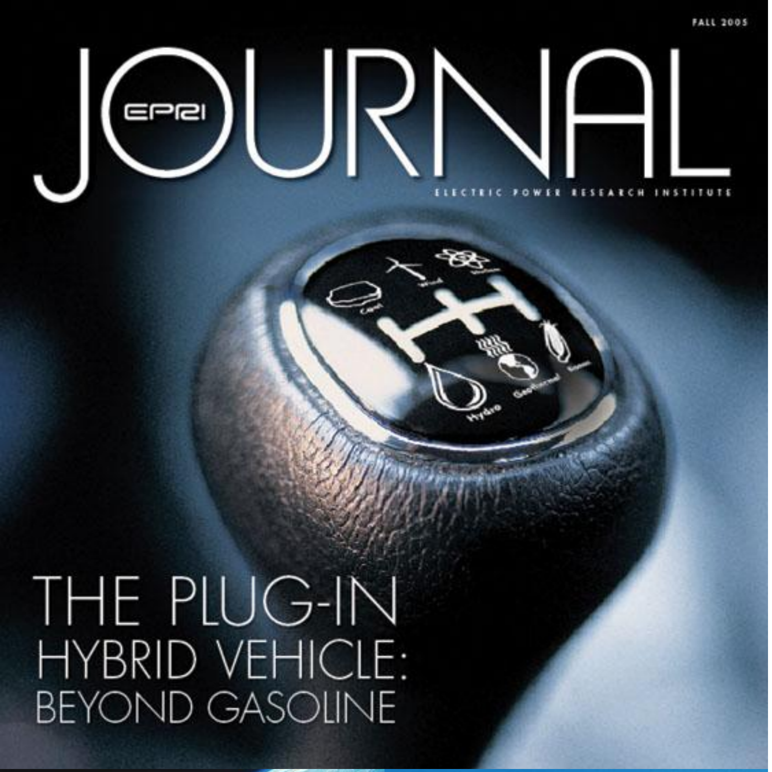

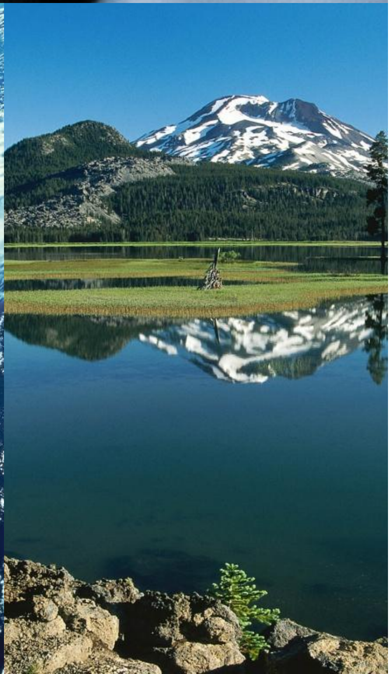

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Plug-In Hybrid Electric Vehicles

Jump Start to Secure, Clean Energy Future

May 7th, 2007

Dr. Mark Duvall

Electric Power Research Institute

Plug-In Hybrid Electric Vehicles Status 2006 – 2007

2006

- Pres. Bush endorses PHEV technology—DOE initiates it first PHEV R&D Program
- First PHEV prototypes from major automaker begin U.S. fleet testing (DCX PHEV Sprinter)

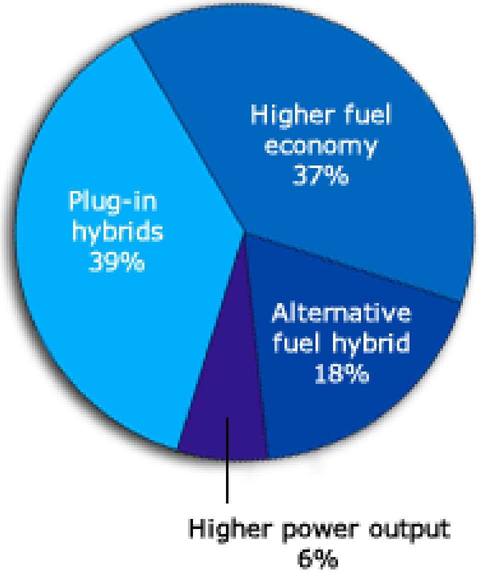
2007

- GM announces Chevy Volt, a PHEV with ~40 miles of EV range
  - GM has 2010 market intro goal
- Toyota announces significant internal program for PHEV development
- DaimlerChrysler developing 2nd generation plug-in hybrid Sprinter Van
- Nissan & Ford announce PHEV development programs

Pre-Commercial Private/Public Research Development & Demonstration

Electricity is a cheap, abundant transportation fuel – can we take advantage of this?

Re-emergence of Auto Manufacturer Interest in Electric Transportation



New Consumer Interest & Awareness

Source – Toyota Hybrid Synergy View 2007

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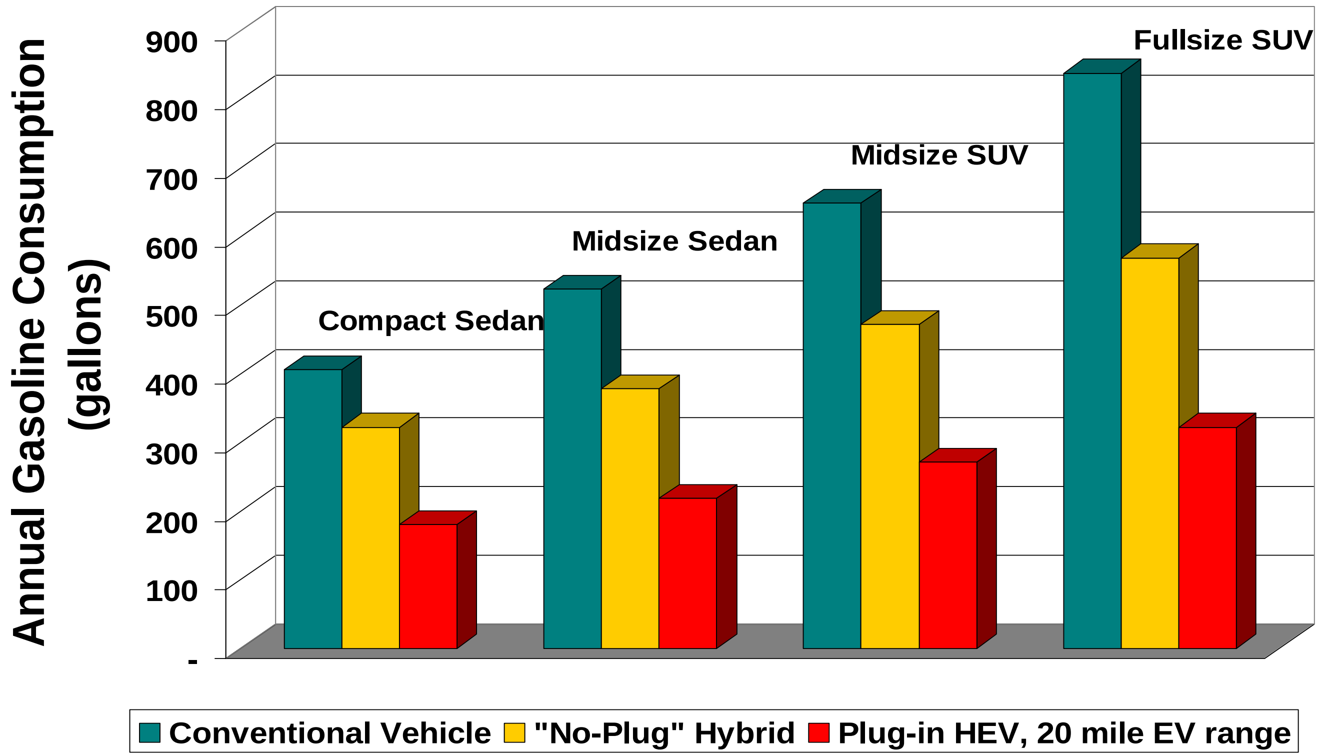
Plug-In Hybrids Significantly Reduce Consumption of Motor Fuels



