Plug-In Hybrid Electric Vehicles Technology Challenges

ZEV Technology Symposium

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Overview

- Energy storage
- Energy management / PHEV electric-only operation
- Certification
- Charging and infrastructure

Energy Storage

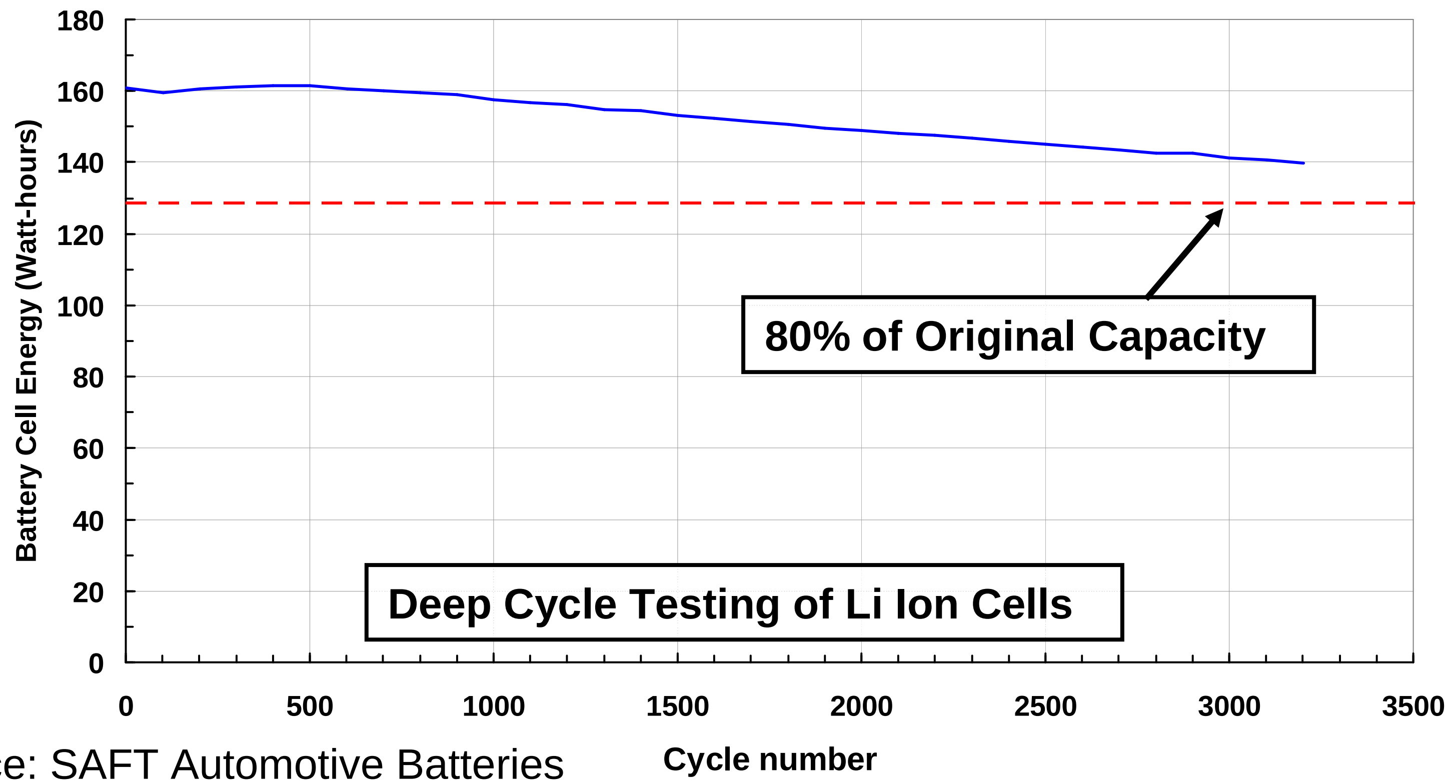
Key Challenge – Advanced Batteries

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

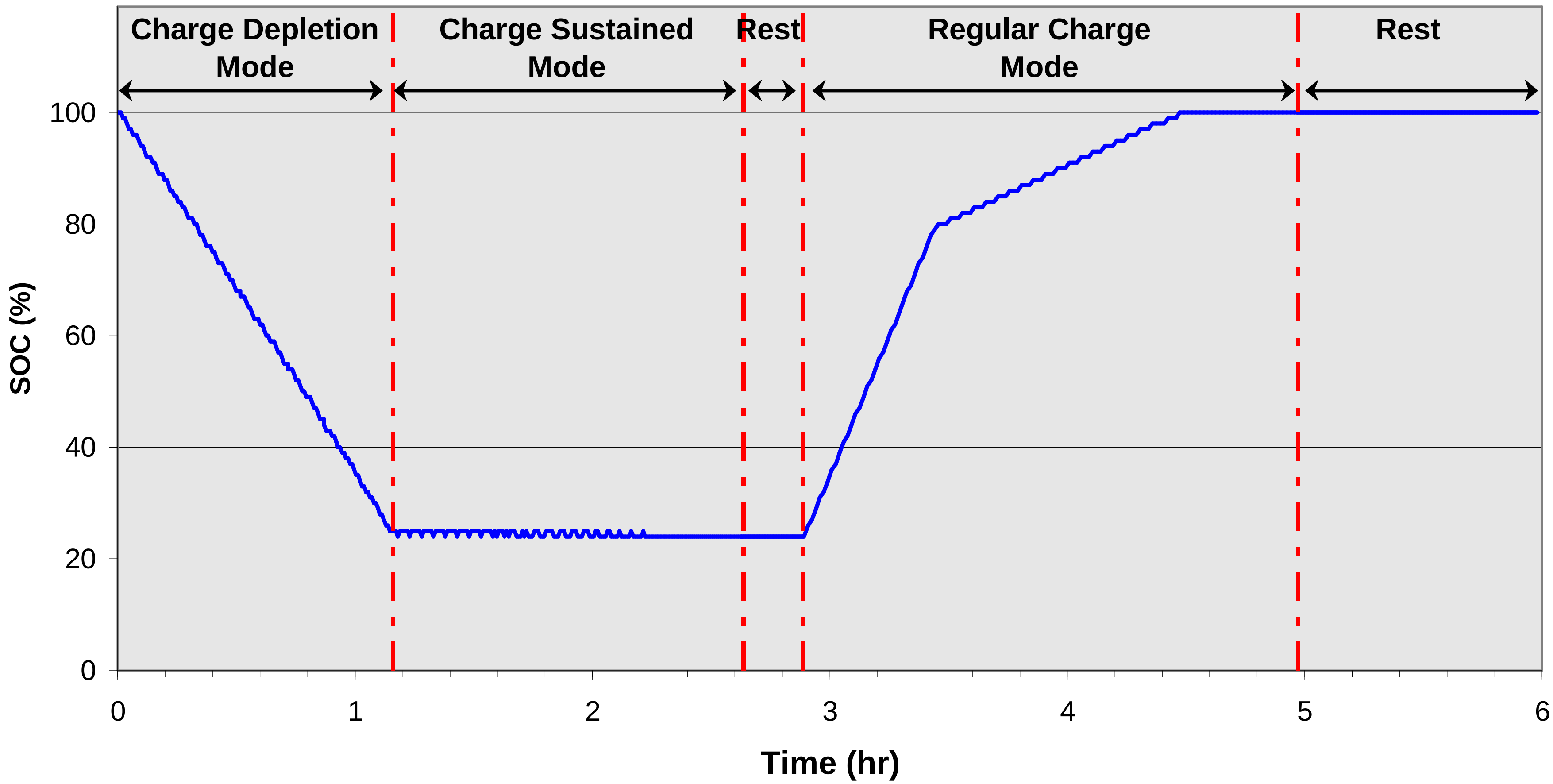
Lithium-Ion Technology is Promising for Plug-in Hybrids

