Plug-in HEVs: A Near-Term Option to Reduce Petroleum Consumption

from FY05 Milestone Report

Tony Markel, Michael O'Keefe, Andrew Simpson, Jeff Gonder, Aaron Brooker

National Renewable Energy Laboratory

Golden, Colorado

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Project Objective

- *Assess the opportunity for a future research program that will address plug-in hybrid electric vehicle (PHEV) market & technology issues.*

- Approach
  - Collect and assemble information and analysis to enhance our understanding of the benefits and barriers of plug-in hybrid technology

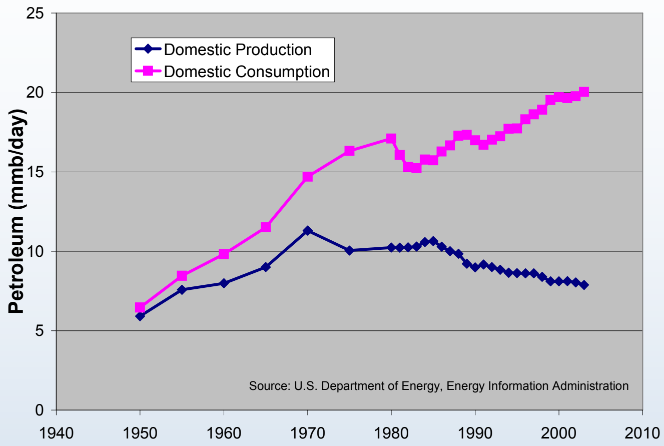
Messages

- Plug-in HEVs have the best near-term potential to reduce petroleum consumption by shifting demand to a variety of domestic sources including renewables

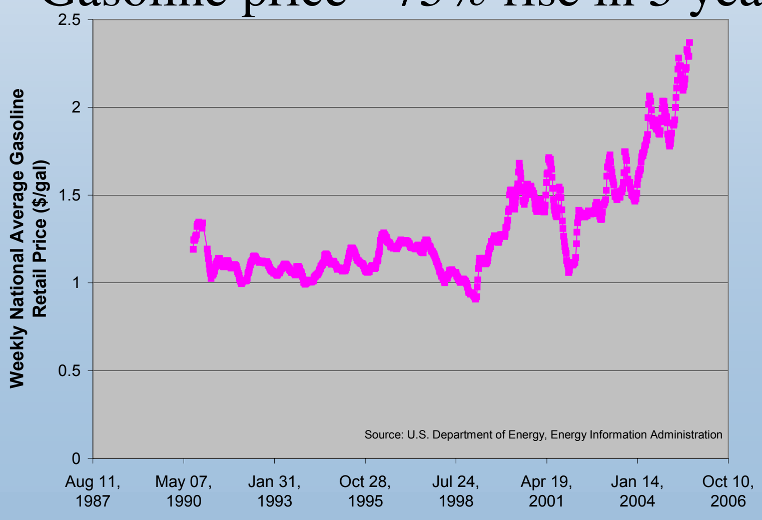
- Systems integration/optimization are essential to provide commercially viable options
  - Battery technology development critical but research pathway depends on application, vehicle configuration, and utility integration approach

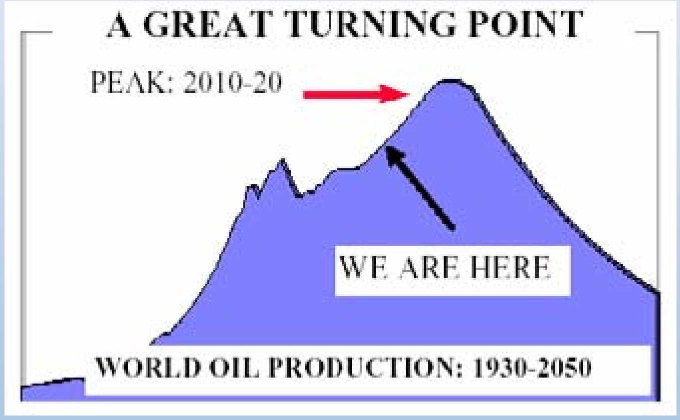
The Perfect Storm

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



Gasoline price - 75% rise in 5 years!





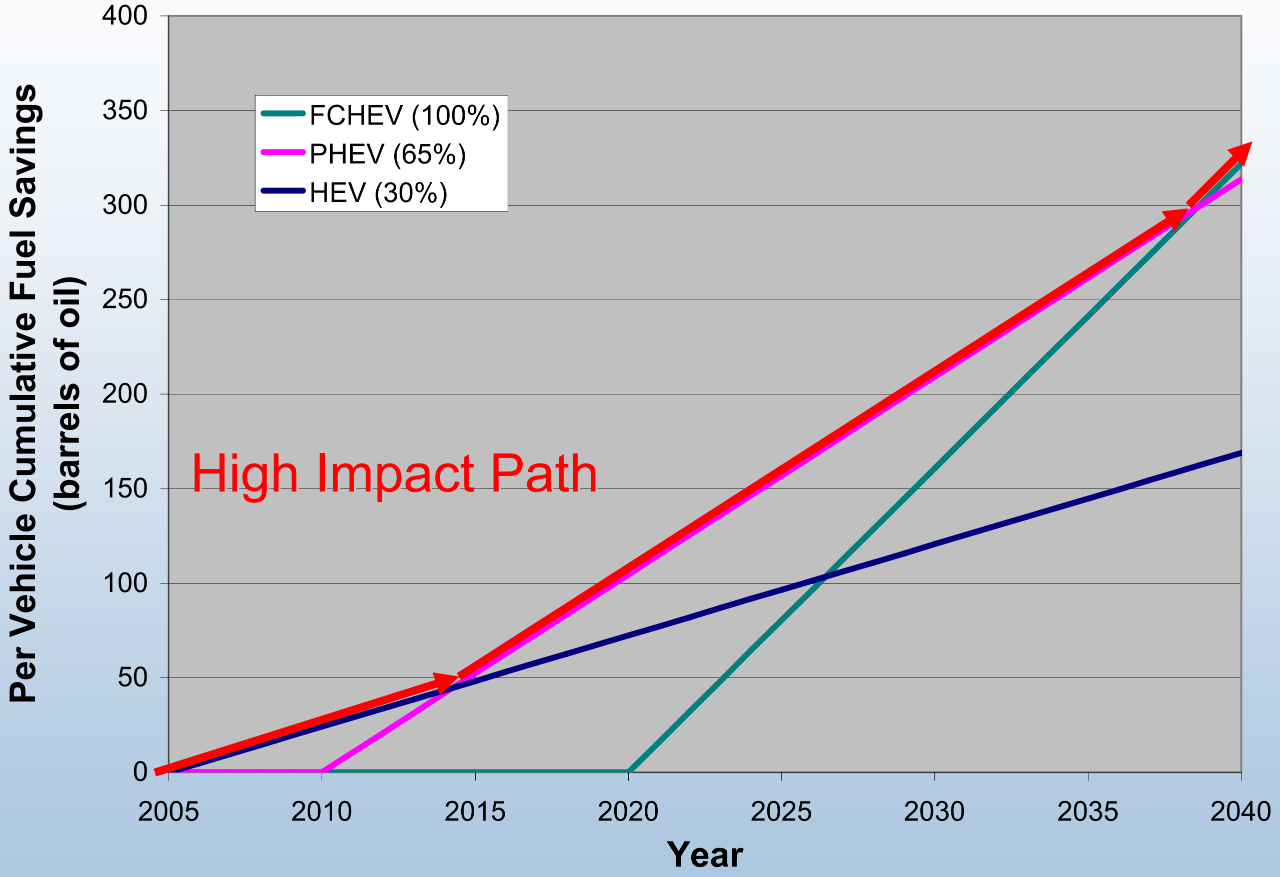
Source: Hubbert Center Newsletter #99/1 R. Udall and S. Andrews

What's our plan?

Vehicle Technology Options to Reduce Petroleum Consumption

- Hybrid electric vehicles (charge-sustaining)
  - Combines petroleum engine with a small energy storage device used over narrow window of operation
- Plug-in HEVs (charge-depleting)
  - Use larger energy storage device with the ability to recharge from both on-board and off-board sources with a petroleum engine providing continuous fast refuel operation
- Fuel cell hybrid vehicles
  - Replaces the petroleum engine with highly efficient fuel cell consuming hydrogen from non-petroleum sources – could be charge-sustaining or charge-depleting
- Electric vehicles
  - Large energy storage is the only source of propulsion energy

