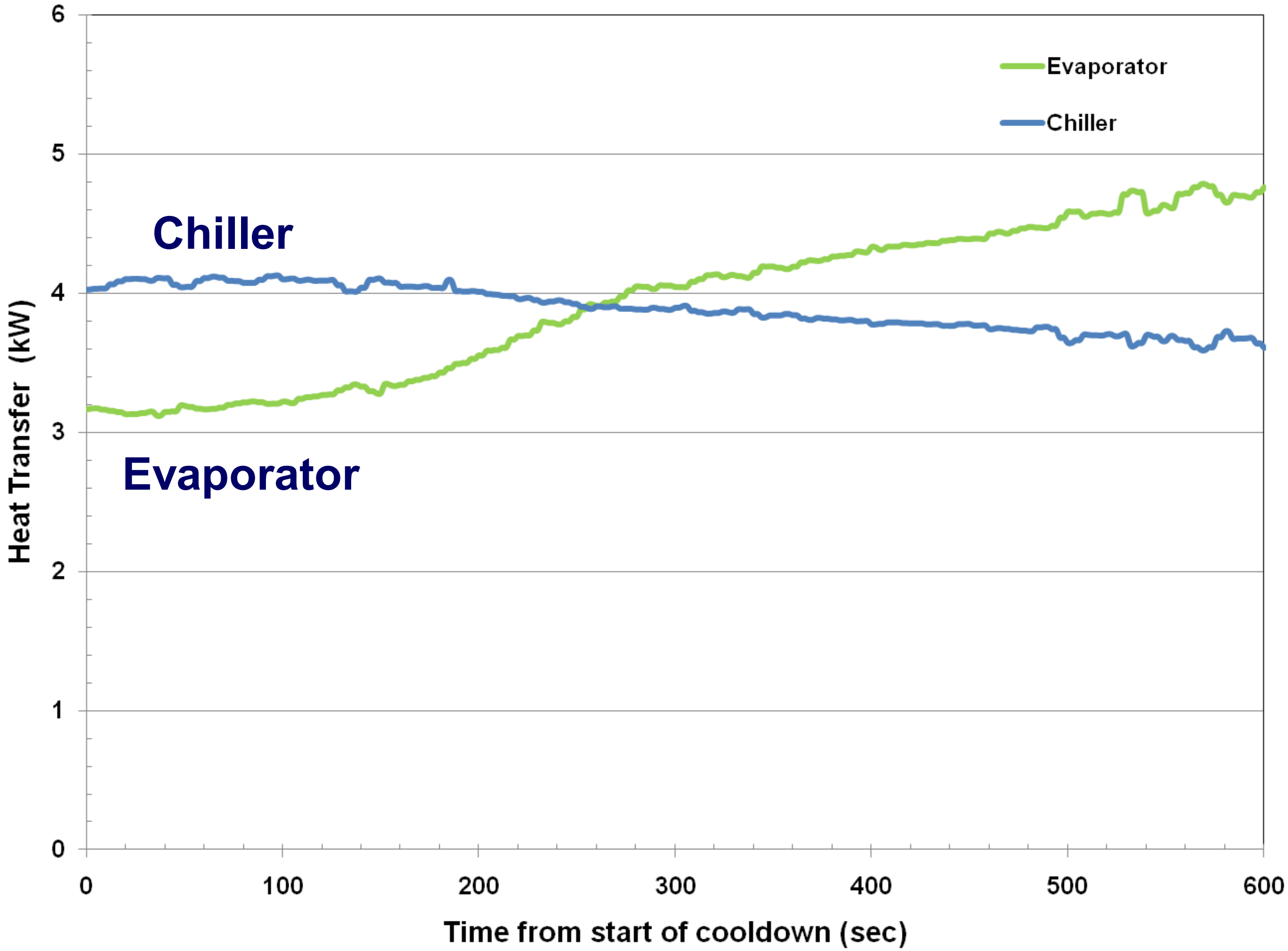
Initially Less Than 50% of the A/C System Capacity is Going to the Cabin



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- Temperature impacts the life, performance, and cost of batteries in HEVs, PHEVs, and EVs
- Battery life and performance are extremely sensitive to temperature exposure
- Thermal management is a must for batteries
- Thermal control of PHEVs and EVs (when parked or driving) could be a cost-effective method to reduce over-sizing of battery for the beginning of life
- Future trends
  - Some variation of today's Li-ion chemistries
  - Same sized packs – larger range
  - Improved cell designs to solve life issues

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For more information:

John P. Rugh
National Renewable Energy Laboratory
john.rugh@nrel.gov
303-275-4413

NREL:

Robb Barnitt
Laurie Ramroth

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