Source: EPRI Report 1000349

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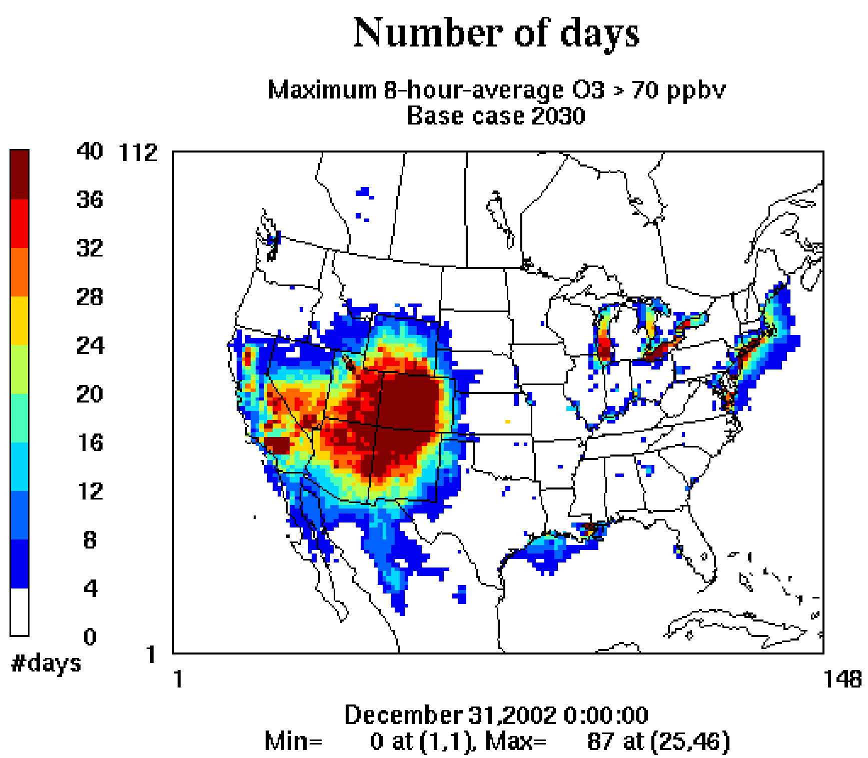
Environmental Impact of Plug-In Hybrids

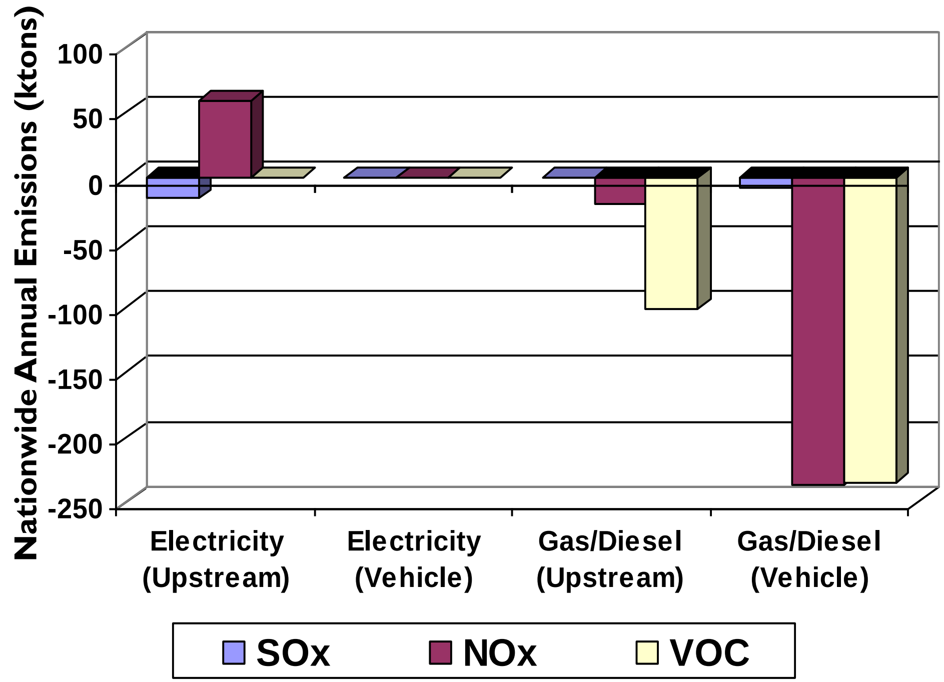
- Air Quality remains a concern
  - Population growth
  - Economic output
  - Increasing per capita VMT
  - Understanding future health concerns
- Global Climate Change
  - Increased probability of carbon-constrained future
- Petroleum Consumption
  - Some ***marginal*** new fuel sources have increased upstream emissions, environmental impacts



Number of Days Exceeding Proposed 8-hour Ozone NAAQS of 70 ppb in Base Case Simulation

PHEVs Likely to Cause Decrease in Net Criteria Emissions

- Power plant emissions essentially constrained in magnitude, location.
- Emissions reduced at ground level, thus a greater potential to improve air quality:
  - Exposure efficiency.
- Significant reductions in gas/diesel emissions:
  - Tailpipe and upstream (e.g. refinery).