Cumulative Petroleum Savings Potential of Technology Options

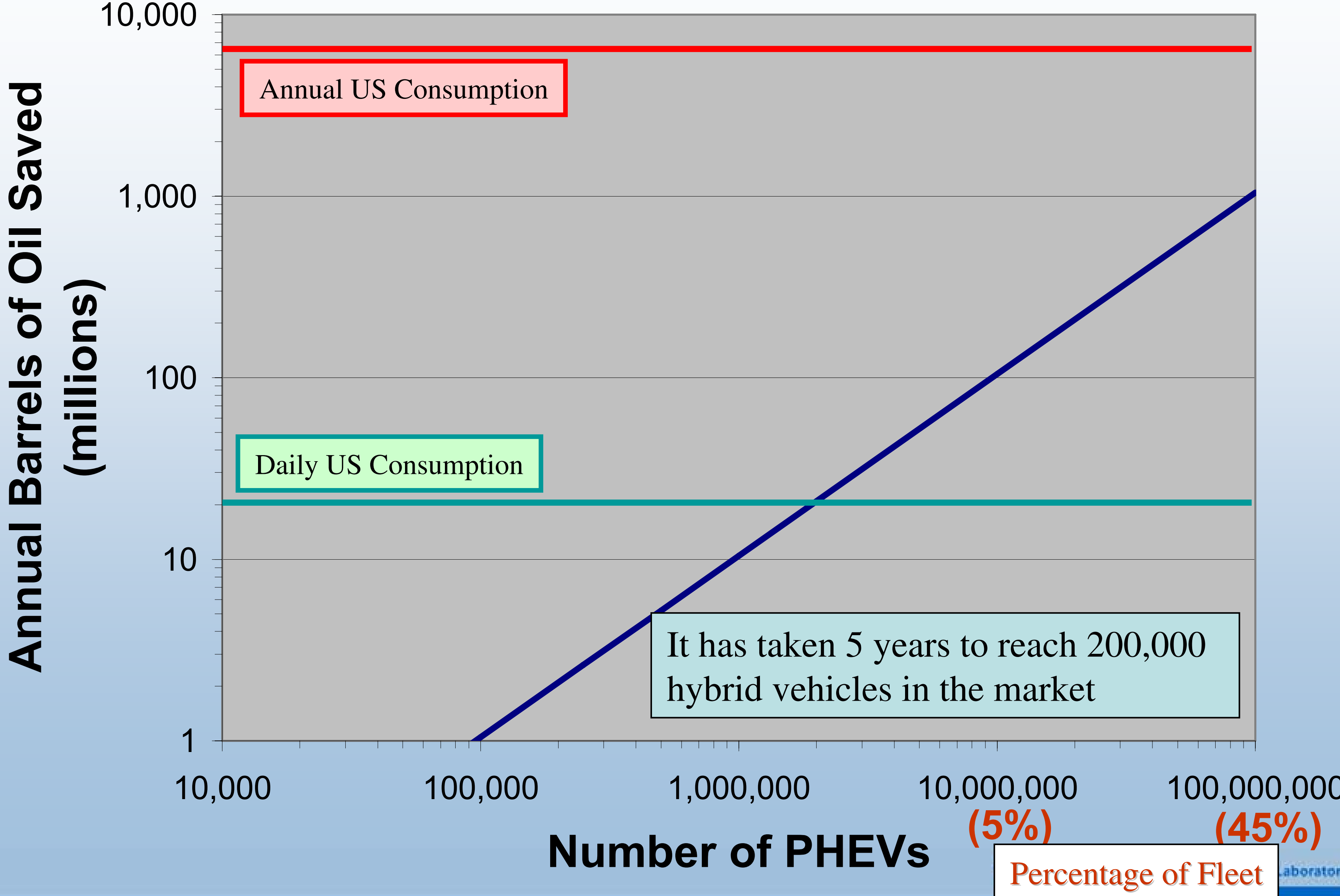


- Benefits from HEVs and PHEVs vary depending on application and design
- FCHEV assumes hydrogen fuel; and gains maximum benefit rate

Market penetration model not included - vehicle to vehicle comparison

❖ PHEVs provide the best combination of rate and timing to provide significant fuel consumption reduction benefits while hydrogen fuel cell technology is being developed

1,000,000 PHEVs Could Save ~10 Million Barrels of Oil Annually



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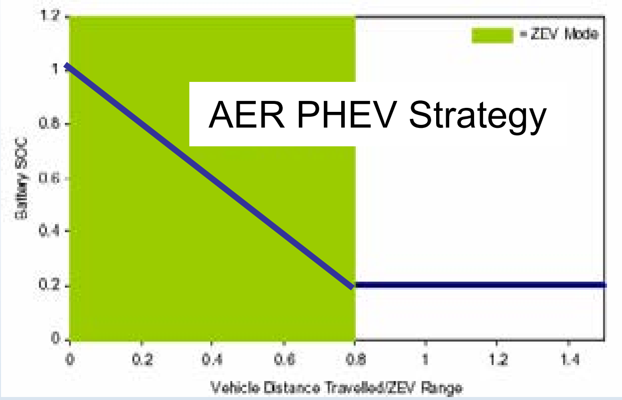
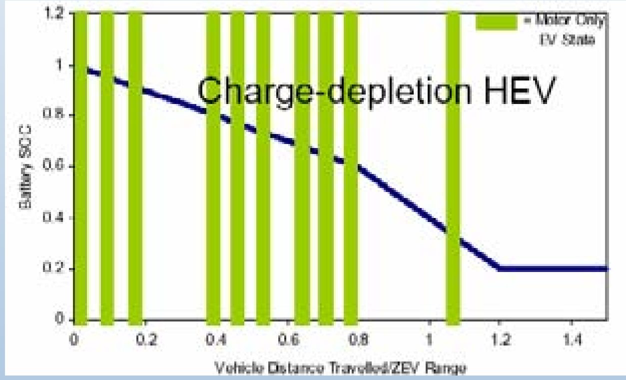
Plug-In HEV Design Options

- Typical Plug-in HEV characterized by All Electric Range (AER)
  - AER - miles driven after a full recharge until the gasoline engine first starts to assist
- Alternatively, Plug-in HEV design may focus on maximizing the electric-only miles dispersed throughout a driving pattern
  - maximizes the effective and efficient use of grid-electricity
- Combination of these two scenarios likely to provide optimal reduction in petroleum consumption
  - Use grid-electricity to off-set use of gasoline improve cycle average efficiency of the engine

