



Idaho National Laboratory
International Nuclear Leadership for the 21st Century

Battery Technology for PHEV's

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Idaho National Laboratory

Department Focus

FreedomCAR & Vehicle Technologies Program

We support U.S. Department of Energy's effort to reduce national dependence on foreign oil through:

Vehicle Systems and Energy Storage

- Technology and Infrastructure Development
- Vehicle and component testing, demonstrations

Introduction

Consumer acceptance of HEVs today is partially due to the durability of the NiMH batteries.

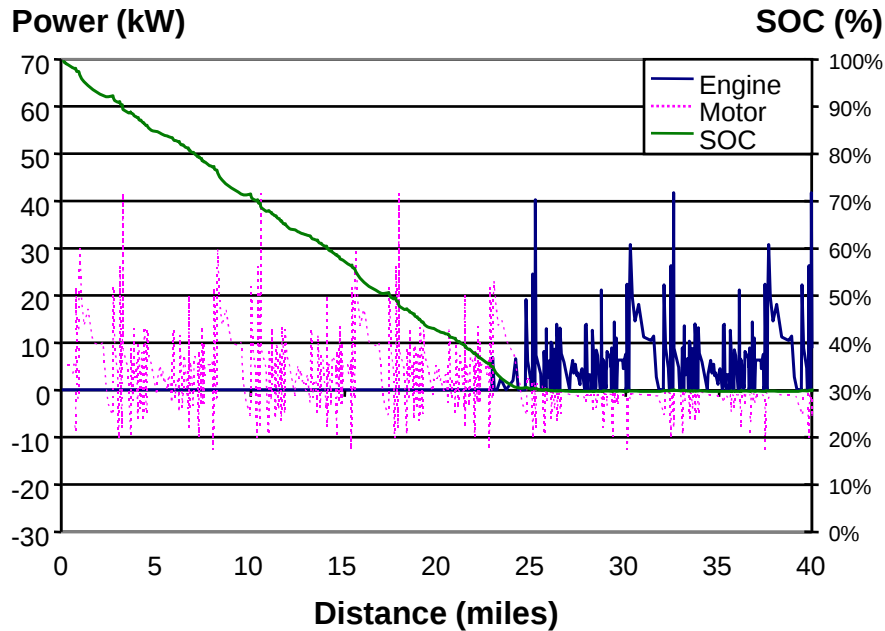
Cost of lithium ion batteries for [consumer electronics](#) is now below that of NiCd and NiMH batteries. (<\$500/kWh)

Lithium ion is viewed as the most commercially viable energy storage option for PHEVs due to its potential for much higher energy and power densities.

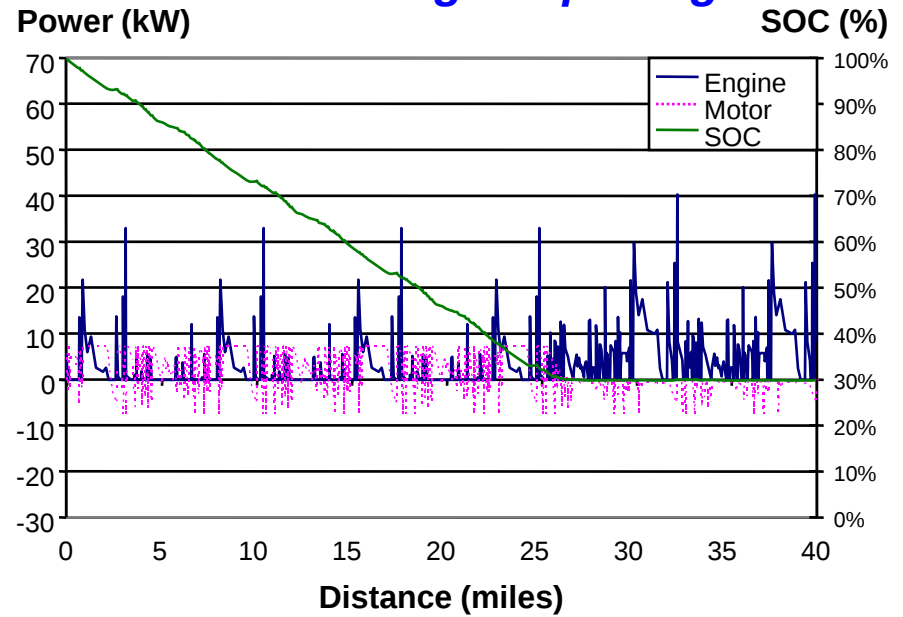
Further improvements are needed for lithium ion before a large penetration of PHEVs and EV's can take place.