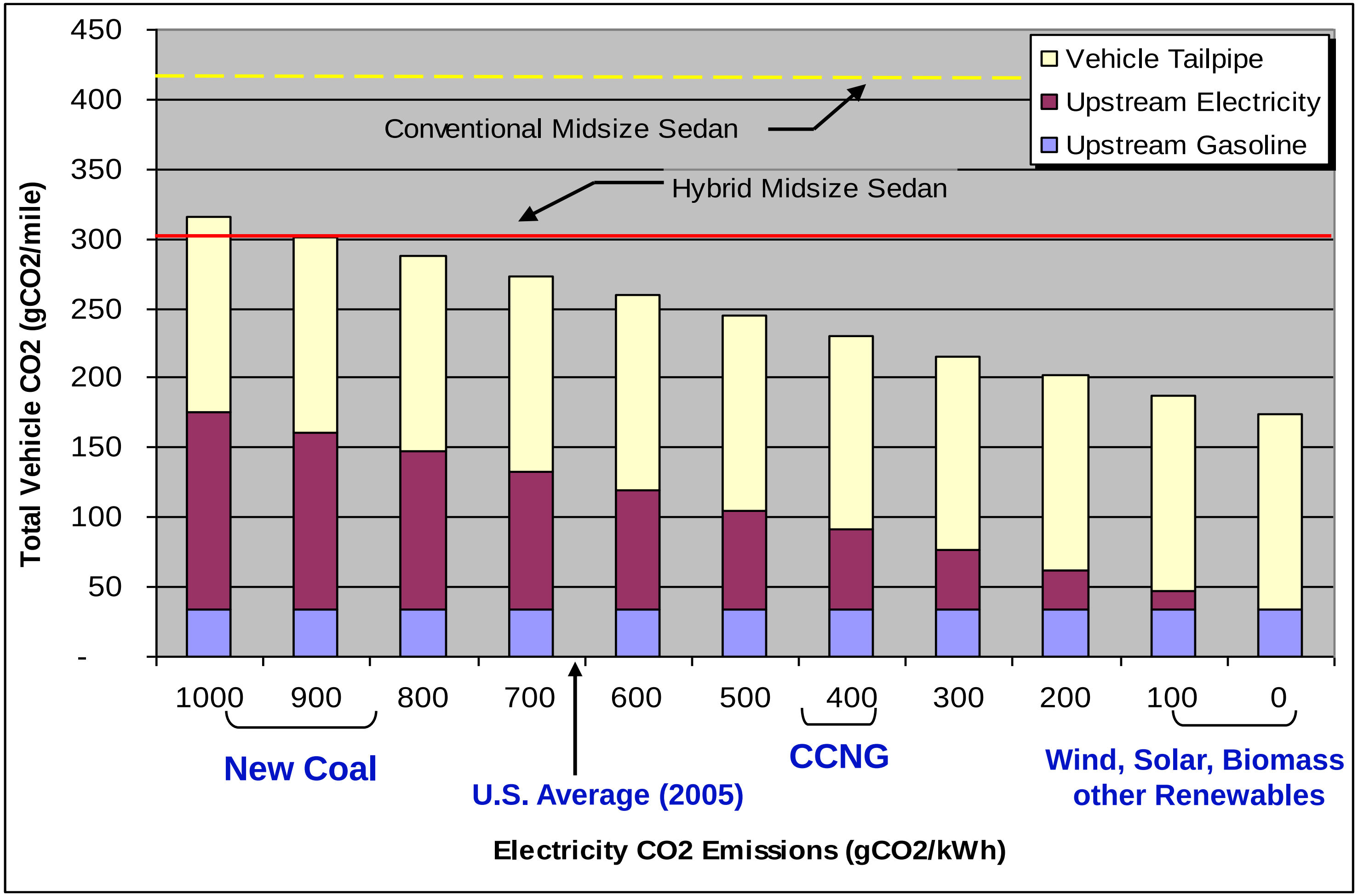


2030 High PHEV Penetration

- Passenger to Class 5 Vehicles.
- ~ 20% of vehicle-miles traveled powered by electricity.
- 5.9% PHEV-caused load growth at utilities.

A Cleaner Grid Reduces PHEV CO_2 Emissions

Plug-In Hybrid Midsize Sedan, 20 Miles Electric Range (or Equivalent)



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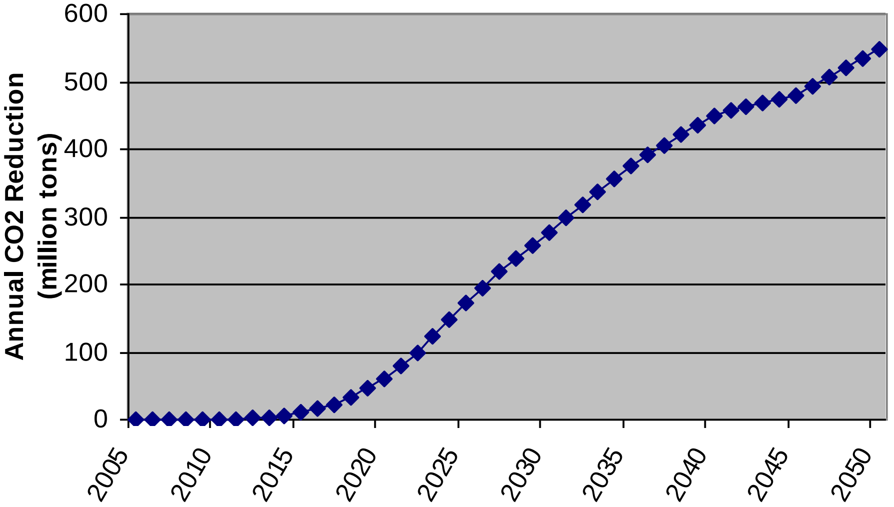
Plug-In Hybrid Adoption Reduces CO_2 Emissions

- Present-day U.S. generation mix is lower in CO_2 intensity than gasoline and diesel fuels.
- CO_2 intensity of generation mix declines over time as new technologies are introduced.
- Plug-in hybrid reduces CO_2 significantly over existing vehicle mix of conventional and hybrid vehicles.



Charging Infrastructure

- Plug-in hybrids require relatively low power charging
- Wide availability of infrastructure
  - Initial focus on private chargers
- Array of options
  - 120 VAC, 15 amp (~1.4 kW)
  - 120 VAC, 20 amp (~2.0 kW)
  - 208/240 VAC, 30 amp (~6 kW)
- 120 VAC strongly preferred due to cost, availability

PHEV 20 Vehicle	Pack Size	Charger Circuit	Charging Time 20% SOC
Compact Sedan	5.1 kWh	120 VAC / 15 A	3.9 – 5.4 hrs
Mid-size Sedan	5.9 kWh	120 VAC / 15 A	4.4 – 5.9 hrs
Mid-size SUV	7.7 kWh	120 VAC / 15 A	5.4 – 7.1 hrs
Full-size SUV	9.3 kWh	120 VAC / 15 A	6.3 – 8.2 hrs