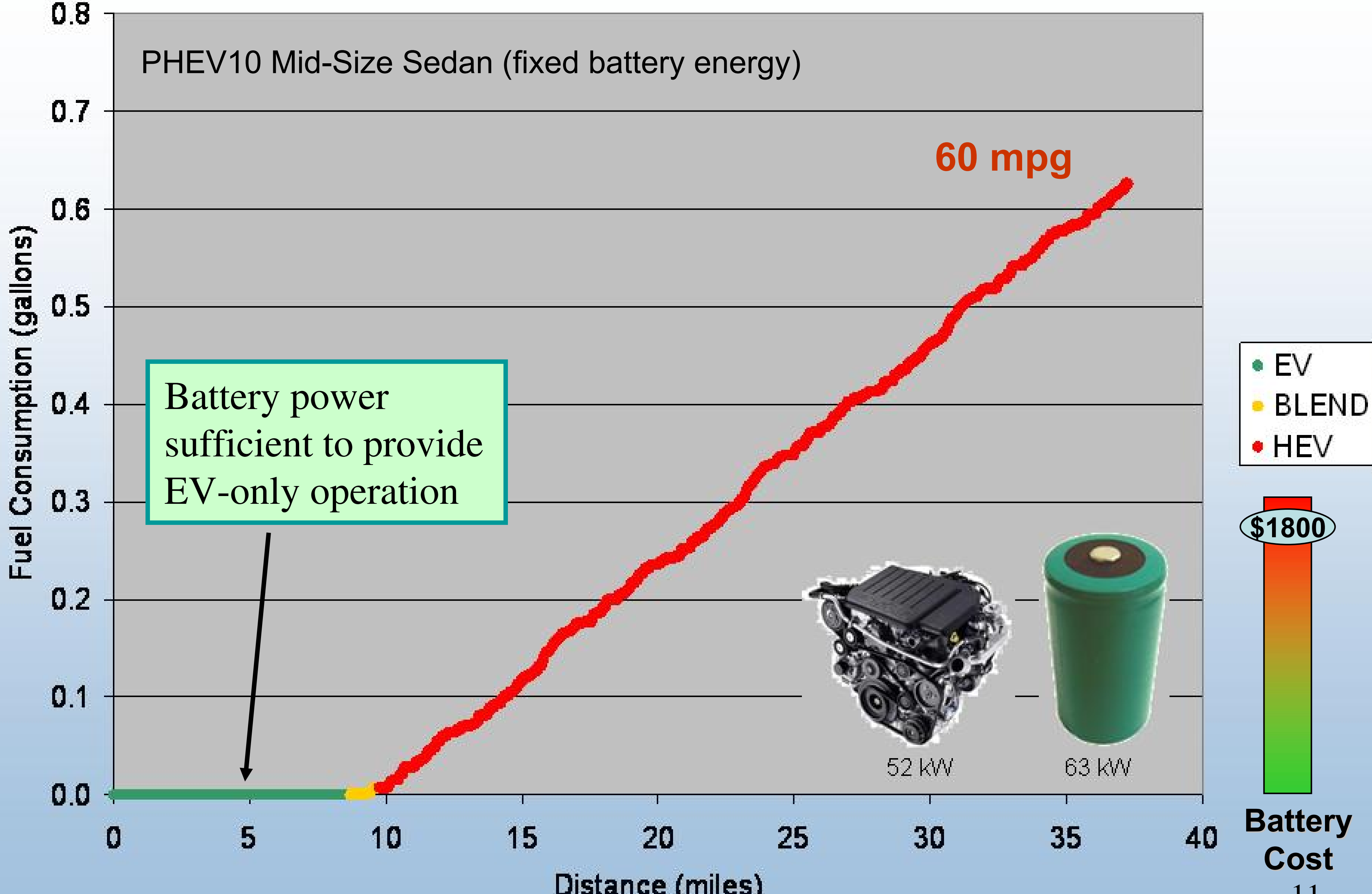




Source: Duval, M. "Plug-in HEV Workshop" EVS20

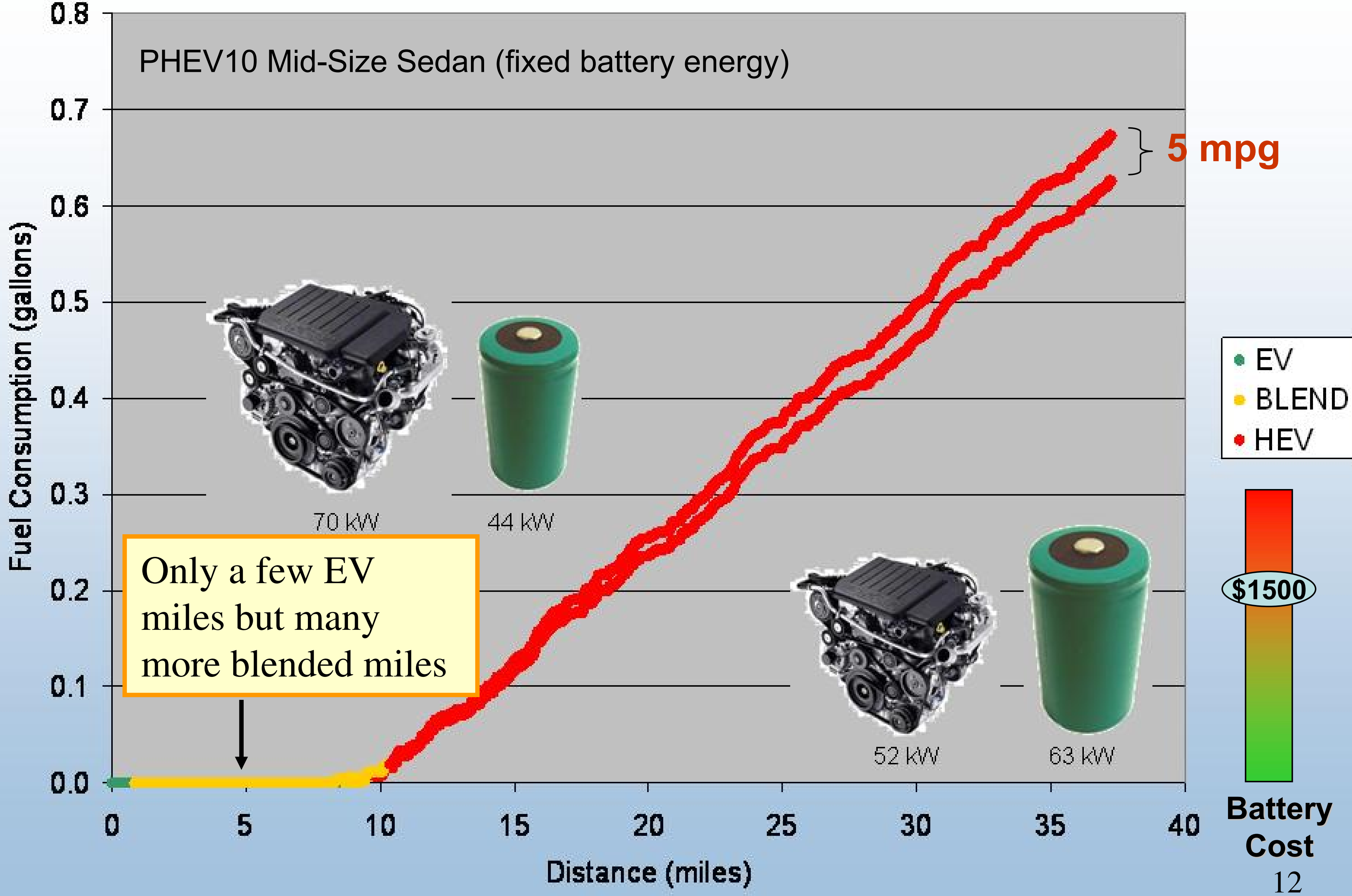
Component Sizing and Control Options

P/E = 20



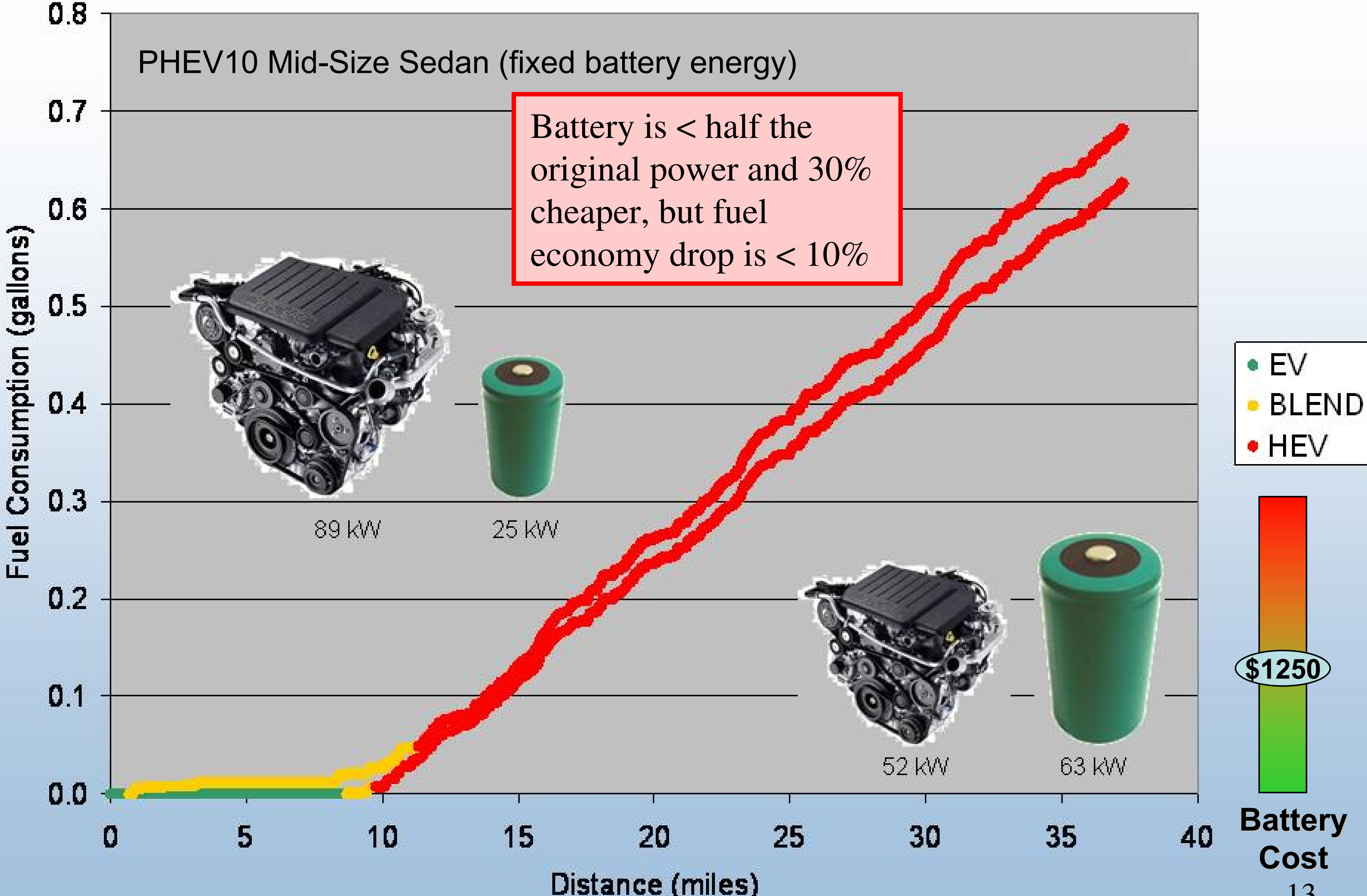
Component Sizing and Control Options

P/E = 14



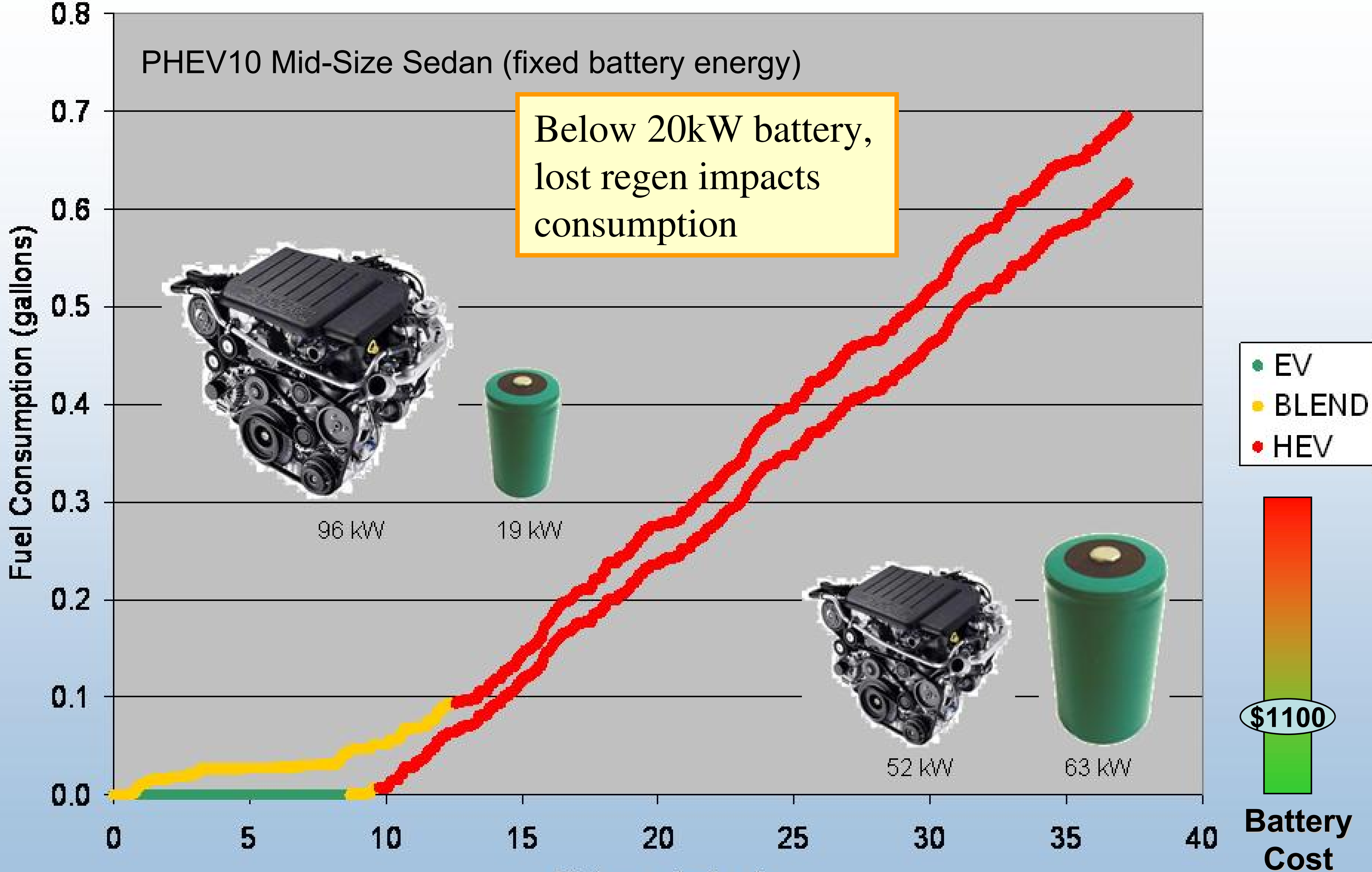
Component Sizing and Control Options

P/E = 8



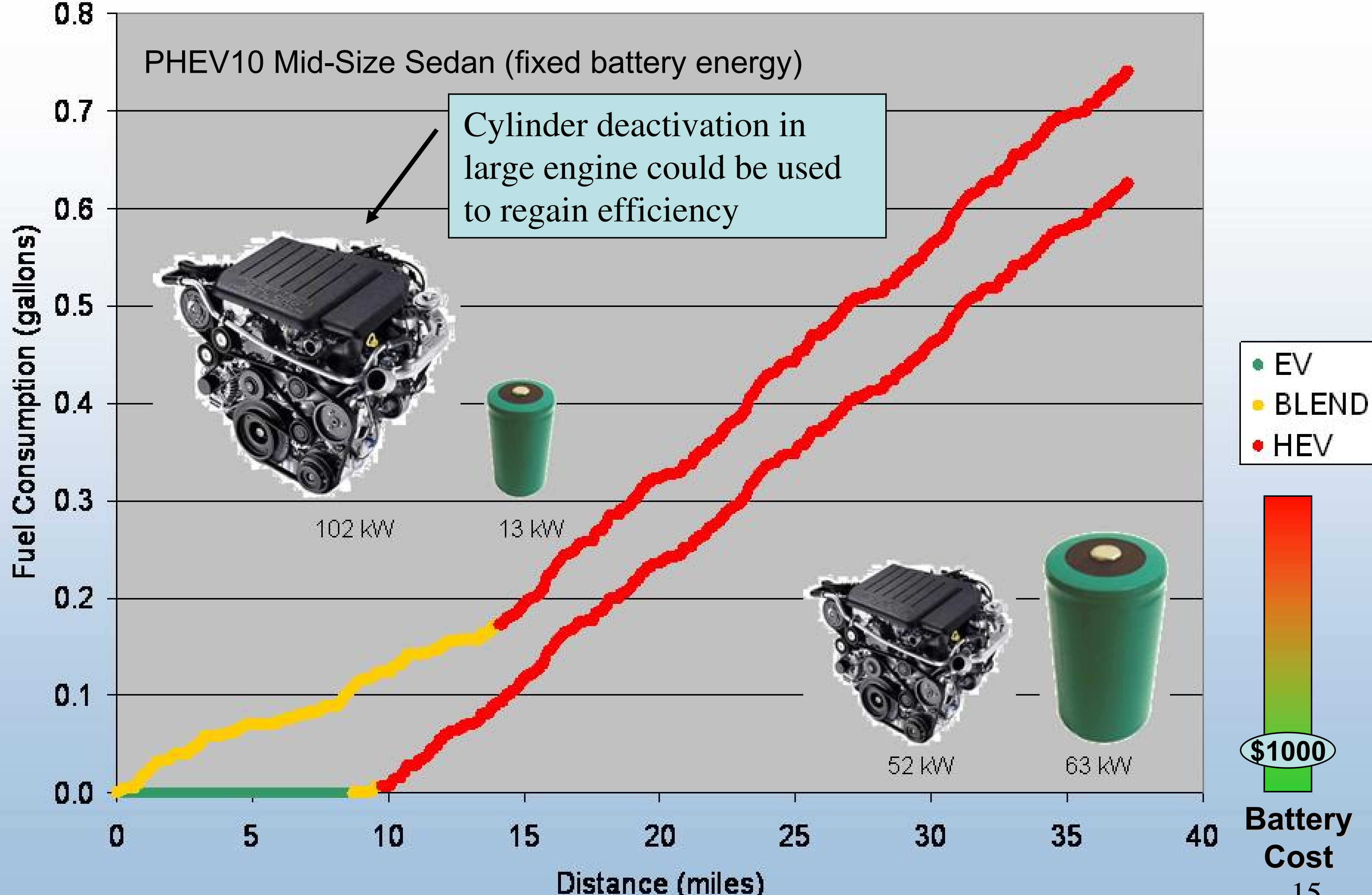
Component Sizing and Control Options

P/E = 6



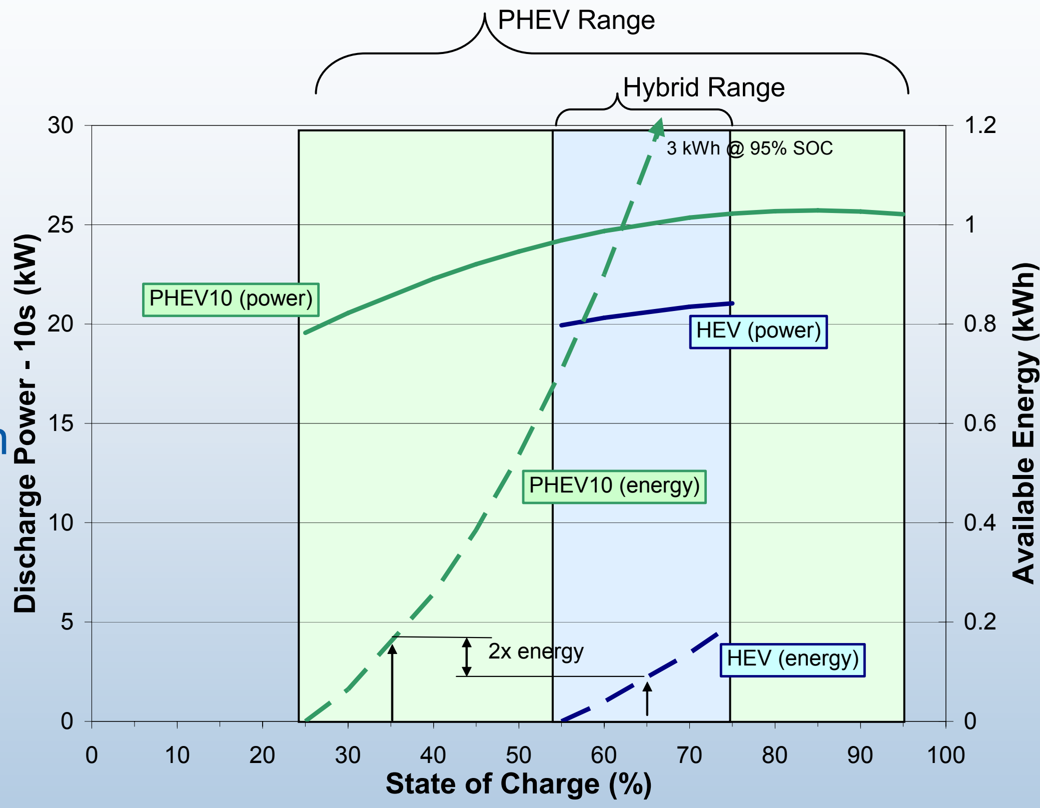
Component Sizing and Control Options

P/E = 4



Performance Variability Challenge

- Larger engine provides better continuous performance
  - Charge-sustaining fuel economy improvement potential directly related to engine downsizing
  - Peak power capability is a function of battery/motor power
- Battery power capability varies with state of charge
  - In charge-sustaining mode, battery/motor must be sized to maintain performance
- If vehicle performs best when fully charged, it is an incentive for the consumer to recharge often



Plug-in HEV10 battery even at low SOC level has equivalent power and twice the available energy of typical hybrid battery

