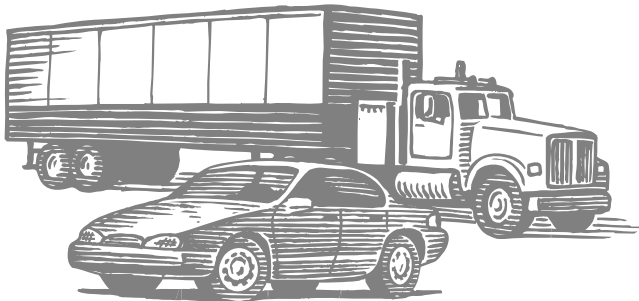


Plug-in Hybrid Electric Vehicle Energy Storage System Design

Advanced Automotive Battery Conference
by

Tony Markel and Andrew Simpson
National Renewable Energy Laboratory

May 19th, 2006



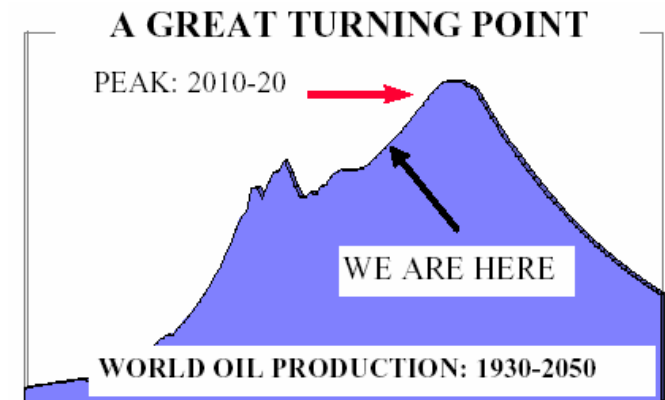
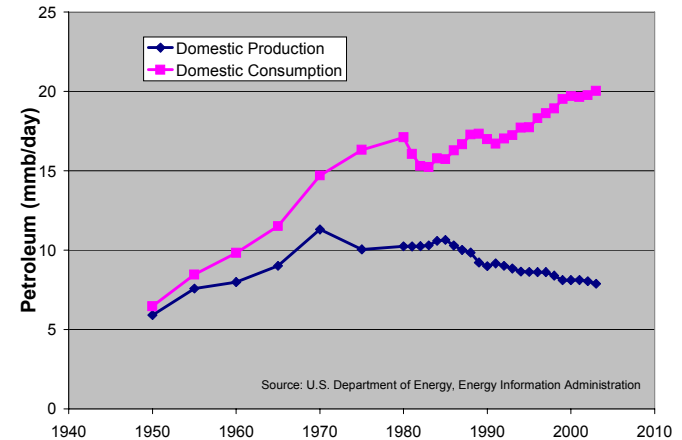
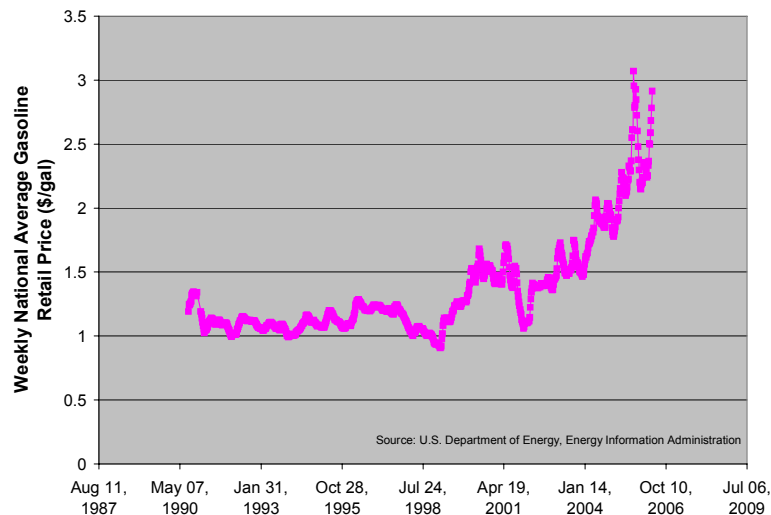
With support from the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
FreedomCAR and Vehicle Technologies Program



The Perfect Storm

- Petroleum **consumption** has steadily **increased** while domestic **production** has continued to **decline**
- World oil **production** predicted to **peak** within the next 5-15 years
- Recent increase in **gasoline price** is indicator of **growing tension** between supply and demand

Gasoline price - 85% rise in 5 years!