- High energy and power density
- Likely to meet target cycle life
- Promising cost-volume relationship (equal or superior to NiMH)
- Potentially promising innovations in new designs



Source: SAFT Automotive Batteries

Simulating a Plug-In HEV Duty Cycle



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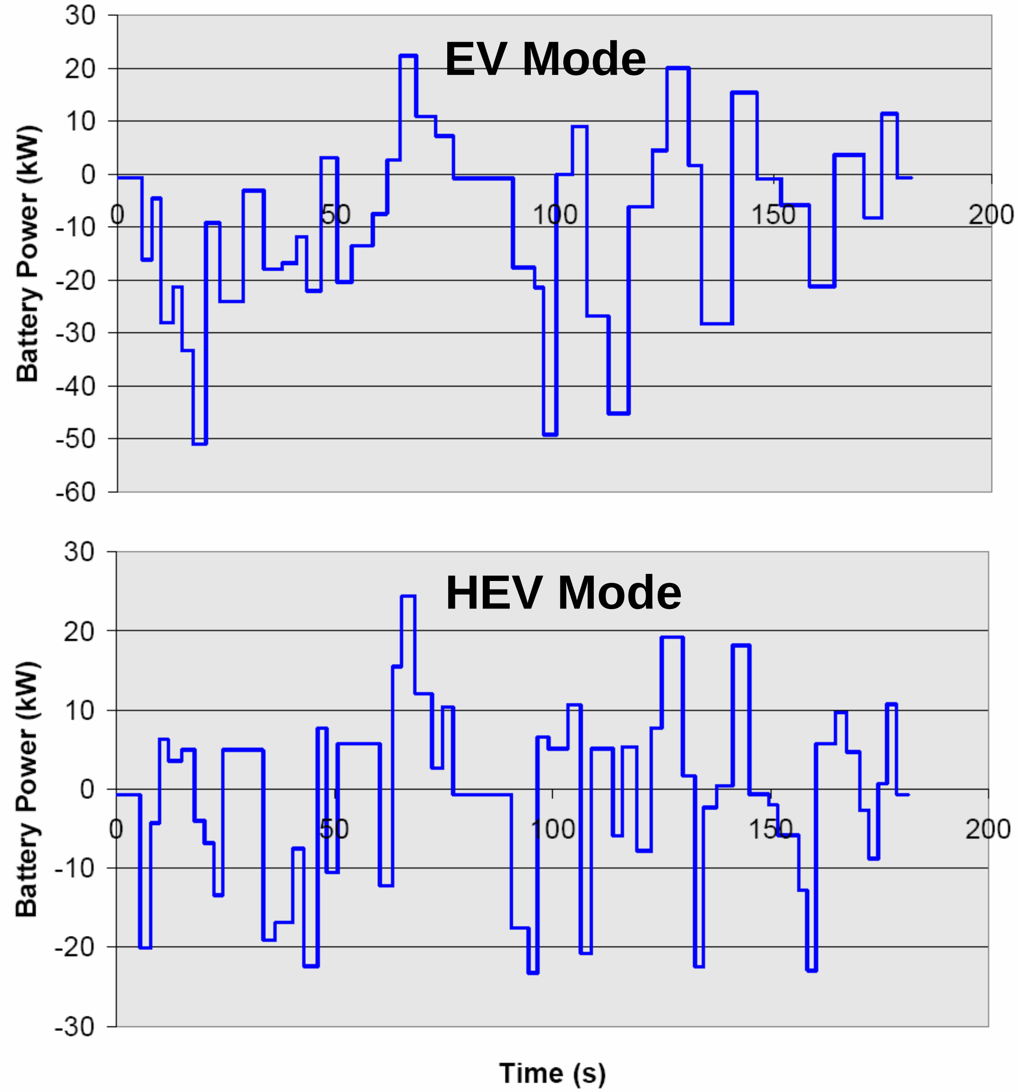
Example of Plug-In Hybrid Battery Testing

- Based on PHEV Sprinter duty cycle
- Test profile composed of three main stages
  - Deplete battery
  - Operate battery at constant state-of-charge
  - Recharge battery

  (Each cycle equivalent to a 2.6-hour / 50-mile drive)

- Electric system highly active in both modes.