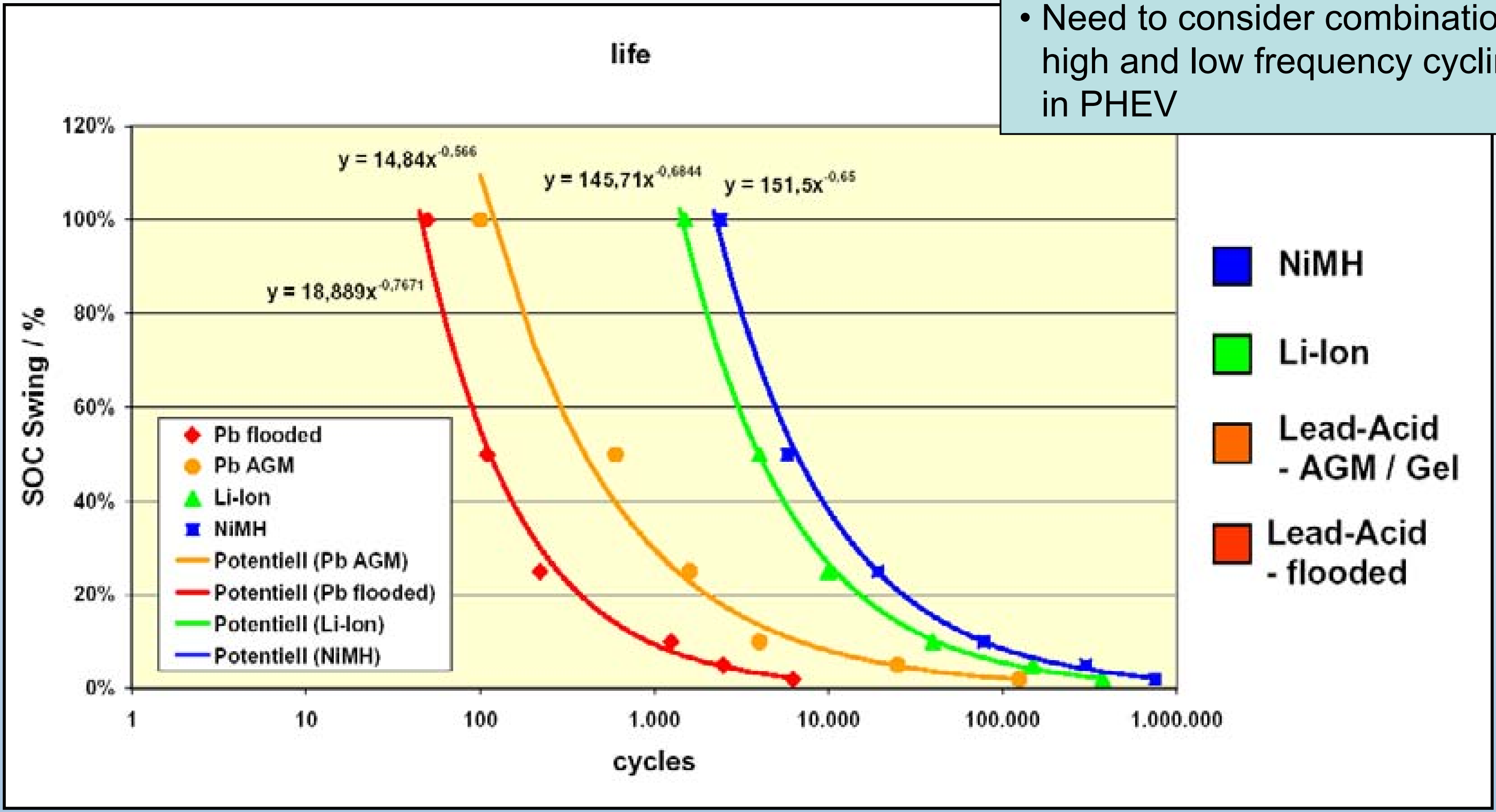
Cost and Life Challenge

- Deep cycling of batteries tends to shorten the number of cycles before end of life
  - Characterization of real-world cycling important
- Cost of advanced batteries high under today's low volume production situation
  - Selection of battery characteristics and system management provides solutions

Existing data sets provide limited view of future potential
Need more data to support conclusions

Battery Cycle Life Data

- Existing data is limited
- Need to consider combination of high and low frequency cycling as in PHEV



Source: Presented by Christian Rosenkranz (JCI) at EVS 20

Battery Cost Model: Specific Cost vs. P/E Ratio

- Slope and magnitude of relationship are long-term and debatable

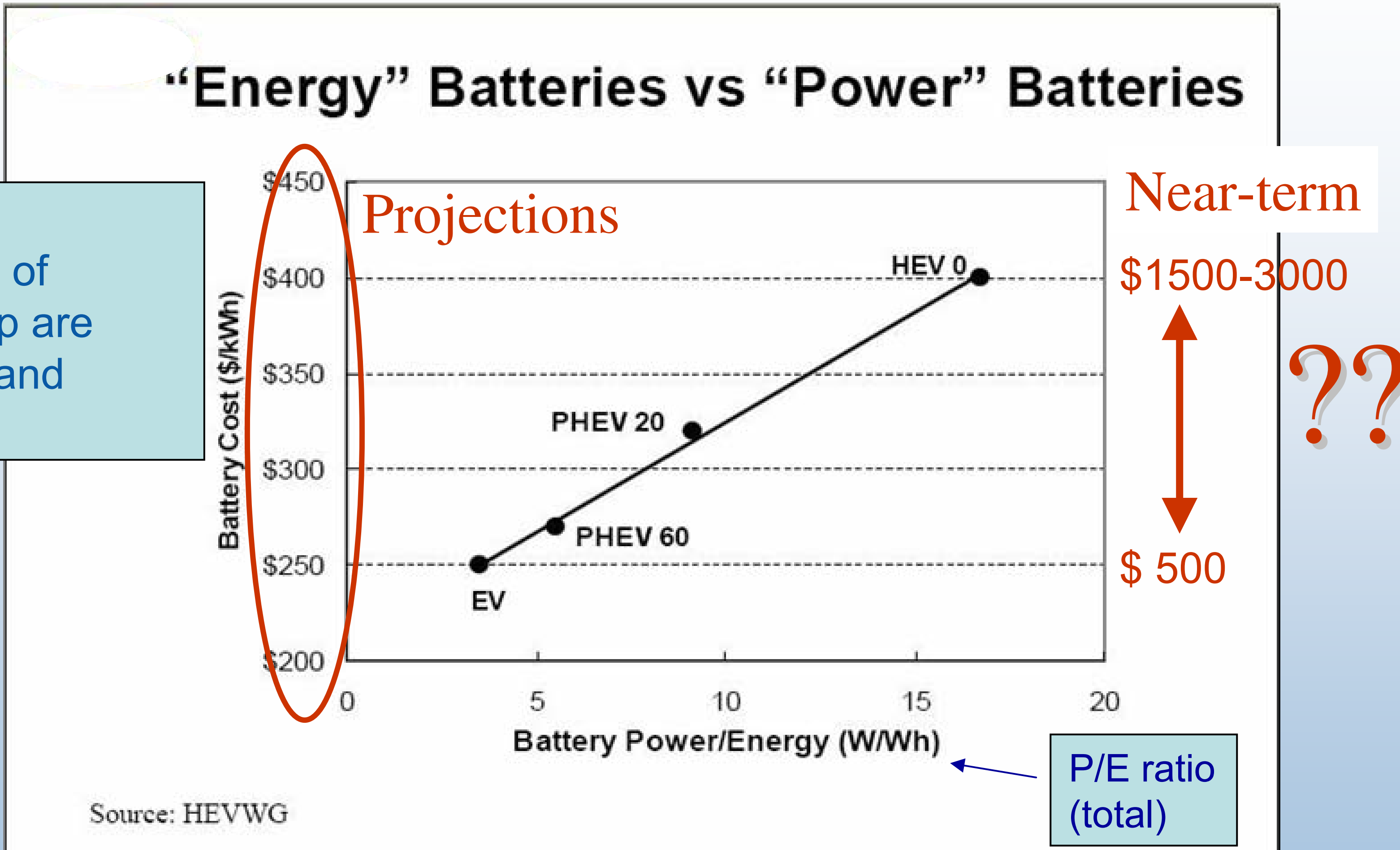
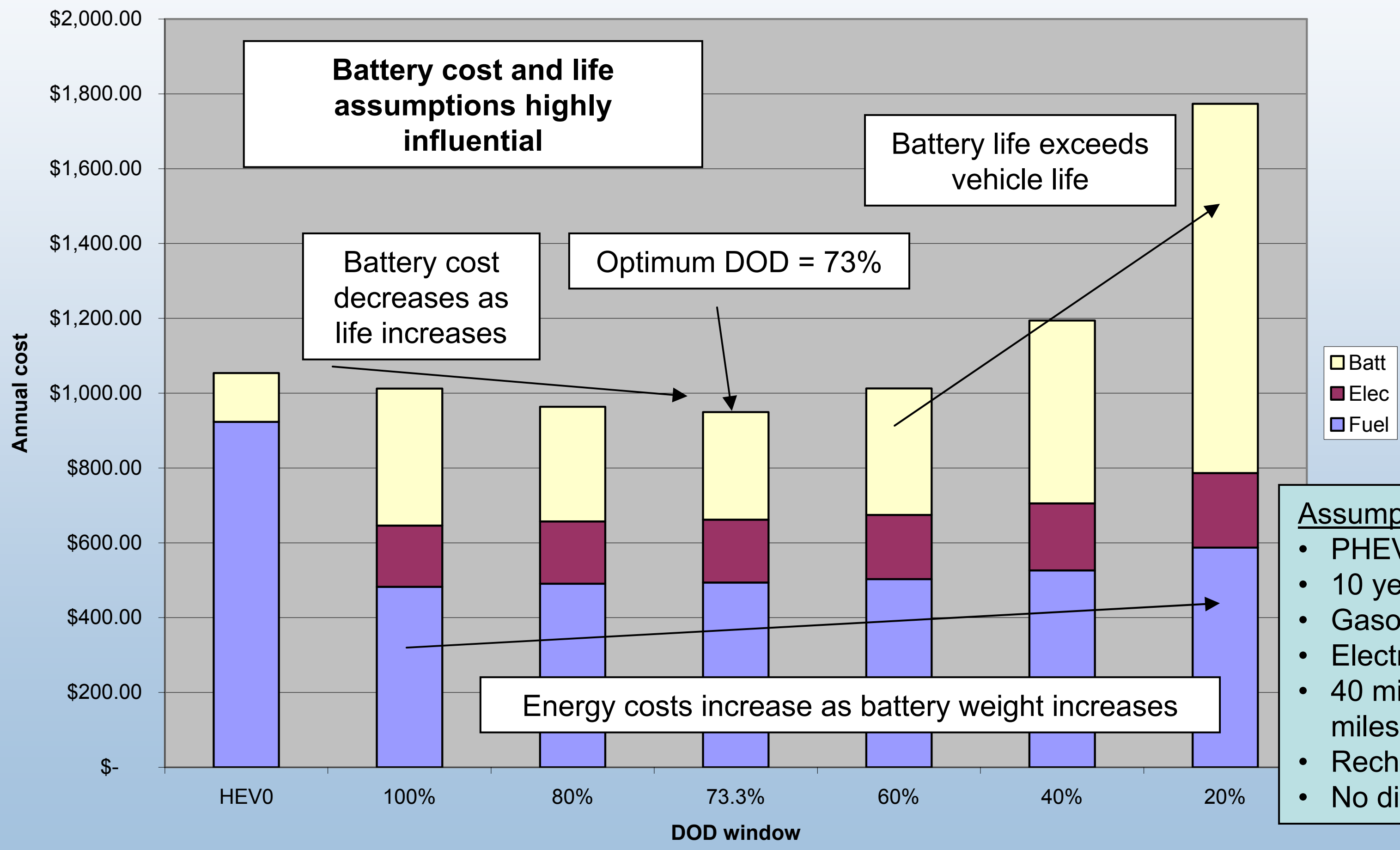