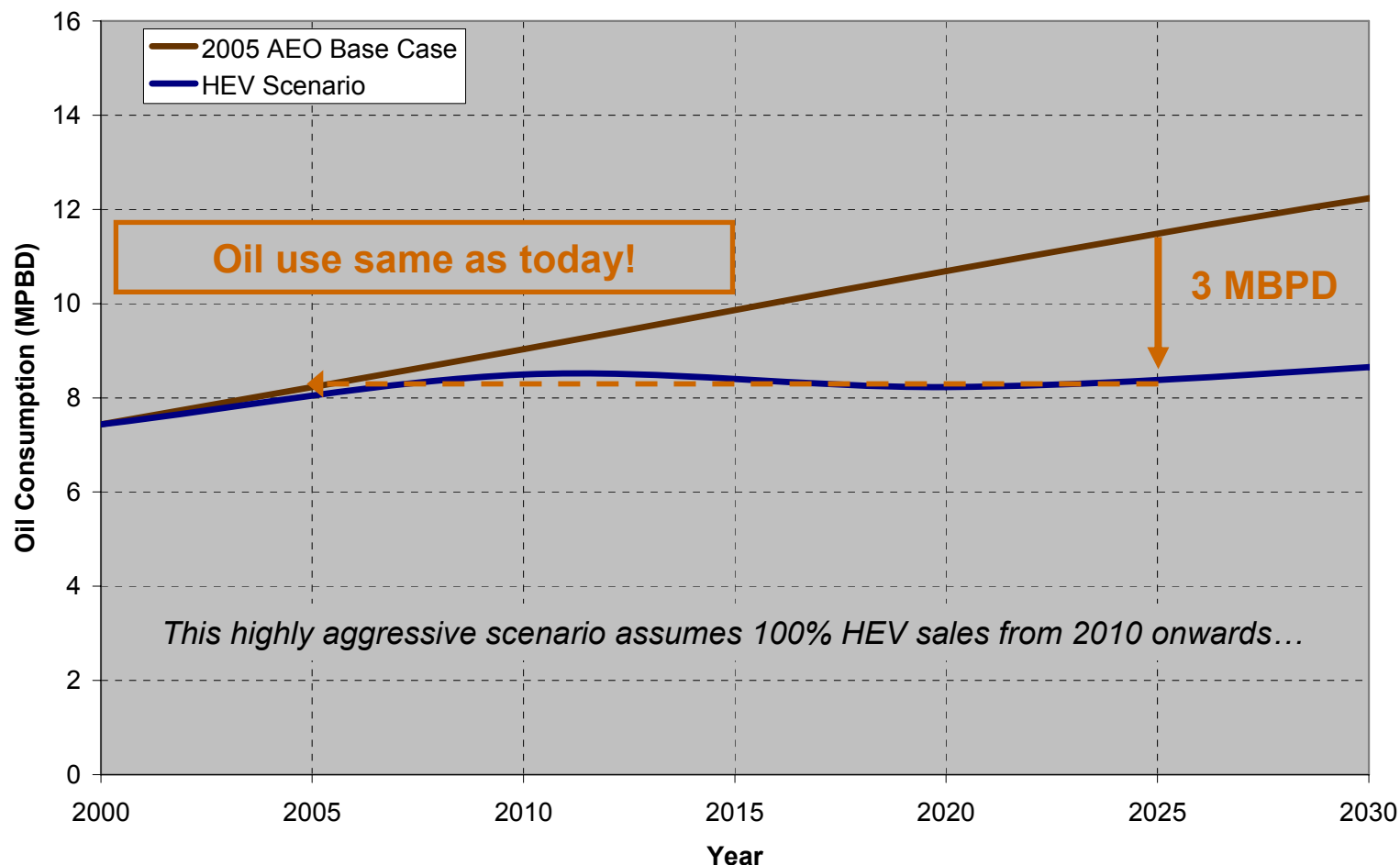


Source: Hubbert Center Newsletter #99/1 R. Udall and S. Andrews

WHAT'S OUR PLAN?