PHEV Design strategies

All-electric



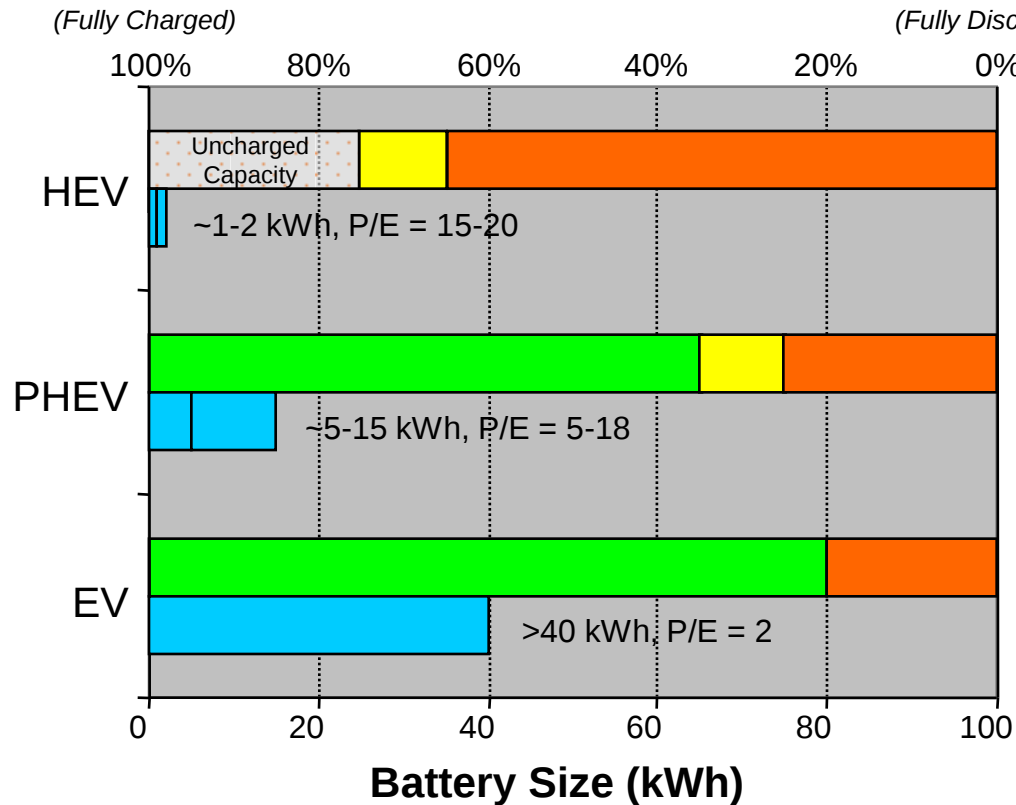
HEV Charge-depleting



- The “all-electric” strategy leads to more petroleum displacement and less emissions with some potential performance penalty; but the cost increase for the electric power-train may not be justifiable.
- The “HEV charge-depleting” strategy leads to the same “equivalent” electric range, a slightly lower fuel economy, higher tailpipe emissions, and an affordable cost without sacrificing performance.

PHEV Battery Operation

Battery State of Charge (SOC)



CS only: 300-500 Wh, 25-40 kW (10 sec) @70% SOC, 300,000 cycles

CS: 300-500 Wh, 25-40 kW (10 sec) @30% SOC, 300,000 cycles

CD: Energy scaled for range (10-40 miles), 5,000 deep discharge cycles

CD only: Energy scaled for 100+ mile range, 1,000+ deep discharge cycles

- Charge Depleting (CD)
- Charge Sustaining (CS)
- Unused Energy
- Battery Size (kWh)

USABC Goals for PHEV Batteries

Power requirements are set to allow an all-electric operation under Urban Dynamometer Driving Schedule (UDDS) in charge-depleting mode

•Characteristics at EOL (End of Life)		High Power/ Energy Ratio Battery	•High Energy/ Power Ratio Battery
Reference Equivalent Electric Range	miles	10	40
Peak Pulse Discharge Power - 2 Sec / 10 Sec	kW	50 / 45	46 / 38
Peak Regen Pulse Power (10 sec)	kW	30	25
Available Energy for CD (Charge Depleting) Mode, 10 kW Rate	kWh	3.4	11.6
Available Energy for CS (Charge Sustaining) Mode	kWh	0.5	0.3
Minimum Round-trip Energy Efficiency (USABC HEV Cycle)	%	90	90
Cold cranking power at -30°C, 2 sec - 3 Pulses	kW	7	7
CD Life / Discharge Throughput	Cycles/MW h	5,000 / 17	5,000 / 58
CS HEV Cycle Life, 50 Wh Profile	Cycles	300,000	300,000
Calendar Life, 35°C	year	15	15
Maximum System Weight	kg	60	120
Maximum System Volume	Liter	40	80