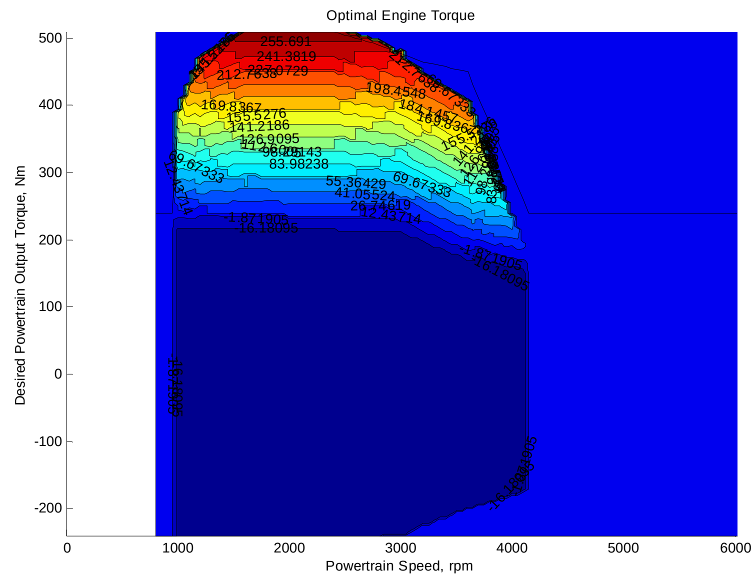
Driving power – negative values,
Regenerative braking – positive



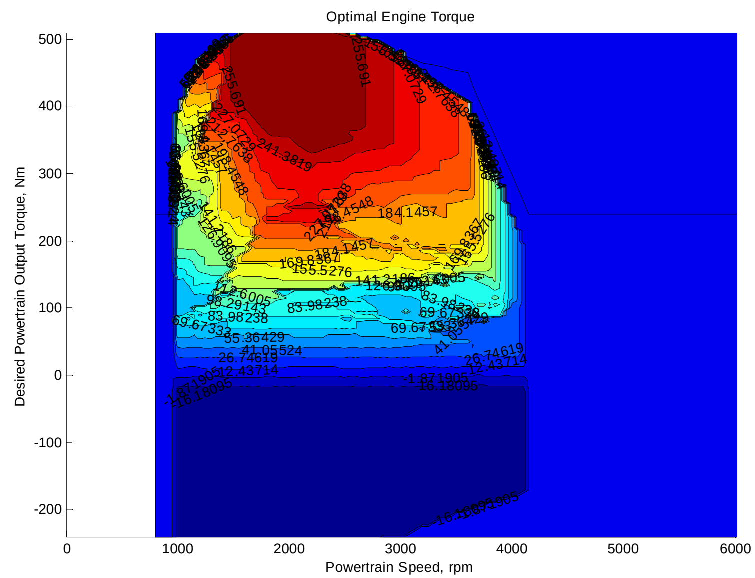
Energy Management and Electric-Only Operation

Energy Management

- High-level control strategy development need to optimize vehicle operation
  - Vehicle performance, efficiency
  - Maximize battery efficiency, durability
- Development influenced by:
  - Driver requirements
  - Vehicle use patterns
  - State of battery and drive technologies