1.2 – 1.4 kW power, 1 or 2 hours conditioning

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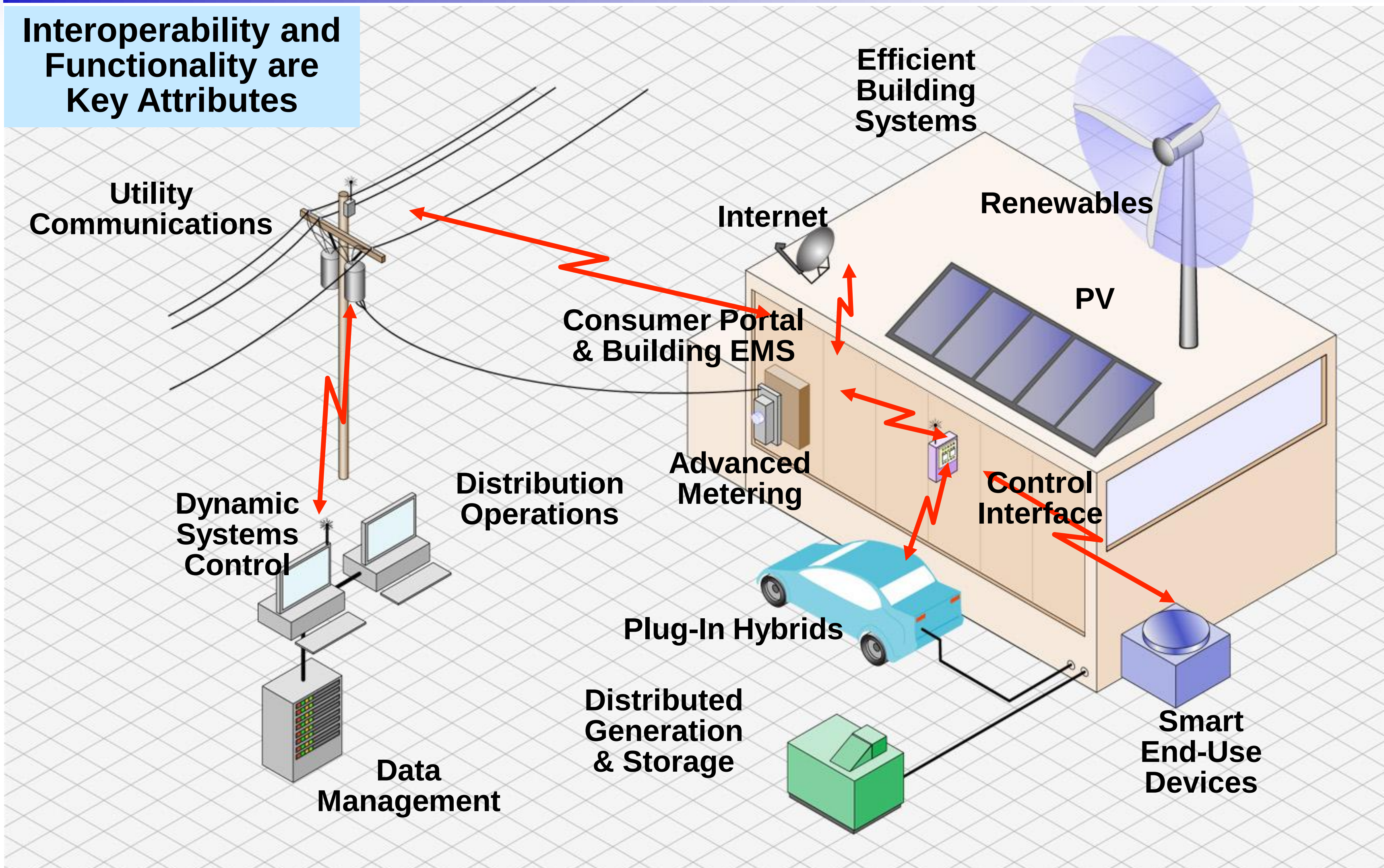
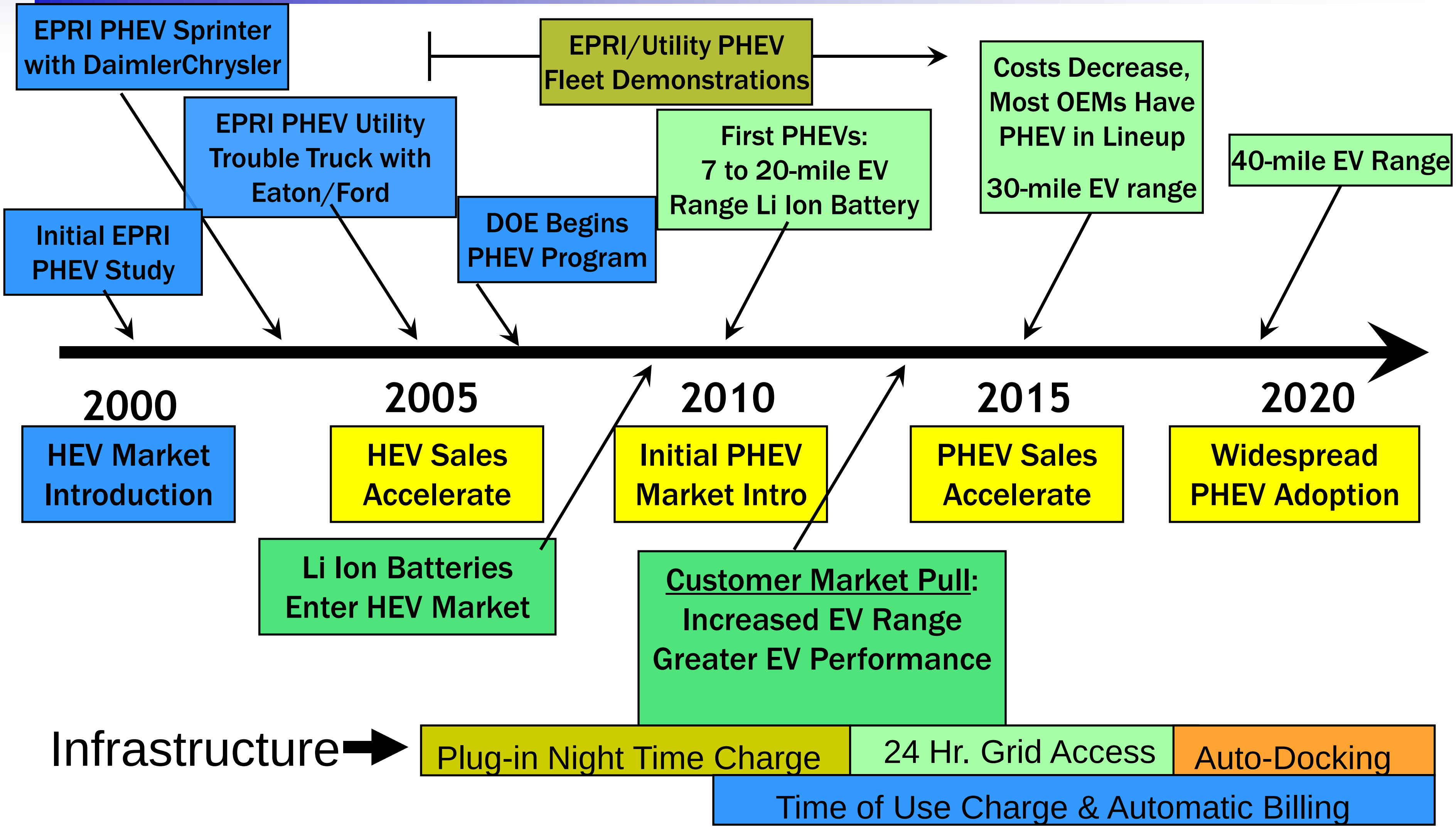
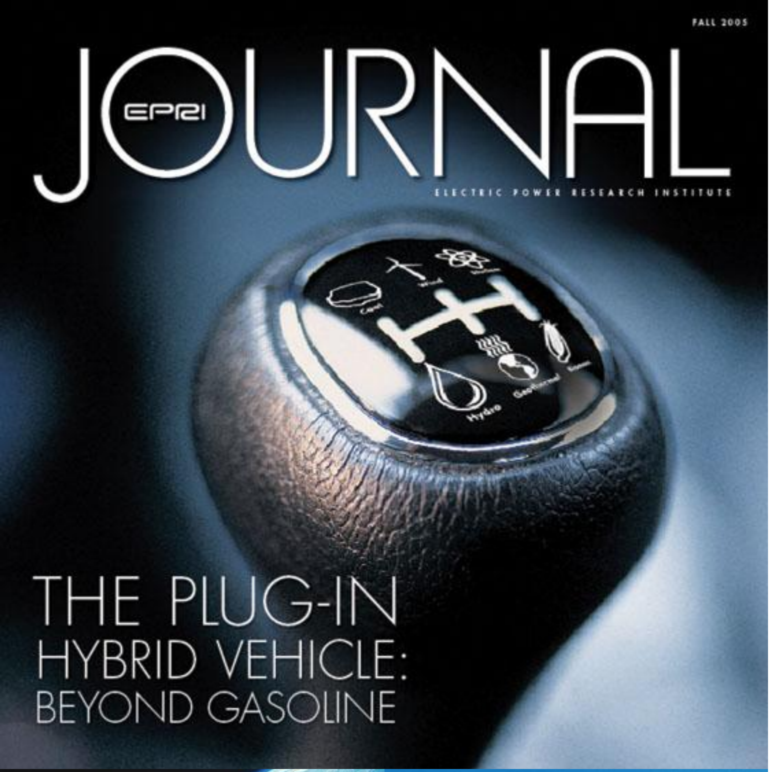
Future Intelligent Infrastructure Enabling PHEVs, Energy Efficiency, Consumer Choice

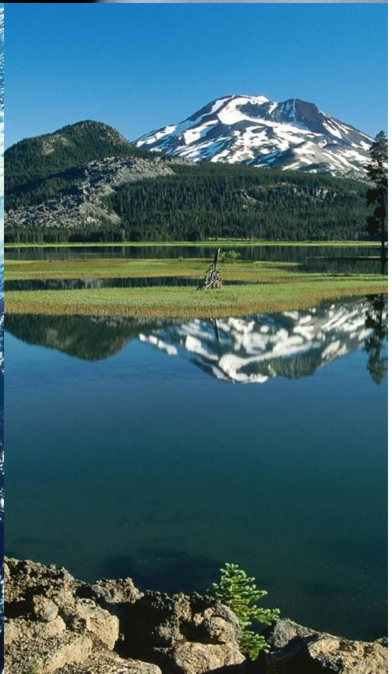
Interoperability and Functionality are Key Attributes



EPRI PHEV Technology Timeline







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Advanced Batteries for Plug-In Hybrid Vehicles

Jump Start to Secure, Clean Energy Future

May 7th, 2007

Dr. Mark Duvall

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The Advanced Battery Challenge for Plug-In HEVs

Consensus conclusion of May 4-5 DOE Meeting on PHEVs

- Key questions are cycle life, and cost/availability of energy batteries for PHEVs
- Current durability test data shows potential for current advanced batteries to meet cycle and calendar life requirements
- Large body of knowledge on battery capabilities for EVs and power assist hybrids (led by USABC)
- **For PHEVs:**
  - Need specific test data for PHEV requirements
  - Must evaluate latest chemistries
  - Continue to evaluate for cycle and calendar life durability, safety