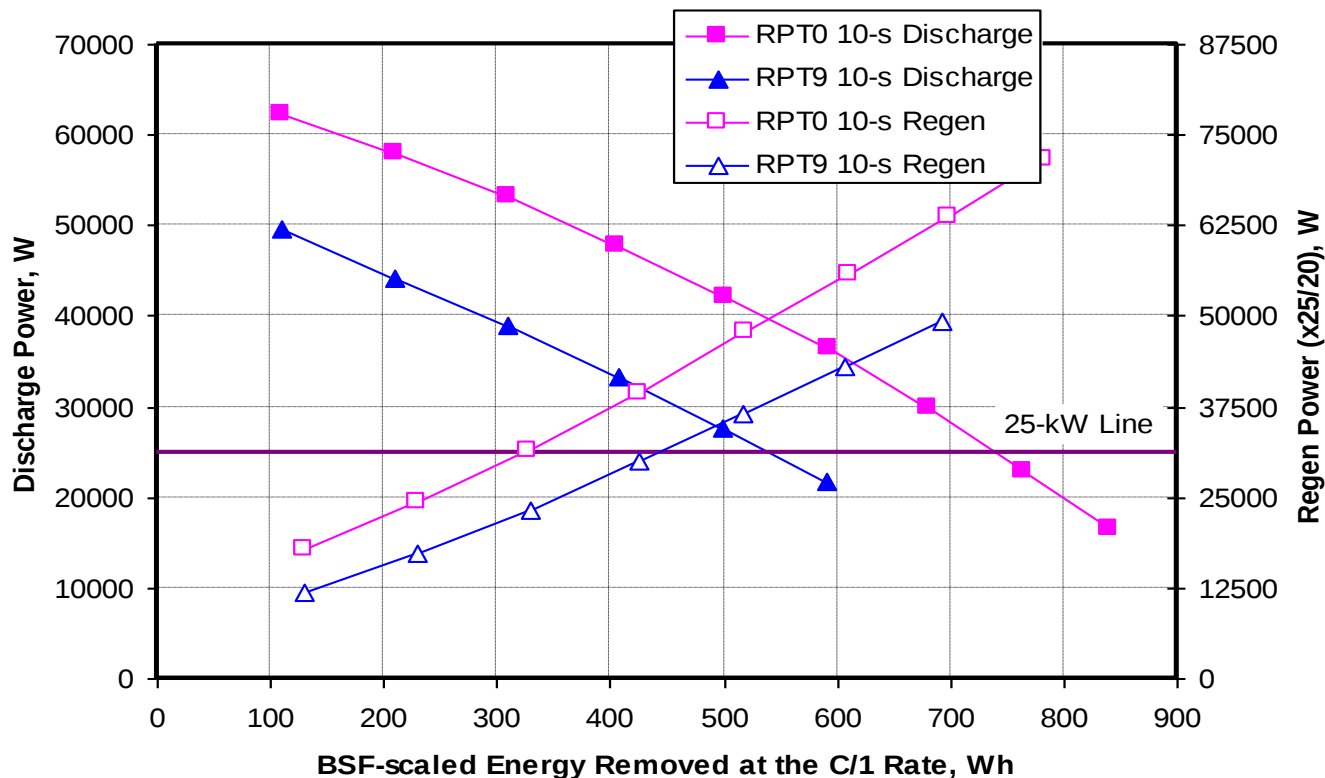
Battery Issues

- **Lithium ion batteries for HEVs are close to commercialization**
 - Gradual displacement of NiMH batteries is expected as Lithium ion promises increased performance and longer life.
- **PHEV battery issues**
 - Limited availability and production capacity
 - Cost: current batteries are 10X the DOE goal (\$3000/kWh today vs. \$250/kWh goal in 2015)
 - Life: projections of 10-15 years are based on limited data
 - Abuse tolerance
 - Low-temperature performance
- **Emerging technologies – Improved chemistry**
 - $\text{Li}_4\text{Ti}_5\text{O}_{12}$ and alloy composite negatives
 - LiFePO_4 , LiMnPO_4 , and other layered-spinel electrodes