Figure 2: NiMH Battery Module Cost vs. Power/Energy Ratio

Taylor D. & Browning L. (2003) "Simplified Life Cycle Cost Analysis of Plug-in HEVs, Engine Dominant HEVs & Conventional Vehicles in 2012", EVS20 Plug-In HEV Workshop, Long Beach, CA.

Optimal Depth of Discharge (DOD) is Dependent on Battery Life and Cost, Vehicle Life, Duty Cycle, …

Requires systems approach!

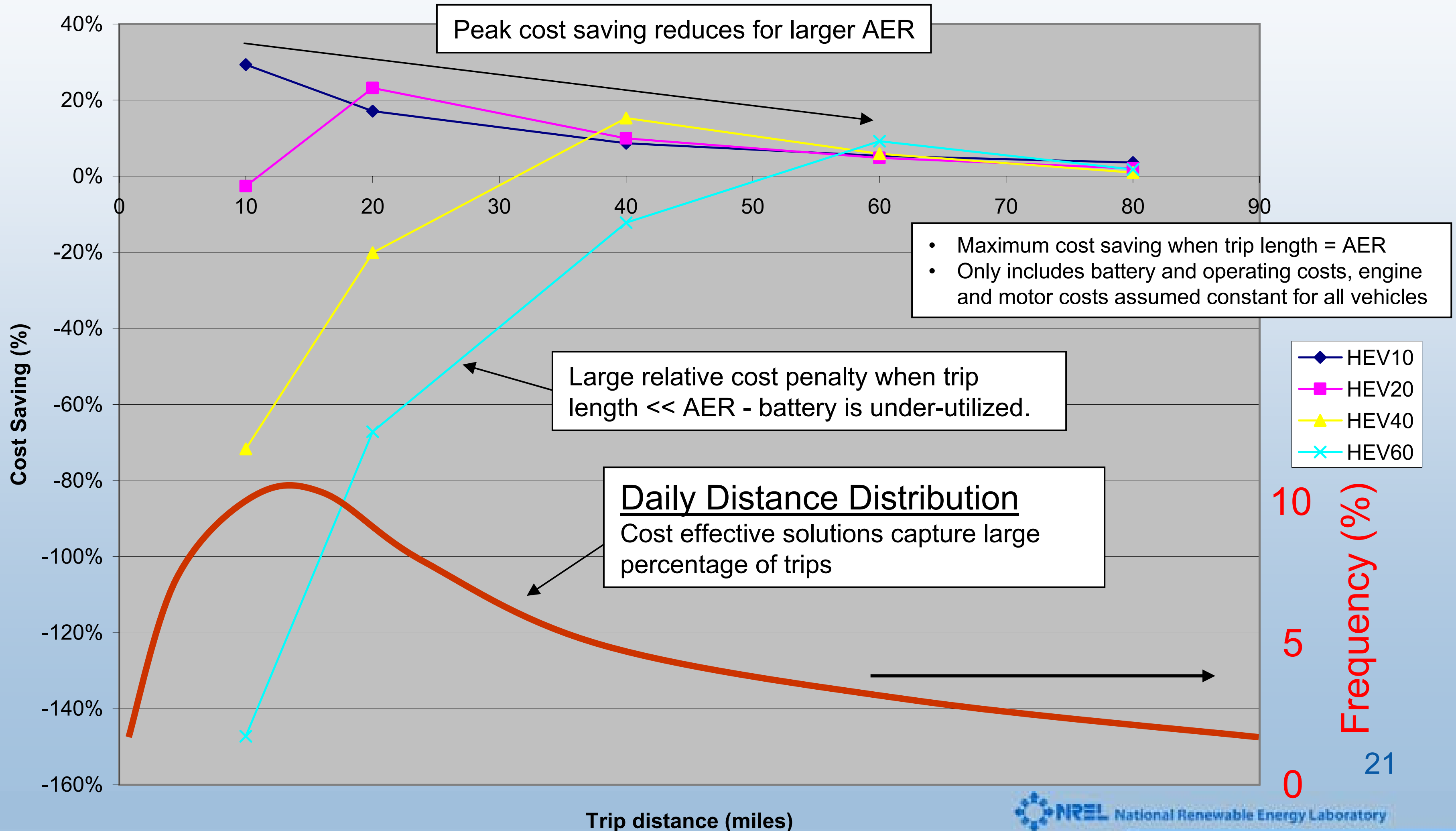


Assumptions:

- PHEV20 (~6 kWh usable)
- 10 year vehicle life
- Gasoline @ $2.50/gal
- Electricity @ $0.06/kWh
- 40 mile daily trip (~15,000 miles annually)
- Recharge daily
- No discount rate

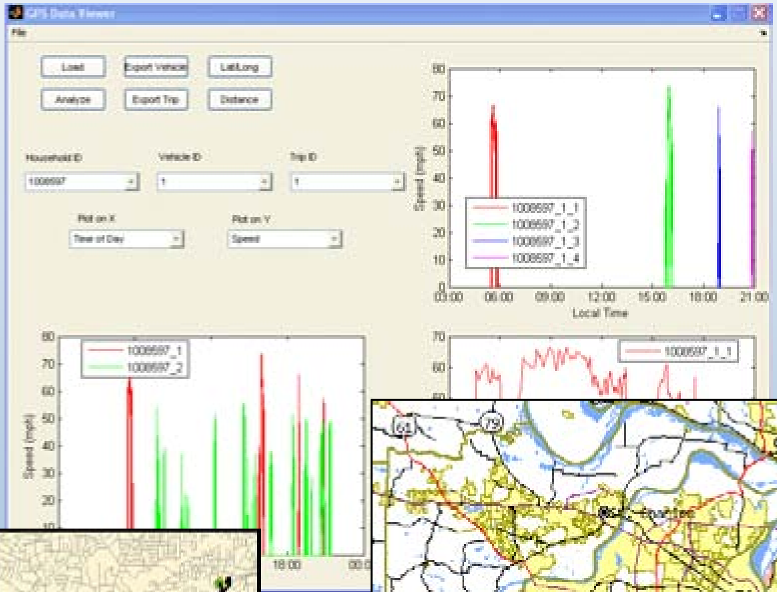
Designing for Requirements Provides Cost Effective PHEV Solution