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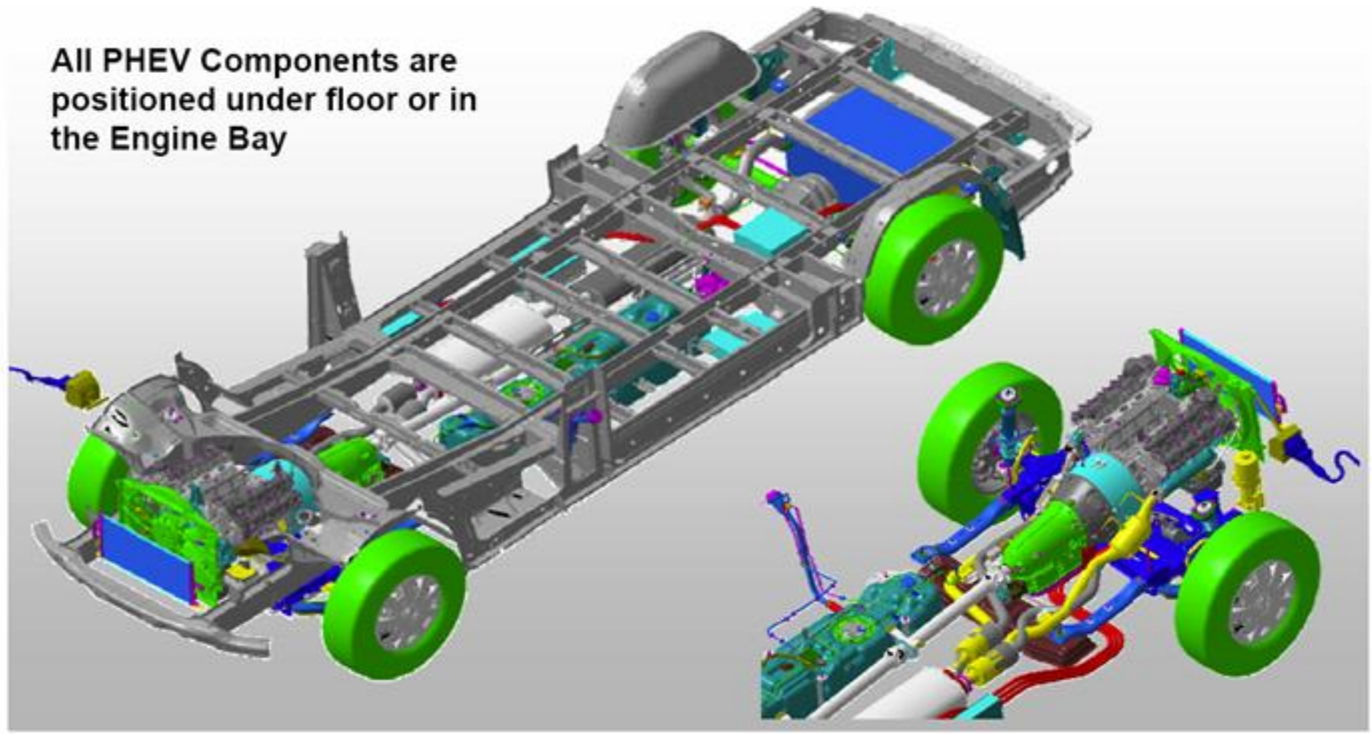
PHEV Sprinter Overview

- Large commercial van platform—cargo or passenger
- PHEV with up to 20 miles EV range in urban driving
- High power, parallel hybrid system



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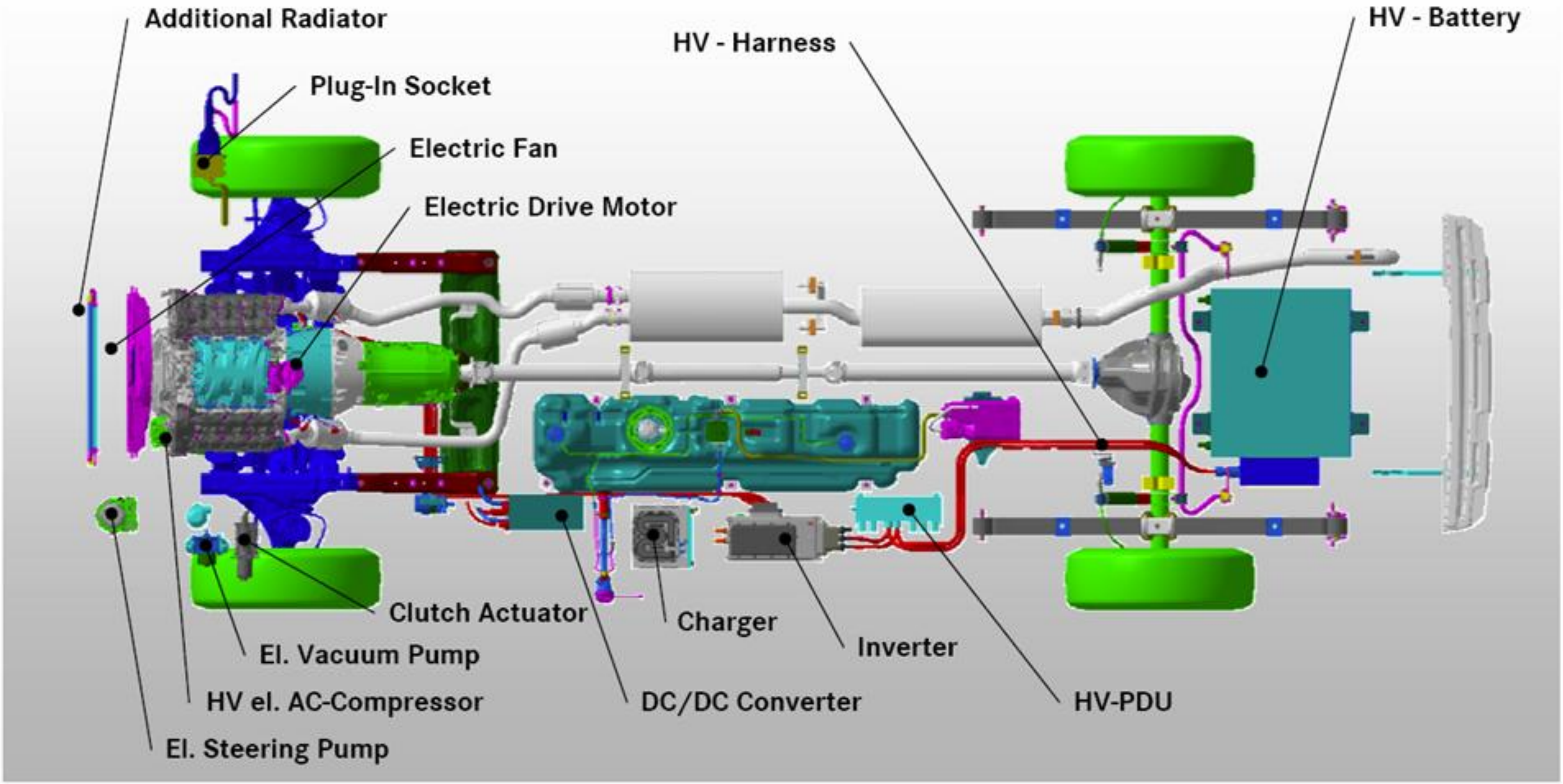
Plug-In Hybrid System Schematic



Battery Technologies

- **VARTA NiMH Vehicle Battery**
  - 280 cells (70 – 4 cell modules)
  - 40 Ah cell capacity
  - 14.4 kWh
  - 70 kW (peak power)
  - 40-cell test pack (50 V nom.)

- **SAFT Li-Ion Vehicle Battery**
  - 102 cells (17 – 6 cell modules)
  - 39 Ah per module
  - 15.5 kWh
  - 87 kW (peak power)
  - 18-cell test pack (65 V nom.)