Oil Use Reduction with HEVs

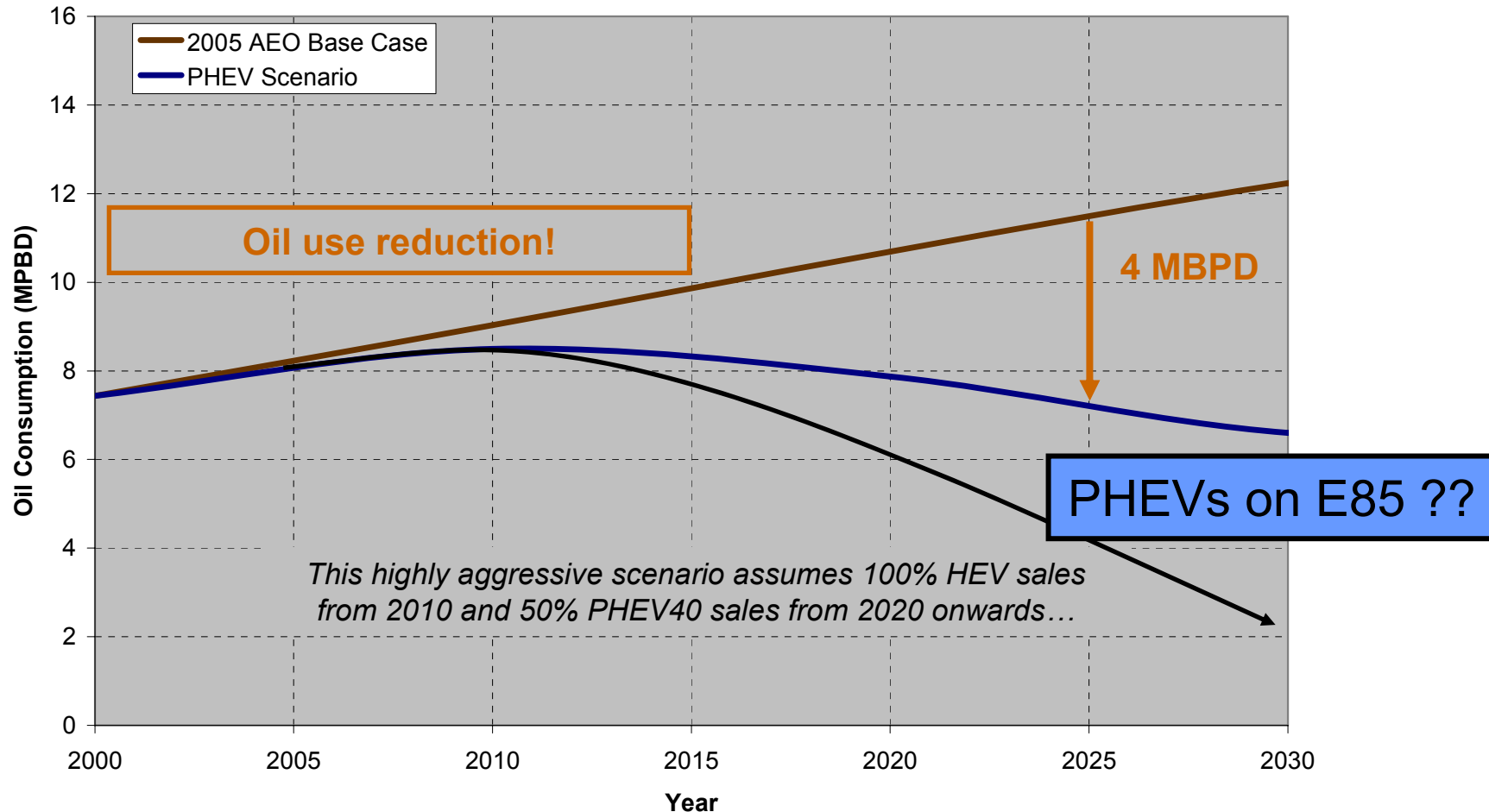
Light Duty Fleet Oil Use - Impact of HEVs on Consumption