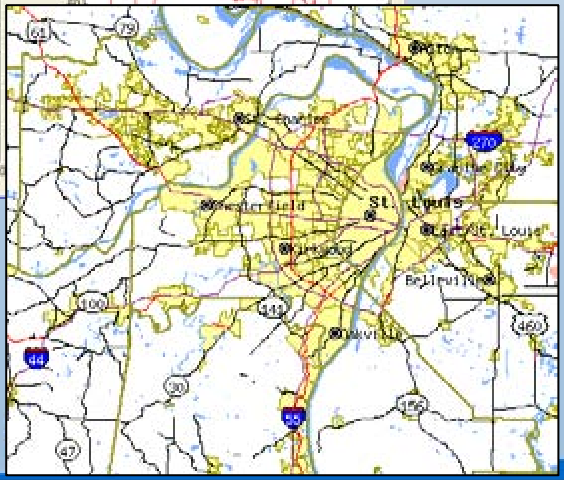
Plug-In HEV Annual Cost savings relative to HEV0 vs. Trip distance (73% DOD window) as a percentage of HEV0 Annual Costs



Development of Vehicle Requirements Based on Real-World Driving Data

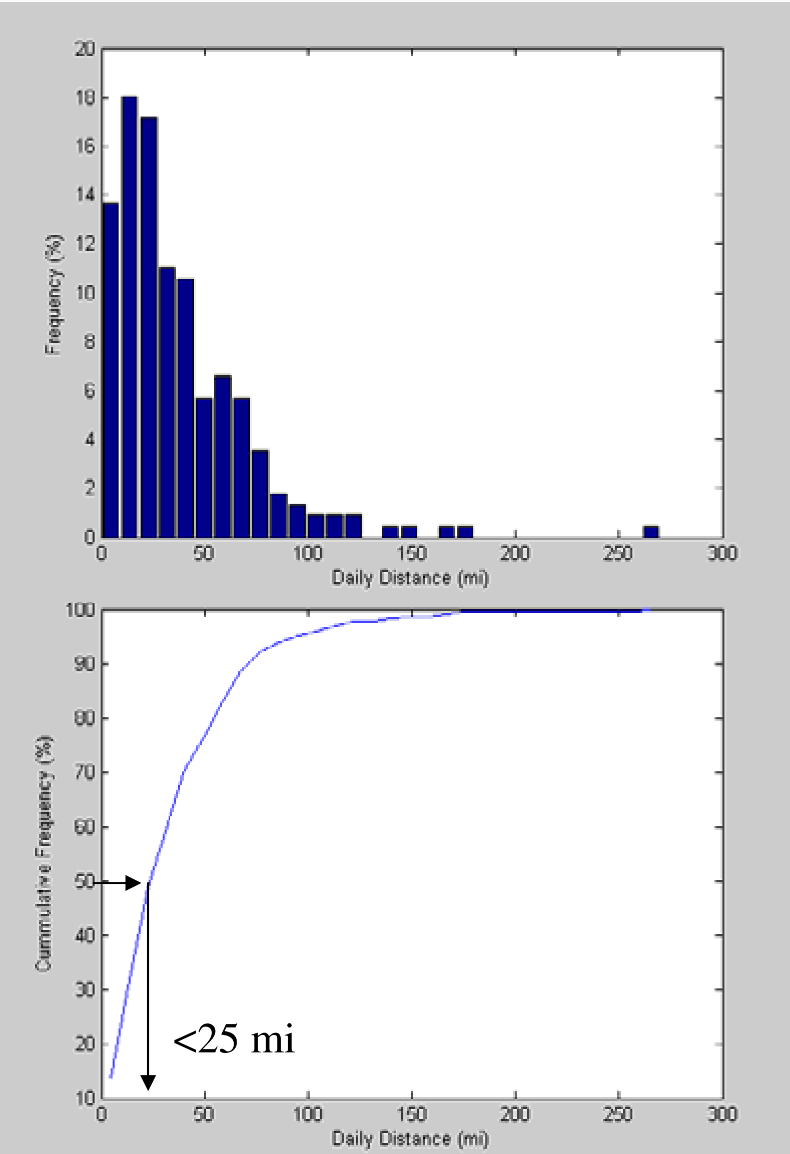
- Optimal design for greatest cost/benefit is highly dependent on duty cycle
- National personal transportation surveys provide a potential data source
- St. Louis data used as an example data set
- Similar data sets for other areas required to fully characterize national behavior