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Test Profile Development

PHEV Test Profile Development

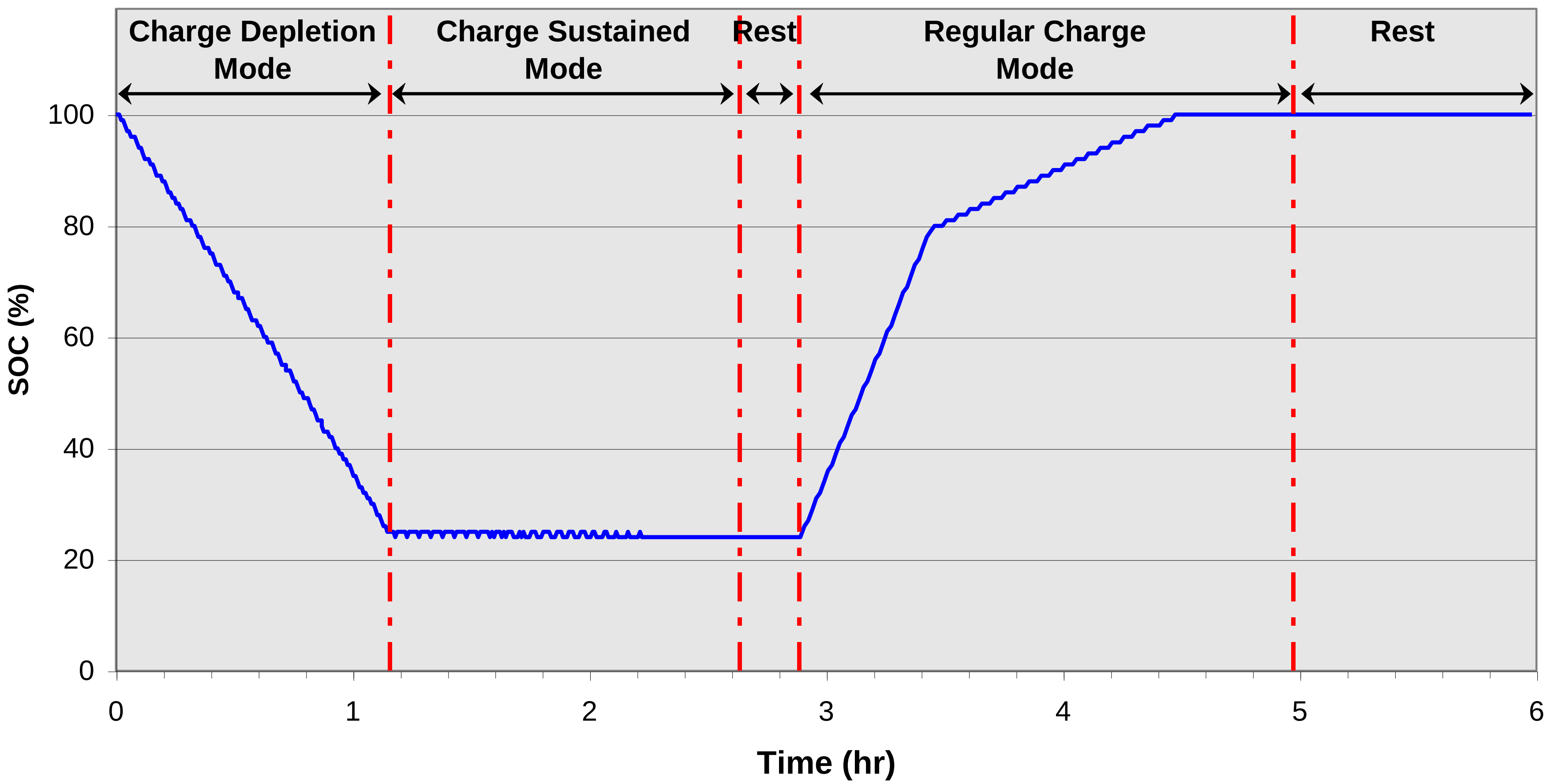
- Derived from a dynamic vehicle-level simulation
- Based on the final portion of the INRETS URB1 vehicle test cycle
- Replicates the urban driving conditions likely to be the most demanding to the battery (low speed, high acceleration and charge-sustained HEV mode at low battery SOC)
- Uses a combination of both HEV and EV driving modes to represent greater than 50% of statistical daily trips

PHEV Test Profile Overview

- Test profile composed of three main modes
  - Charge depletion mode, simulating the EV operation
  - Charge sustained mode, simulating the hybrid operation (HEV mode)
  - Regular charge mode, simulating the vehicle being recharged from an outlet

(Equivalent to a 2.6 hours / 50 miles drive)

Simulating a Plug-In HEV Duty Cycle



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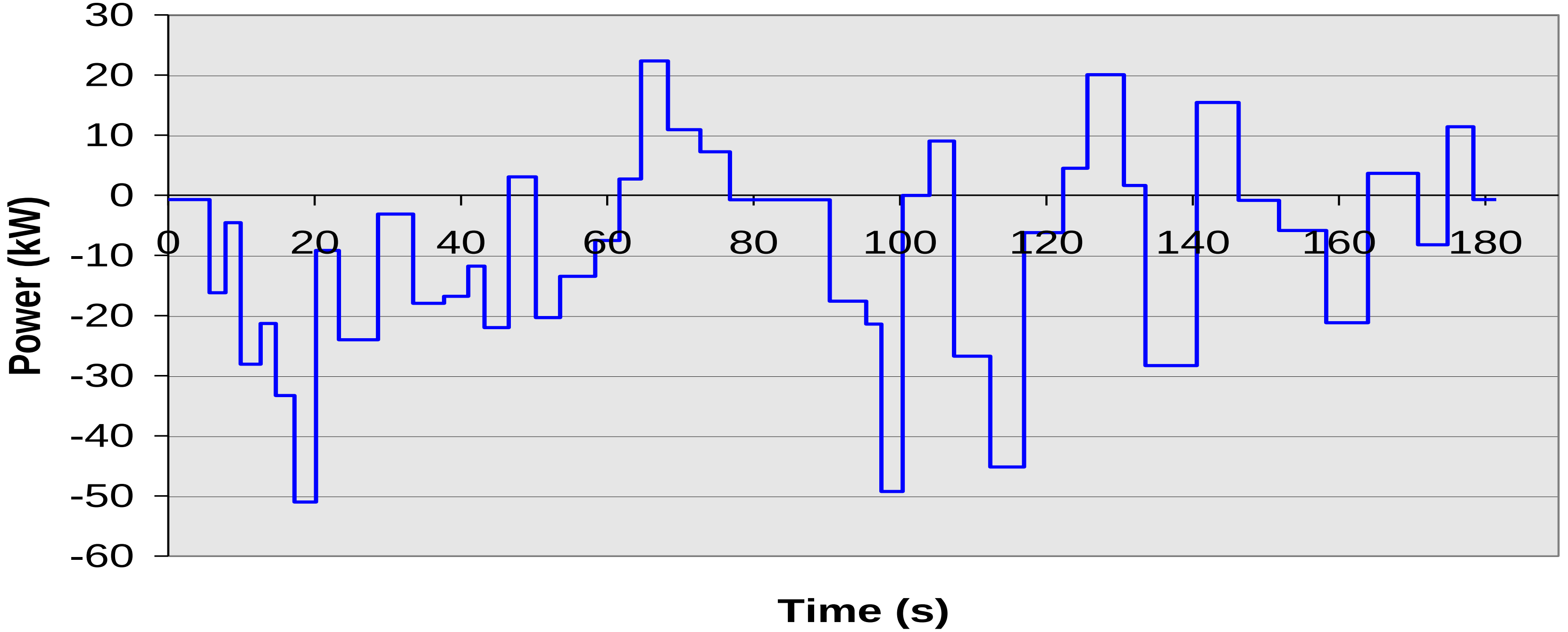
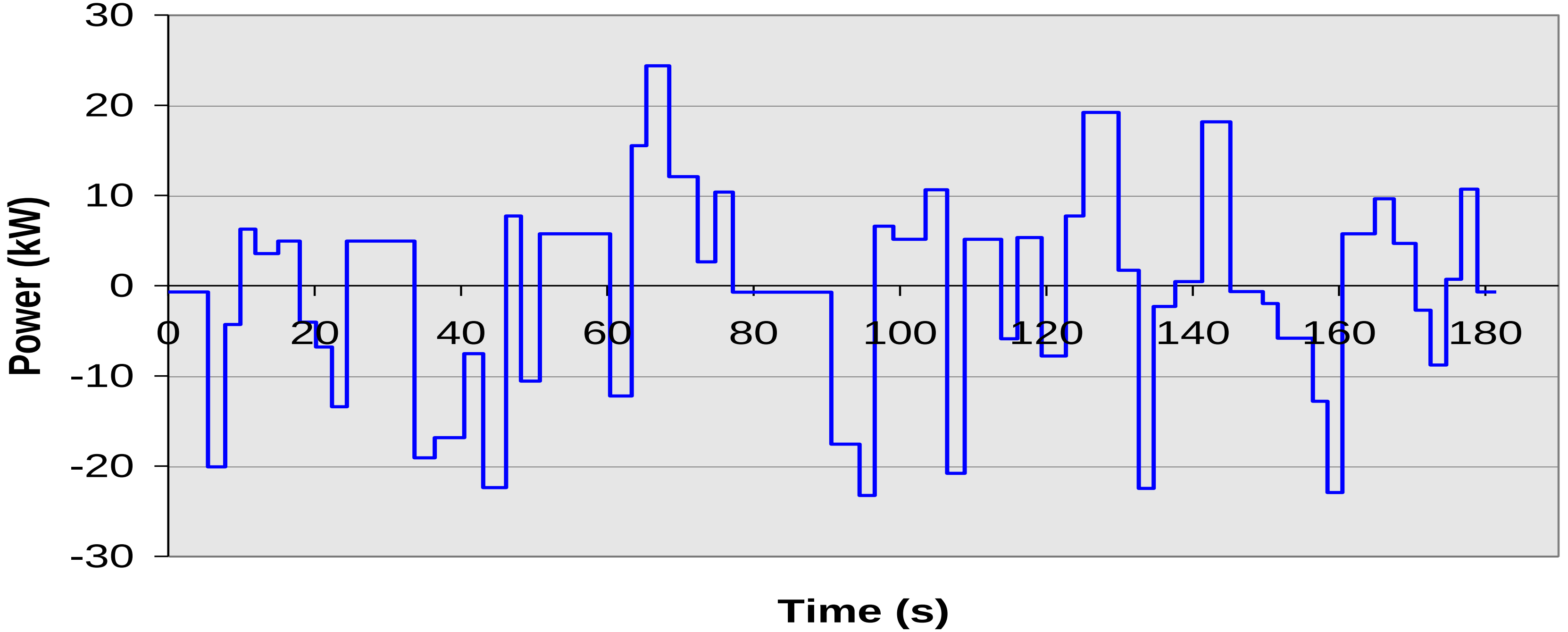
Charge Depletion Mode