Battery Depleting – Fueling Cost Optimized



Battery Sustaining

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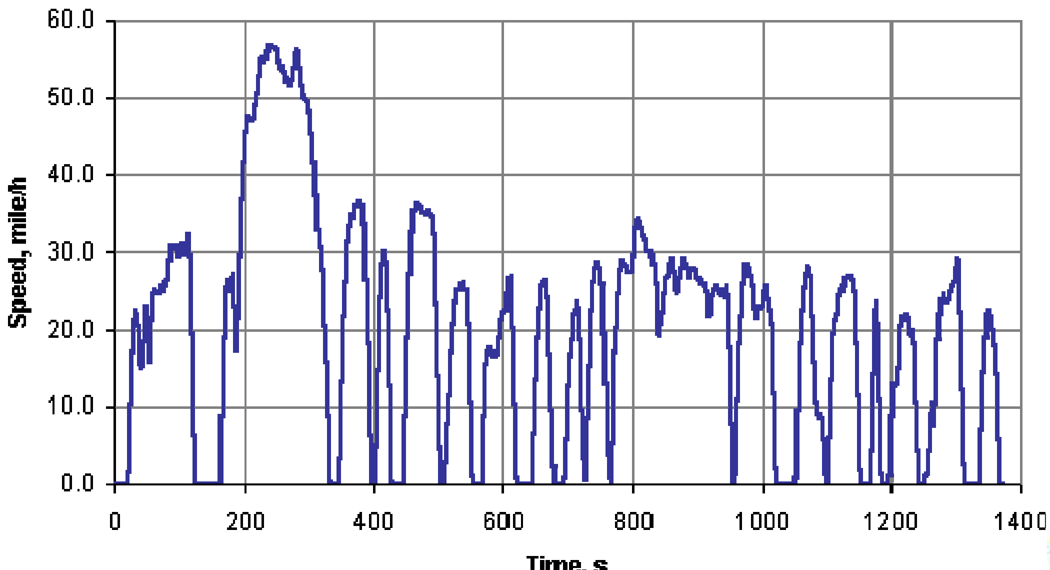
All Electric Range Definition for PHEVs
Zero-Emission VMT Requirement on UDDS Test Cycle

- Electric VMT capability imposes two key requirements:
  1. Electric motor/battery system power and powertrain architecture capable of meeting cycle (speed and power)
  2. Cold-start emissions capability throughout test cycle
- Definition does not imply a mandated AER (engine will come on at high loads and speeds) but does implies that many urban trips likely to be completed using only electricity.



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Some High Level Tradeoffs between PHEVs with or without ZEV VMT capability

Vehicle	Pros	Cons
PHEV 20 ARB – certified 20 miles AER on UDDS	• Likely higher efficiency and performance • Fewer cold-starts • Lower engine-on time • Greater potential for emissions reductions • **Possibly a superior long-term solution (e.g. PHEV 40)**	• Higher power electric-drive and battery • Powertrain must allow higher speeds • Require different emissions aftertreatment approach to handle engine starts
PHEV 20 “Blended” Battery energy equivalent to above PHEV	• Lower power electric-drive and battery • Similar emissions system requirements to HEV • Greater synergies with current HEVs • **Potentially a lower cost, nearer term product**	• Reduced or no emission benefits over PZEV • Potentially lower performance (relative) • Takes longer to use battery energy

Other Factors

- There is a difference between test cycles and real world driving which will determine electric-operation and the user's experience
  - Even modest levels of electric performance could result in numerous all-electric trips or "electric vehicle miles"
- Performance feel may be different—customer preference could drive configuration (e.g. electric vehicle – like performance.

Certification

Plug-in Hybrid Certification

- How do we test PHEVs?
  – Variable impact of stored energy
  – Use patterns of primary importance
  – Relative performance/efficiency of internal combustion engine vs. electricity components
- Two main issues
  – EPA or CARB certification for emissions
  – Fuel economy measurement
- Need to develop consensus among stakeholders
- Need to account for different PHEV architectures
- Certification drives emissions control for PHEVs

Charging and Infrastructure

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