HEVs unable to reduce consumption below today's consumption level

Oil Use Reduction with PHEVs

Light Duty Fleet Oil Use - Impact of PHEVs on Consumption



PHEVs reduce oil consumption with a transition to electricity

Recent PHEV Prototypes



EnergyCS Plug-In Prius



HyMotion Escape PHEV



DaimlerChrysler
Sprinter PHEV



Renault Kangoo
Elect'road



AC Propulsion
Jetta PHEV



Esoro AG H301



AFS Trinity
Extreme Hybrid™

PHEV Batteries



Johnson Controls / SAFT



Cobasys

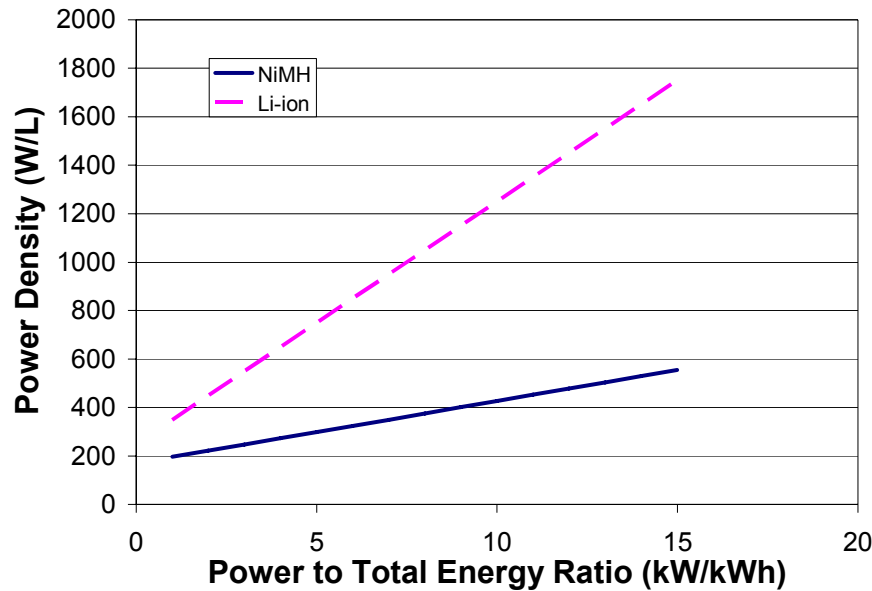


Valence Technologies

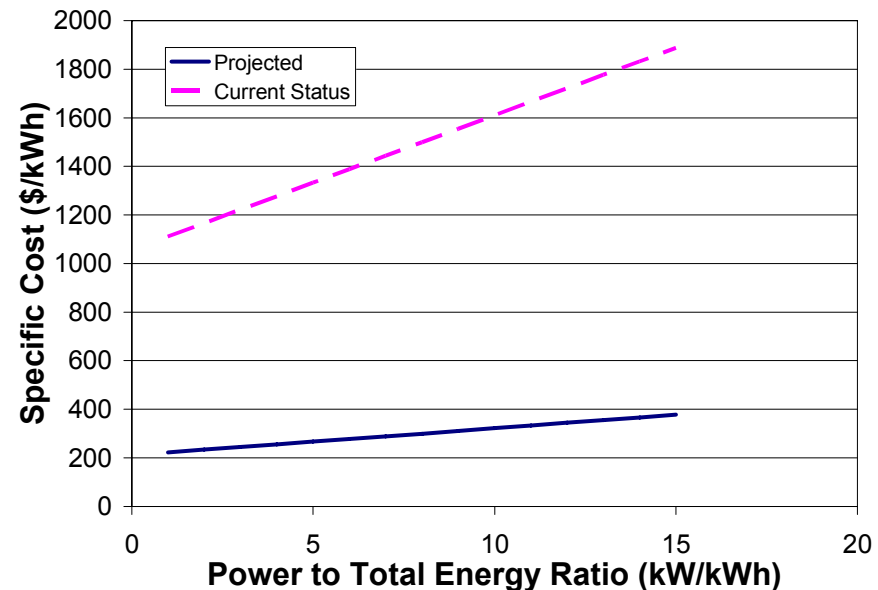
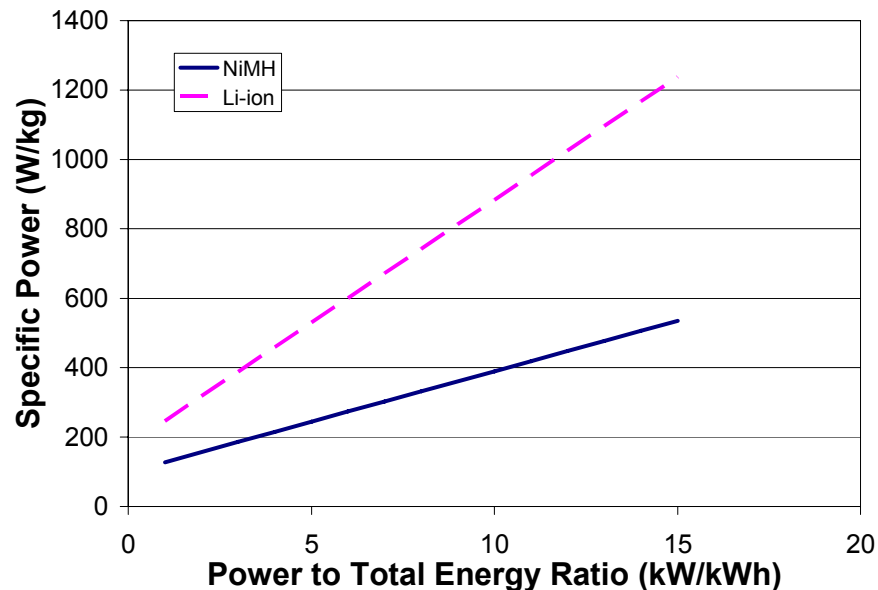


Hymotion

Battery Characteristics

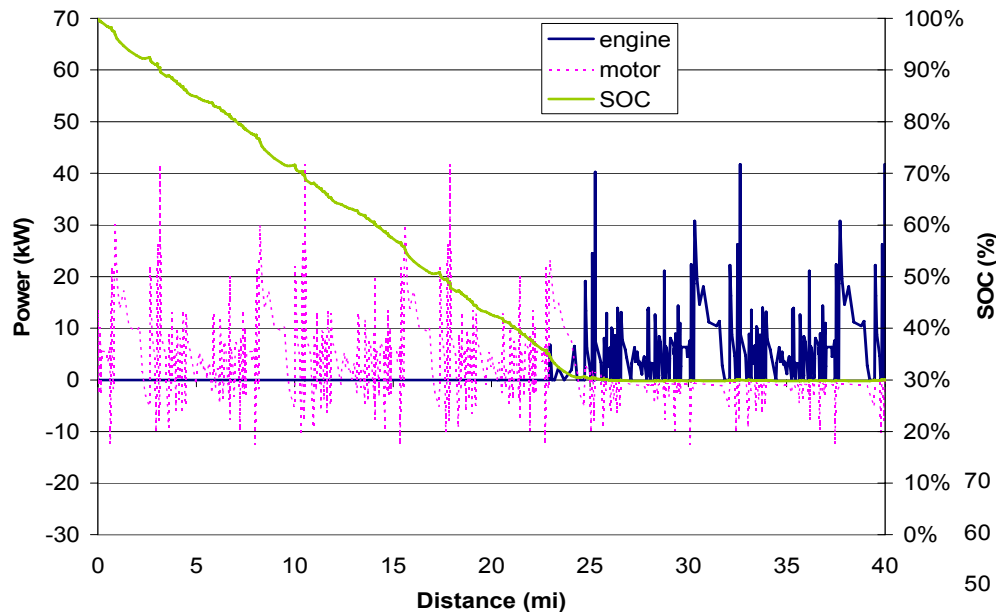


Lower power to energy ratio leads to lighter, smaller, and less expensive energy storage system