- 180 sec test cycle
- Run from 100% SOC down to approximately 25% SOC
- Mode ends when the battery voltage stays below a pre-defined threshold for more than 10 sec

Charge Sustained Mode



- 180 sec test cycle
- Run at approximately 25% SOC
- Mode ends when the duration of the charge depletion mode plus the duration of the charge sustained mode reaches 2.6 hours

Regular Charge Mode

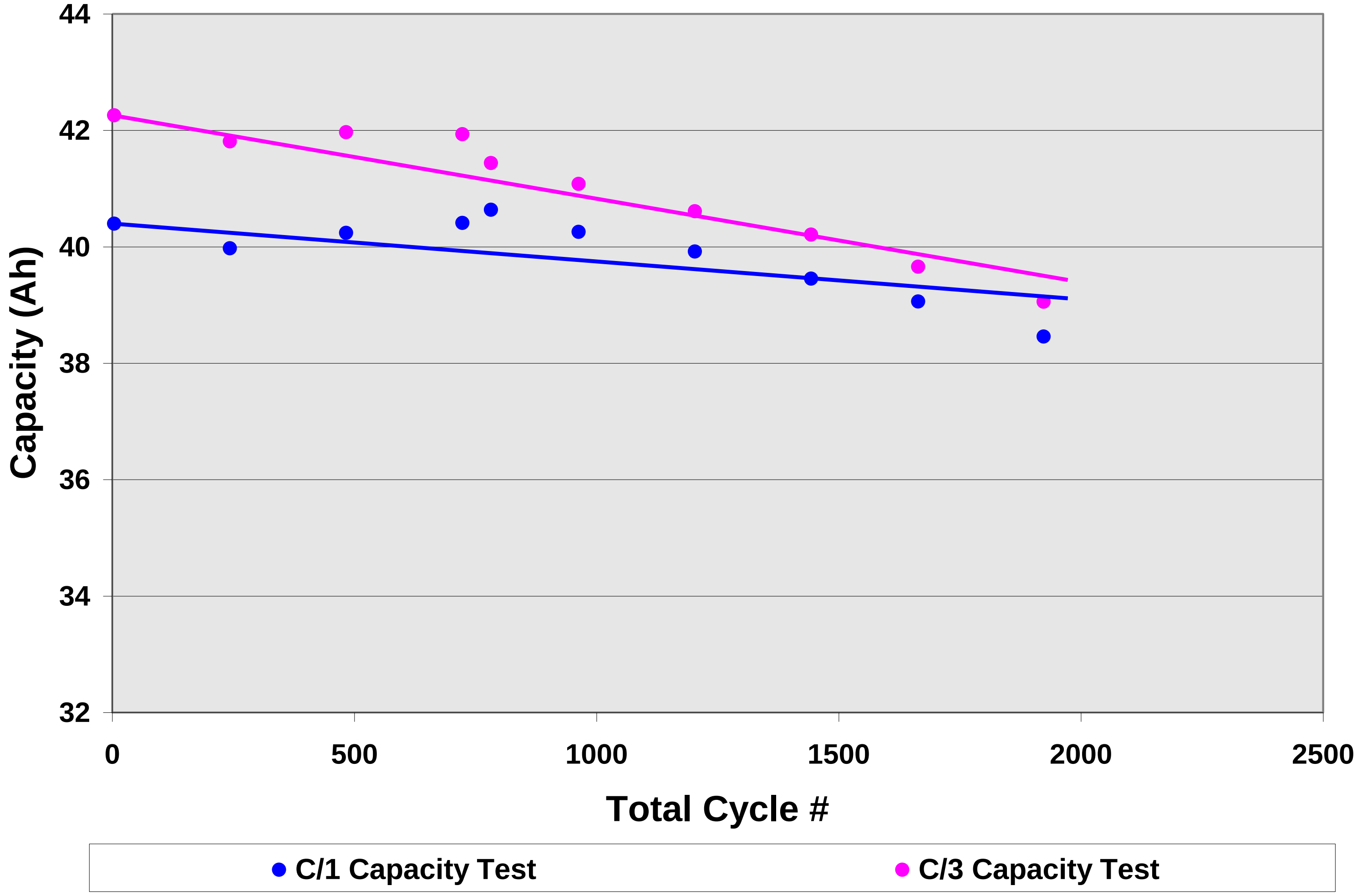
- A regular charge, following the manufacturer recommendation, is applied to the battery
  - Charge rate is C/1 for the VARTA NiMH battery
  - Charge rate is C/2 for the SAFT Li-Ion battery

Current Status of Test Results

Reference Performance Test

- RPTs are performed every 200 cycles (approximately 50 days) and includes:
  - A C/1 Capacity Test
  - A C/3 Capacity Test
  - A Peak Power Test (USABC Test Manual)
  - An HPPC Test (Hybrid Pulse Power Characterization – PNGV Test Manual)