HEV Batteries - power and energy fade

Power level decreases with time

Energy window at constant power decreases with time



DOE Technology Development Roadmap

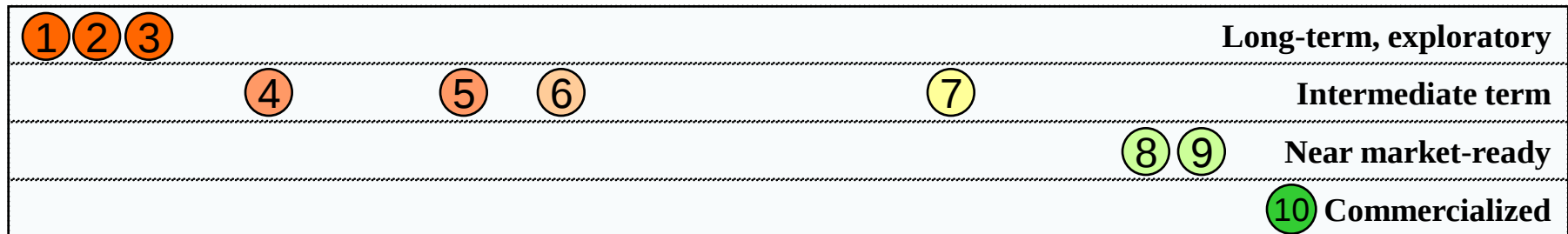
HEV to PHEV to EV

Research Goals

Specific Energy: 100 Wh/kg (by 2010)
150 Wh/kg (by 2015)

Cost Goals

HEV: \$20/kW (by 2010)
PHEV: \$250/kWh (by 2015)



- | | | |
|-------------------------------|----------------------------|------------------------|
| 1. Li Metal Polymer | 5. Graphite/Mn spinel | 8. Ultracapacitors |
| 2. Li/Sulfur system | 6. Graphite/Iron phosphate | 9. Low cost separators |
| 3. Li alloy/high V TMO system | 7. Graphite/Nickelate | 10. NiMH |
| 4. Li titanate/Mn spinel | | |

DOE PHEV Battery Activities

- DOE PHEV R&D Plan
- Prototype Saft Li-ion 41Ahr, 10kWh packs and cells
- Evaluated at ANL, INL, So California Edison
- PHEV Battery Test Procedures Manual in development
- DOE/USABC solicitation
- Testing batteries in PHEV vehicle conversions

DOE Vehicle Testing

- Vehicle systems – FreedomCAR Program
 - **Advanced Vehicle Testing Activity (AVTA)**
 - Hydrogen ICE
 - EV and HEV
 - **Plug-in HEV (PHEV)**
 - Power Electronics
 - PHEV grid interaction studies (Planned)
 - Fuel type testing (Ethanol and Bio-diesel fuels Planned)
 - **Vehicle energy storage**
 - Heavy vehicle technology

AVTA Focus

Provide benchmark data for DOE technology modeling, simulations, research and development activities, as well as fleet managers and other vehicle purchasers for informed purchase and operations decisions