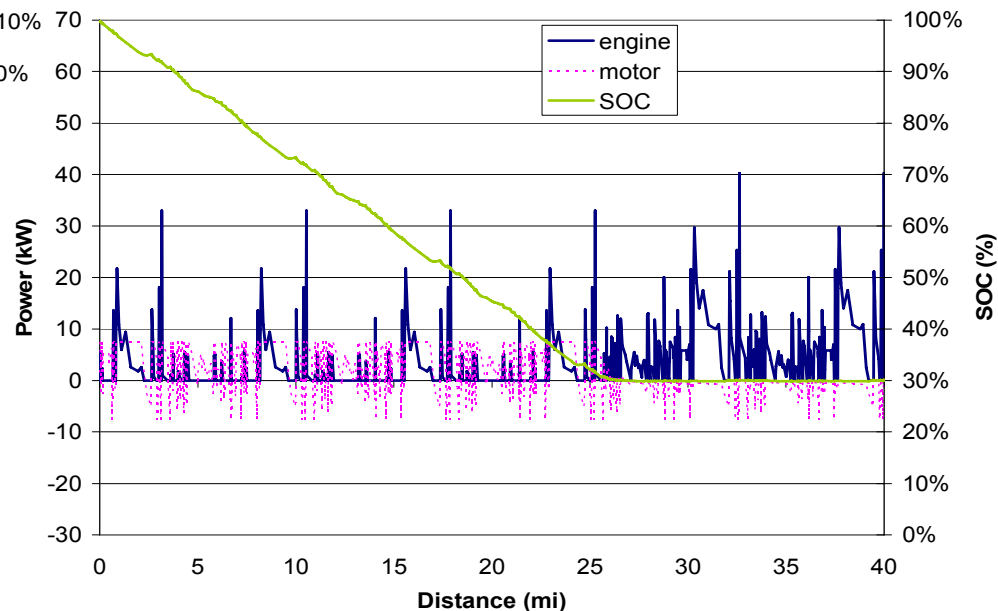
All-Electric vs Blended Strategy

All-Electric



- Engine turns on when battery reaches low state of charge
- Requires high power battery and motor