SAFT Lithium Ion – Capacity Test Results



Source: Southern California Edison

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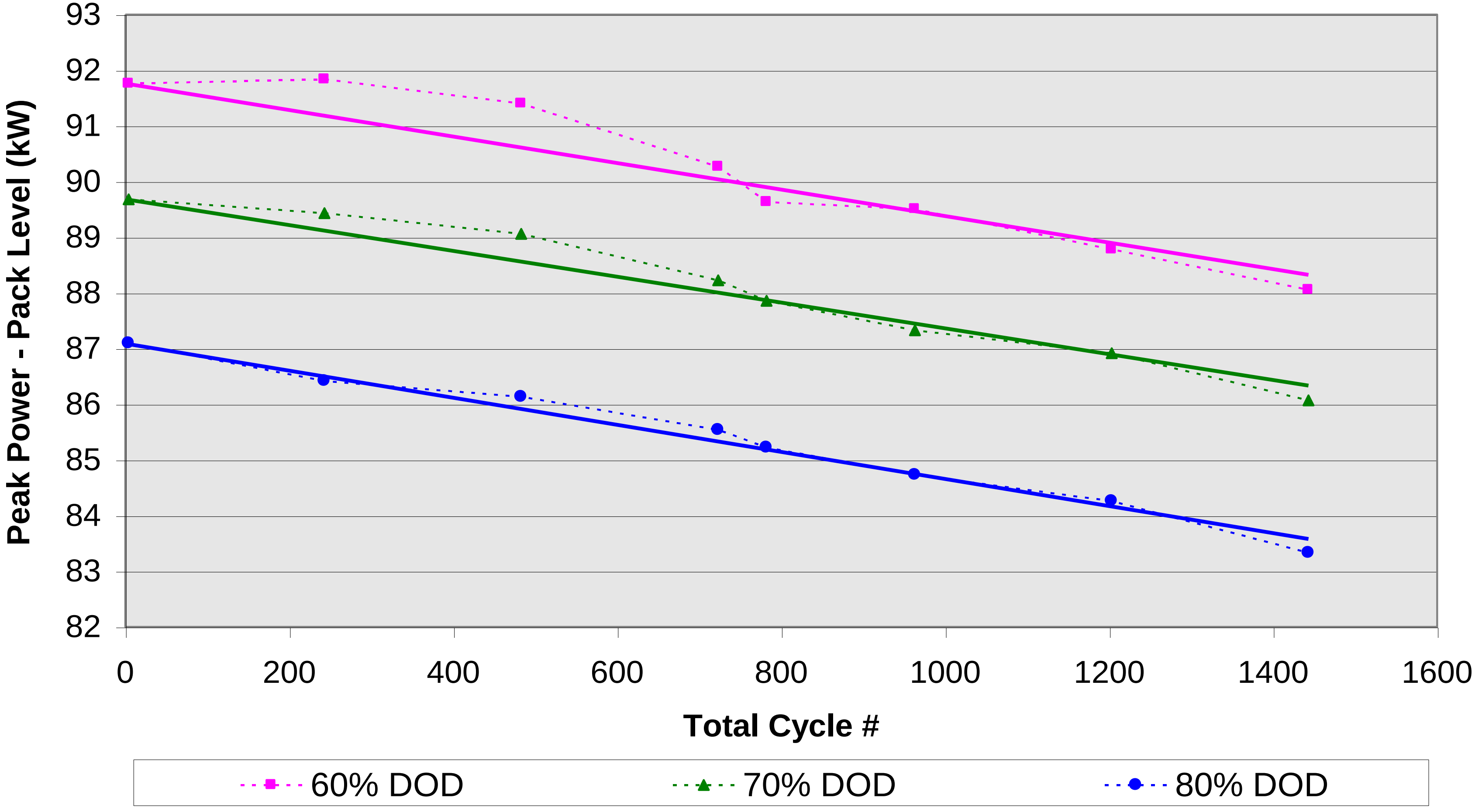
SAFT – Peak Power Test Results



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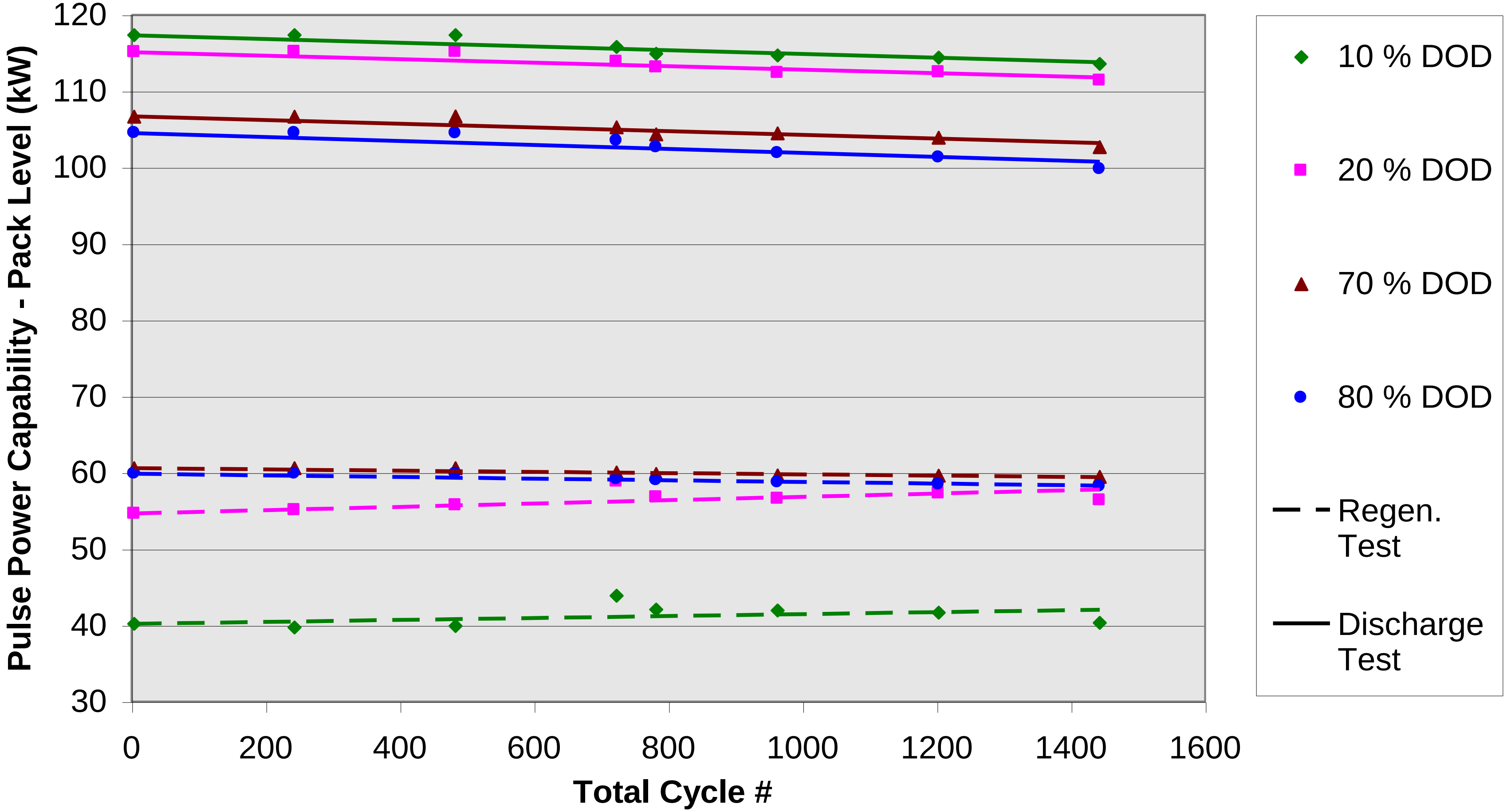
SAFT – HPPC Results



Acknowledgements

Loïc Gaillac – Southern California Edison

Contact Info

Loic.Gaillac@sce.com

mduvall@epri.com