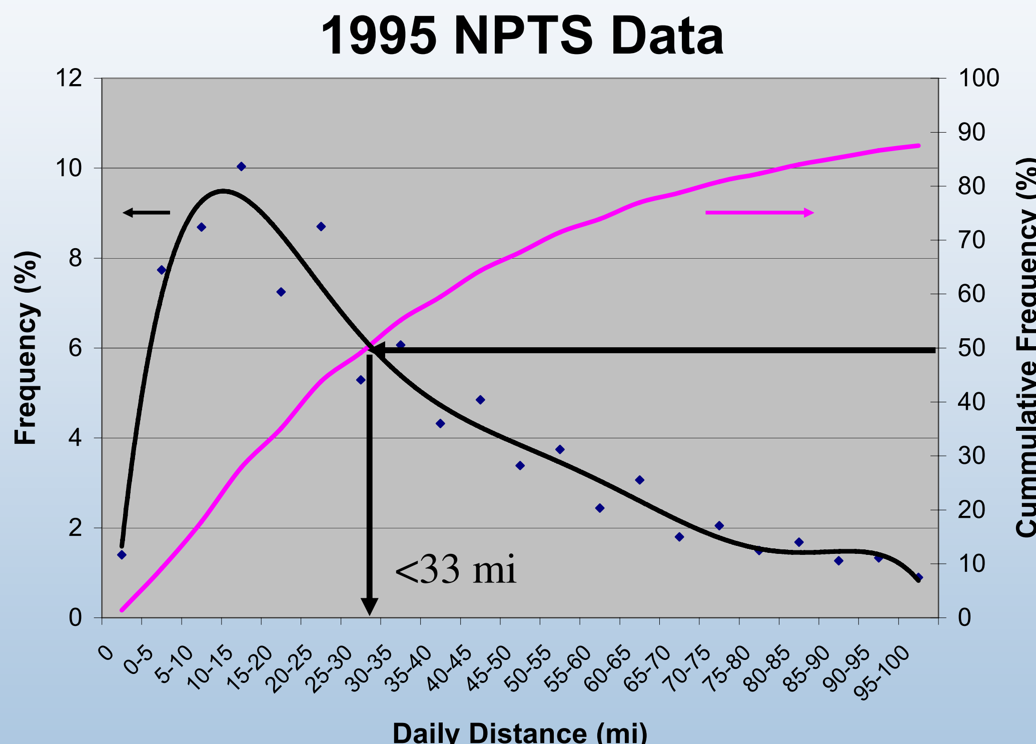




St. Louis Travel Data Analysis

Daily Driving Distance Slightly Shorter than 1995 NPTS Data

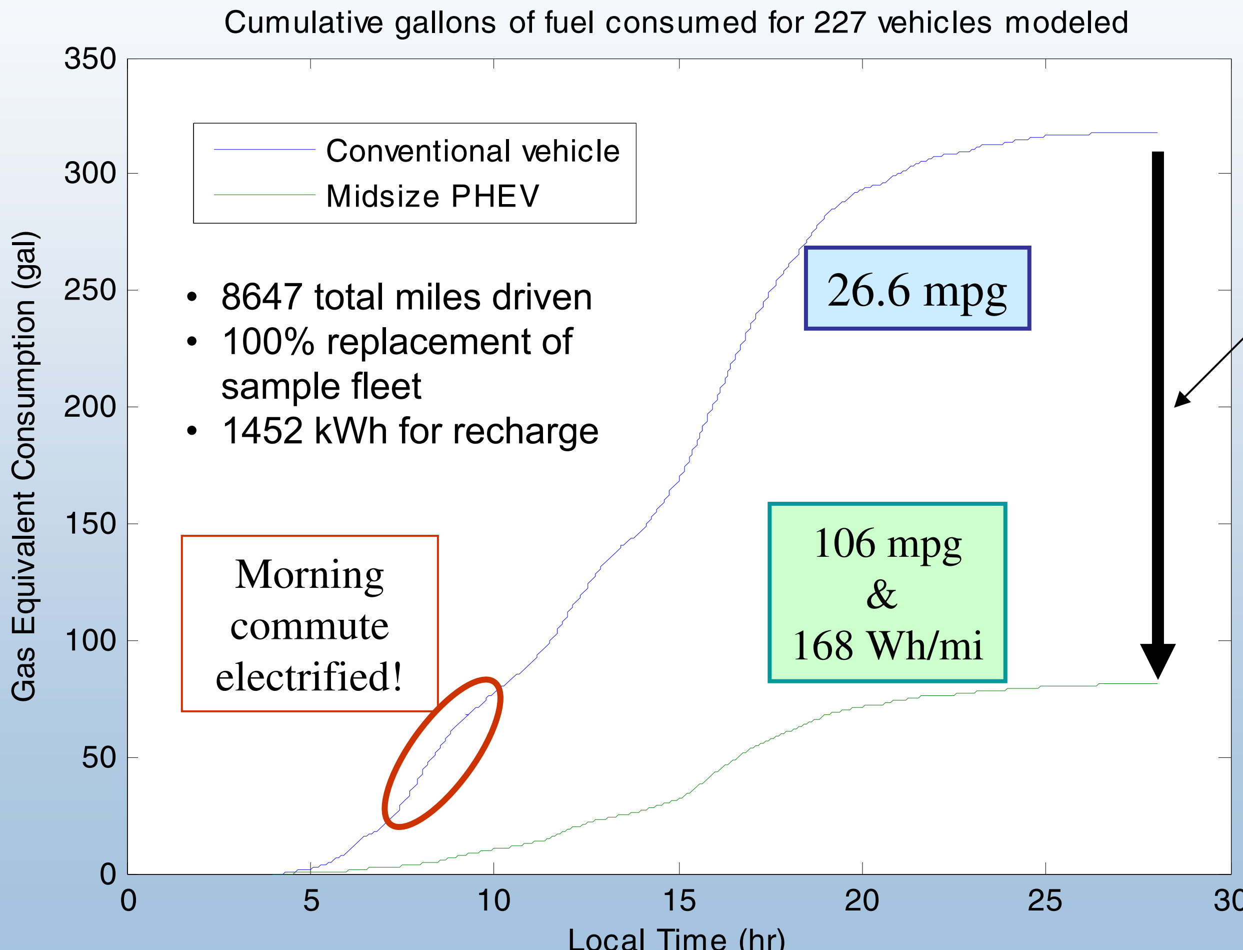




St. Louis is a fairly dense metro area

Preliminary PHEV In-Use Fuel Consumption

Each vehicle in St. Louis data set was modeled both as a conventional and PHEV



PHEV30 saves ~1 gal/day/vehicle

	Conv	PHEV
Gas	\$3.50	\$0.90
Elec	\$0	\$0.38
Total	\$3.50	\$1.28
¢/mile	9.2	3.4

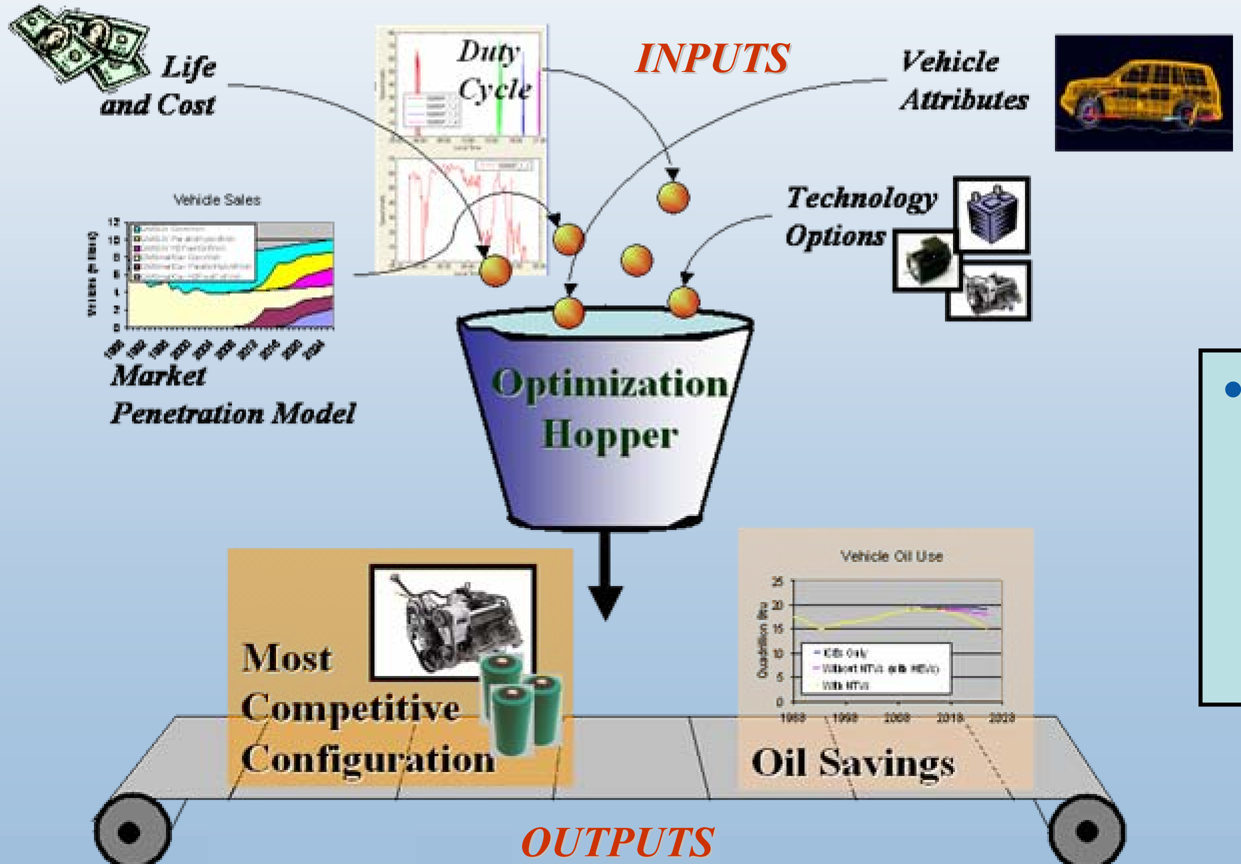
>50% reduction in operating costs

~\$700 annual savings

Assumes \$2.50/gal and 6¢/kWh

Optimal Configuration & Associated Oil Savings Based on Realistic Market Penetration

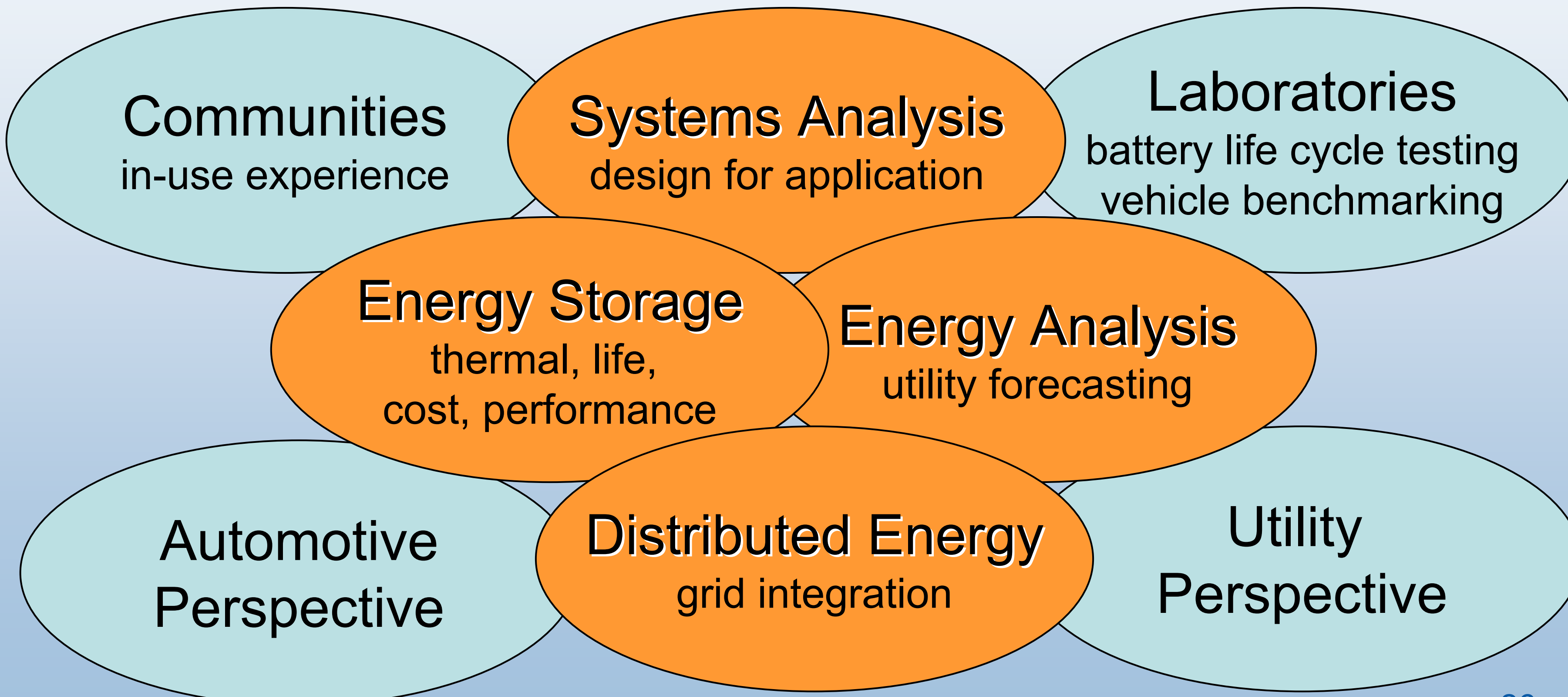
- Technical Target Tool (T3) competes PHEVs, HEVs, conventional, and FCHEVs
- Sales predictions based on vehicle attributes



- **Outputs:**
  - Most competitively configured PHEV
  - Associated oil savings

Opportunity for Collaboration

- Multidisciplinary challenges can be best solved with collaborative effort



Future Work

- Planned FY06 Activities
  - Explore design options to address challenges and define requirements
  - Develop realistic 24hr PHEV drive cycle including charging for life cycle testing
  - Demonstrate technology viability and functionality

Focus on:
- Battery Cost and Life
- Systems Integration
- Hybrid Evolution

- Additional Needs
  - Collaborative multidisciplinary modeling effort to model integration and implementation opportunities (WinDS, HOMER®,…)
  - Support the development of parametric battery cost and life models through data collection
  - Estimate market penetration potential and oil savings for Plug-in HEVs using analysis tools

Messages (Just a Reminder)

- Plug-in HEVs have the best near-term potential to reduce petroleum consumption by shifting demand to a variety of domestic sources including renewables

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  - Battery technology development critical but research pathway depends on application, vehicle configuration, and utility integration approach