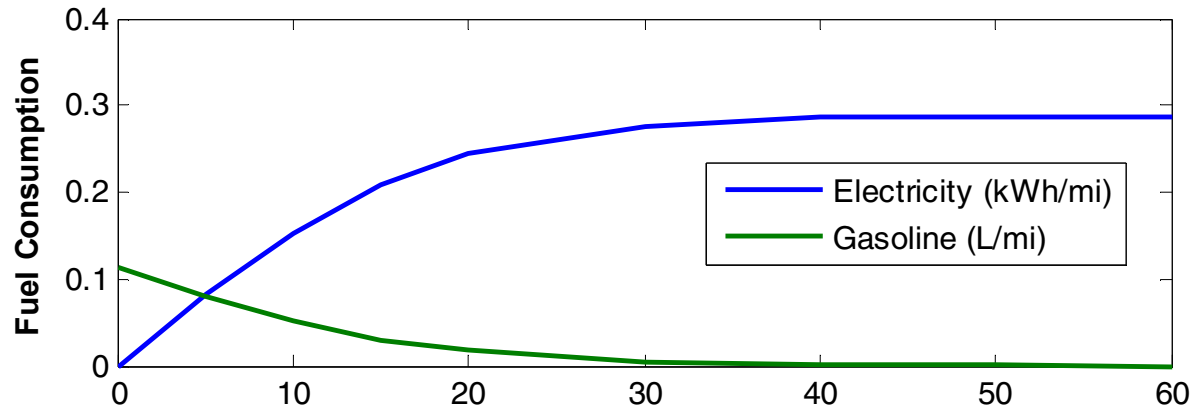
Blended



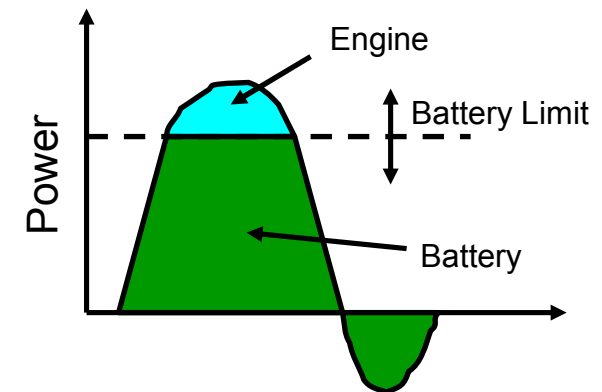
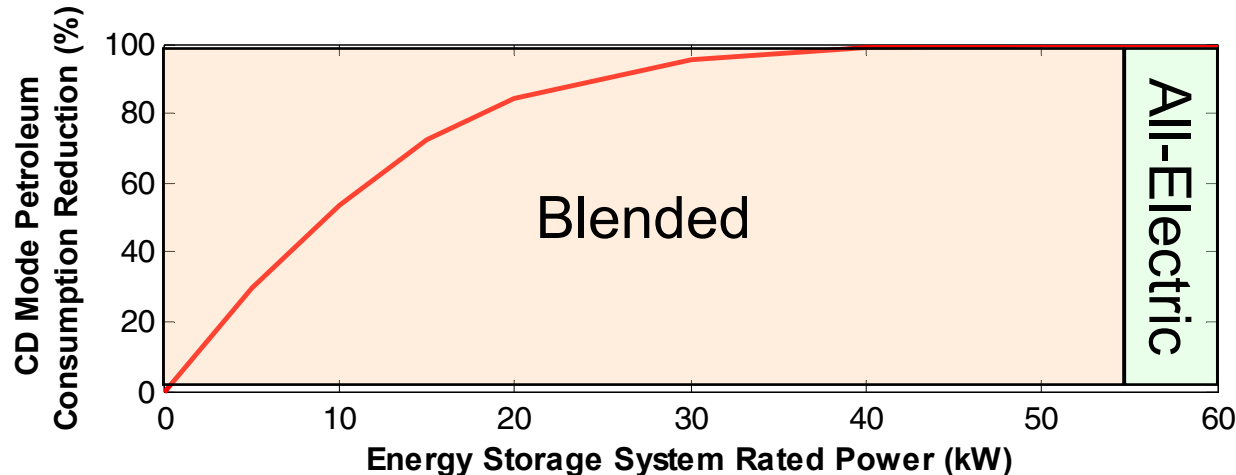
- Engine turns on when power exceeds battery power capability
- Engine only provides load that exceeds battery power capability