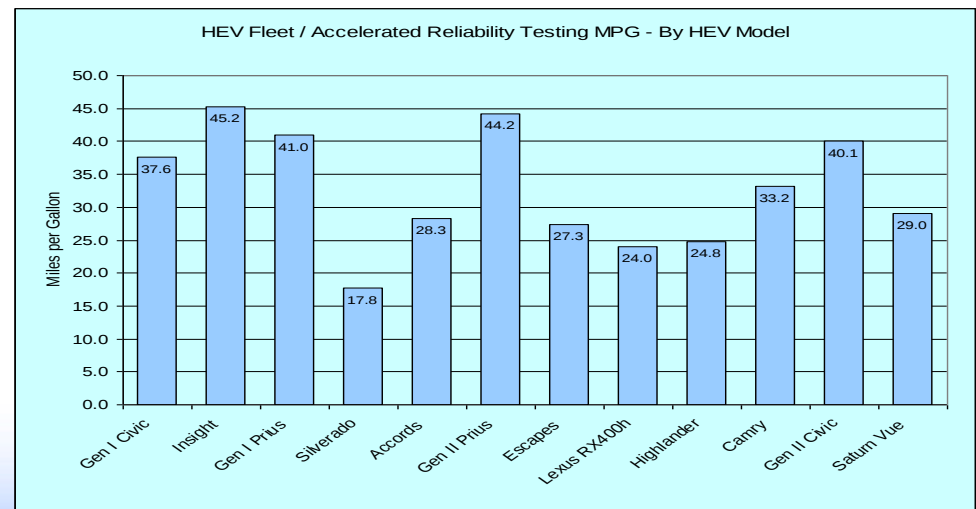
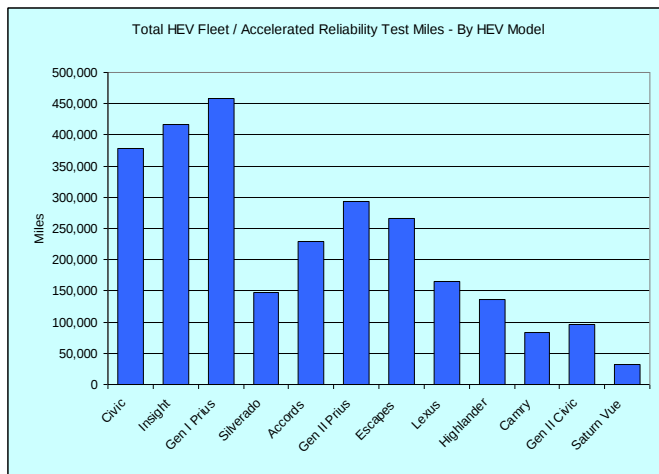
Vehicle Testing Methods

- Baseline performance testing
 - Test track and 26 drive cycle dynamometer tests
 - Battery capacity (Static Capacity) & power testing (Hybrid Pulse Power Characterization)
- Fleet testing
 - Fuel use and type, miles, maintenance, repairs, insurance, registration, new & residual values = life cycle costs
- Accelerated testing
 - Utilizes dedicated drivers using on-road drive cycles
- End-of-life testing
 - Battery capacity (Static Capacity) & power testing (Hybrid Pulse Power Characterization)

Experience – HEV Testing



- 12 HEV models baseline performance tested to date
- At least 2 HEVs per model tested 160,000 miles per HEV in 36 months – capture fuel & operating requirements, & life cycle costs
- 35 HEVs with 2.7+ million test miles to date
- HEV battery capacity (Hybrid Pulse Power Characterization) & power tested (Static Capacity) when new & end-of-life



PHEV Testing Status

- Developed Draft PHEV test plan
 - Validated using EnergyCS Prius and Renault Kangoo
 - Available and under review
 - Covers baseline performance, accelerated, fleet and battery testing
- Vehicles and batteries in testing
 - Kangoo (Renault) - **NiCd**
 - Hymotion (Civic, Escape and Prius), Energy CS (Prius), Electrovaya (Escape), HybridsPlus (Prius) - **all lithium ion**
 - Valence, A123, Electrovaya (lithium ion batteries)
 - High cost, >1000 small cells, life undetermined



PHEV Accelerated Testing – per vehicle

- Executed in Phoenix - 4,280 miles / ~3 months
- GPS unit tracks distance, average & max speeds

Cycle (mi)	Urban (10 mi)	Highway (10 mi)	Charge (hr)	Reps (N)	Total (mi)	Reps (%)	Miles (%)	Cum. (mi)
10	1	0	4	60	600	45%	14%	600
20	1	1	8	30	600	23%	14%	1200
40	4	0	12	5	200	4%	5%	1400
40	2	2	12	5	200	4%	5%	1600
40	0	4	12	5	200	4%	5%	1800
60	2	4	12	10	600	8%	14%	2400
80	2	6	12	8	640	6%	15%	3040
100	2	8	12	6	600	5%	14%	3640
200	2	18	12	3	600	2%	14%	4240
Total	1740	2500	984	132	4240			4240
Average	41%	59%	7.5	32.1				

PHEV battery charging study

- Understand the requirements & costs of PHEV charge infrastructure based on use patterns.
- PHEV trip analysis – vehicle survey & actual PHEV use
- Infrastructure cost analysis based on charging locations
- PHEV cost effectiveness versus “standard” HEV

Additional PHEV Grid Activities

- Site Evaluations and economic/infrastructure impacts
 - Deploy vehicles at various sites and conduct charging pattern evaluations for real world data on loads and charging use patterns as well as other V2G connection challenges.
 - Work with utilities to determine grid distribution and infrastructure issues associated with PHEV load growth.
 - Catalog regulatory requirements impacting PHEV connections to the grid.
 - Various economic and generation issues and impacts in partnership with utilities.

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