Blended vs. AER Consumption Tradeoff

PHEV20 on LA92

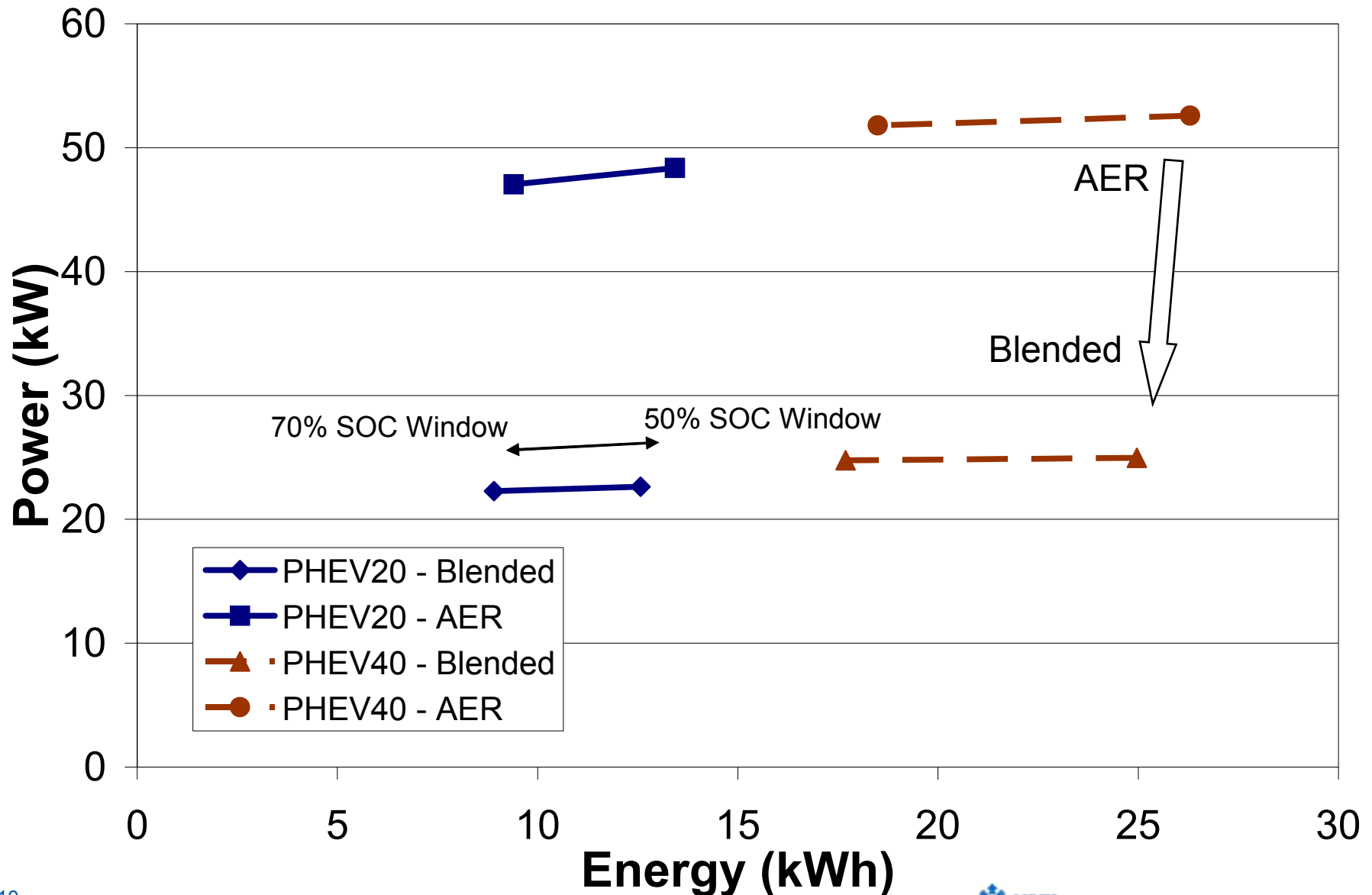


- Reducing ESS power should reduce cost, mass, volume
- 50% reduction in power still provides almost all of the fuel consumption benefit



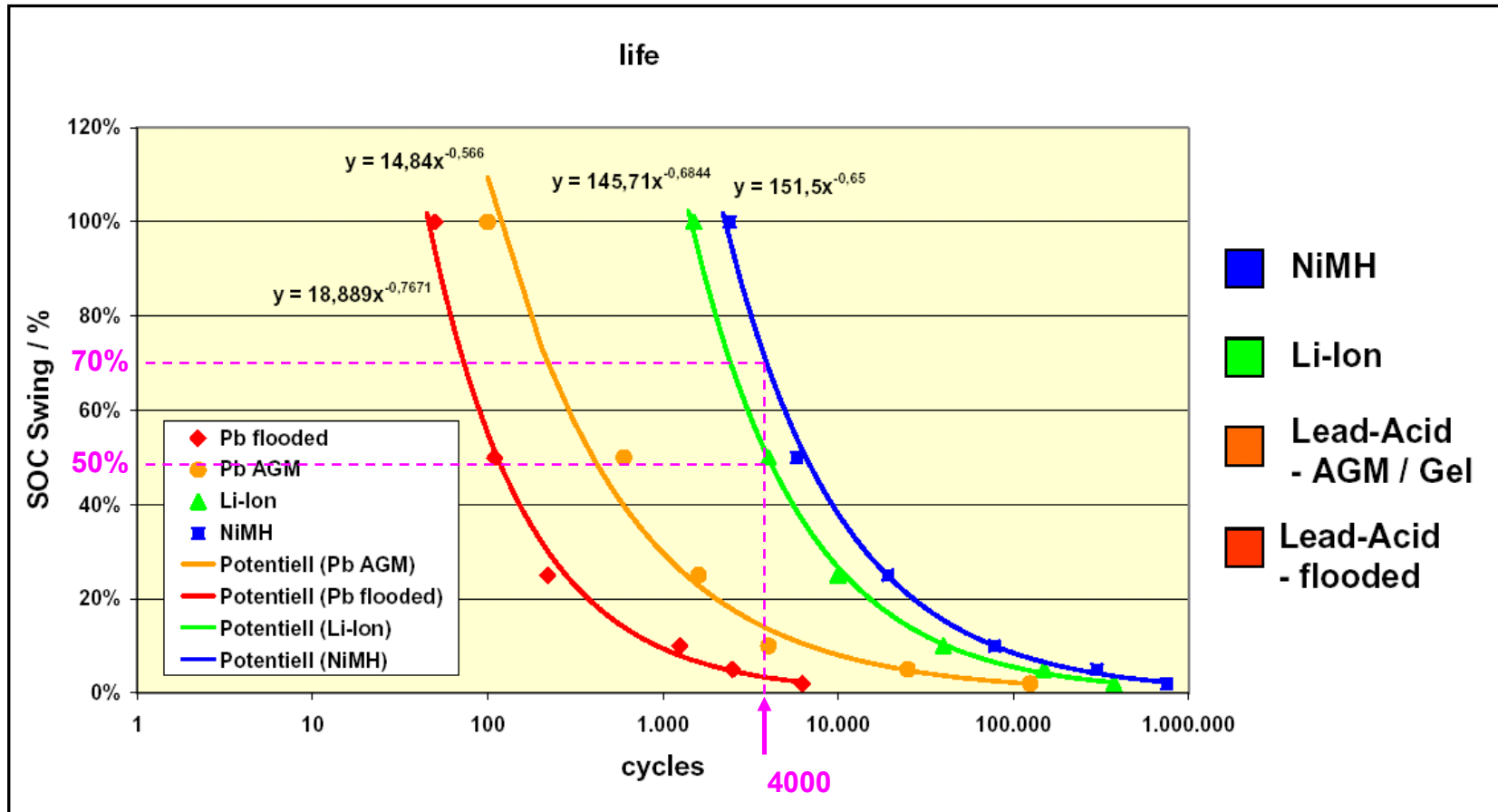
* CD = Charge Depleting

PHEV Battery Sizing Alternatives



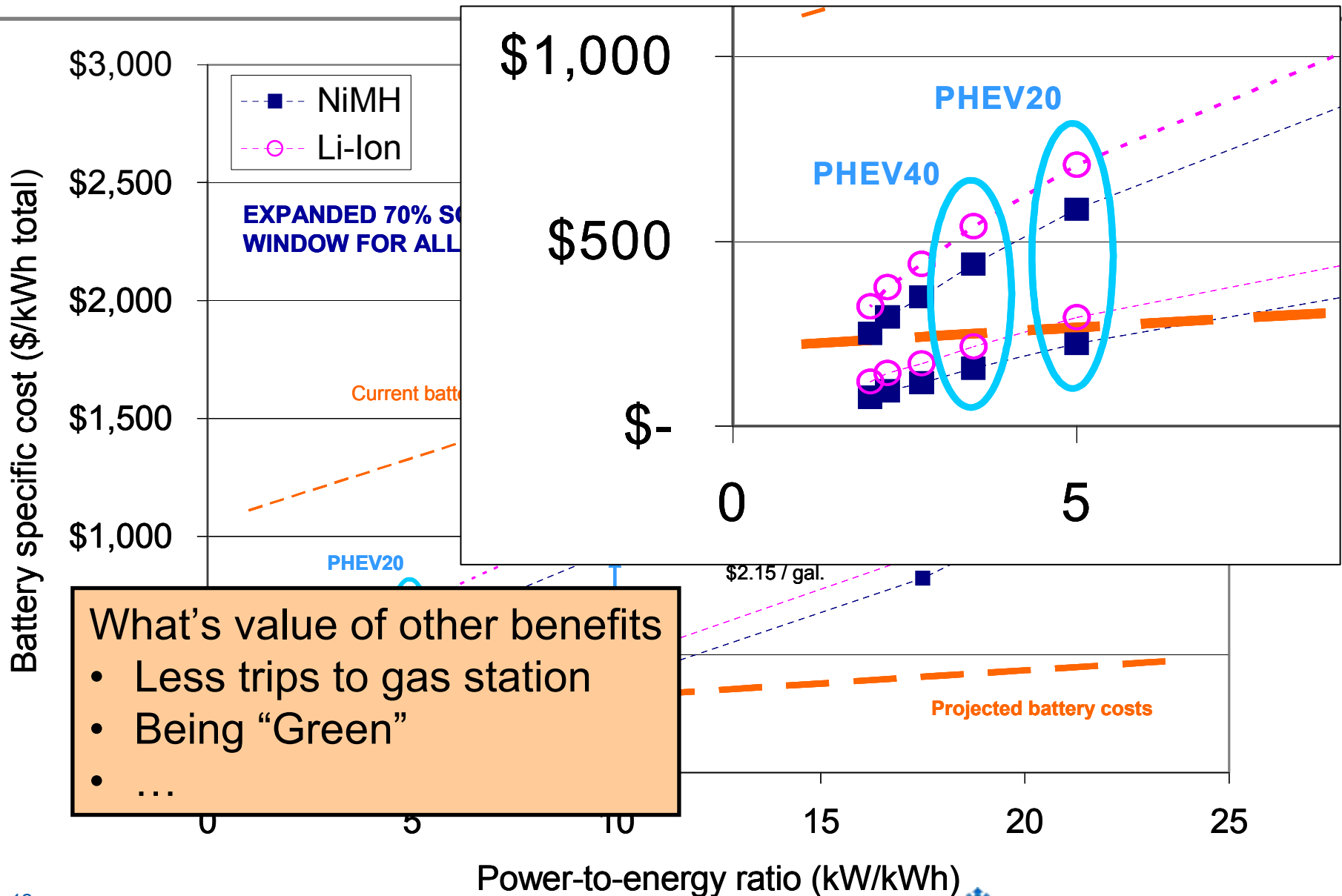
Battery Life

- PHEV battery likely to deep-cycle each day driven: 15 yrs equates to 4000-5000 deep cycles
- Also need to consider combination of high and low frequency cycling



Data presented by Christian Rosenkranz (Johnson Controls) at EVS 20

PHEV Battery Cost Requirements for 5 Year Payback



- Plug-in hybrid technology can reduce petroleum consumption beyond that of HEV technology
- The study highlighted some of the PHEV design options and associated tradeoffs
 - Expansion of the energy storage system usable state of charge window while maintaining life will be critical for reducing system cost and volume
 - A blended operating strategy as opposed to an all electric range focused strategy may provide some benefit in reducing cost and volume while maintaining consumption benefits
- The key remaining barriers to commercial PHEVs are battery life, packaging and cost