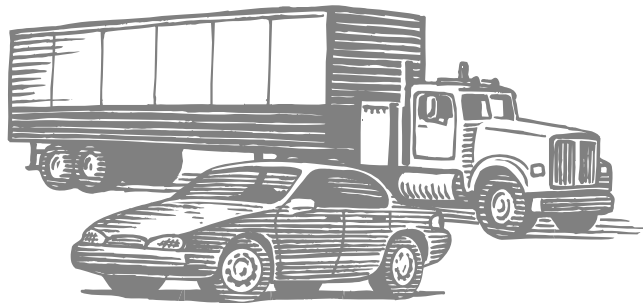


Cost-Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology

*22nd International Electric Vehicle Symposium
Yokohama, Japan
October 25-28, 2006*

Ahmad Pesaran
Andrew Simpson and Tony Markel
Tony_Markel@nrel.gov
National Renewable Energy Laboratory



With support from
Lee Sleight

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
FreedomCAR and Vehicle Technologies Program



Presentation Outline

- Plug-in hybrid-electric vehicle (PHEV) as a solution
- Potential petroleum reduction from PHEVs
- Simulation of PHEV efficiency and cost
 - Baseline vehicle assumptions
 - Powertrain technology scenarios
 - Components models (cost, mass, efficiency)
- Results
 - Component sizing
 - Fuel Economy
 - Incremental cost
 - Payback scenarios
- Conclusions & Next Steps

A Plug-In Hybrid-Electric Vehicle (PHEV)

An HEV with wall recharge capability and fuel flexibility

BATTERY RECHARGE

Fuel Flexibility

PETROLEUM

AND/OR

ELECTRICITY

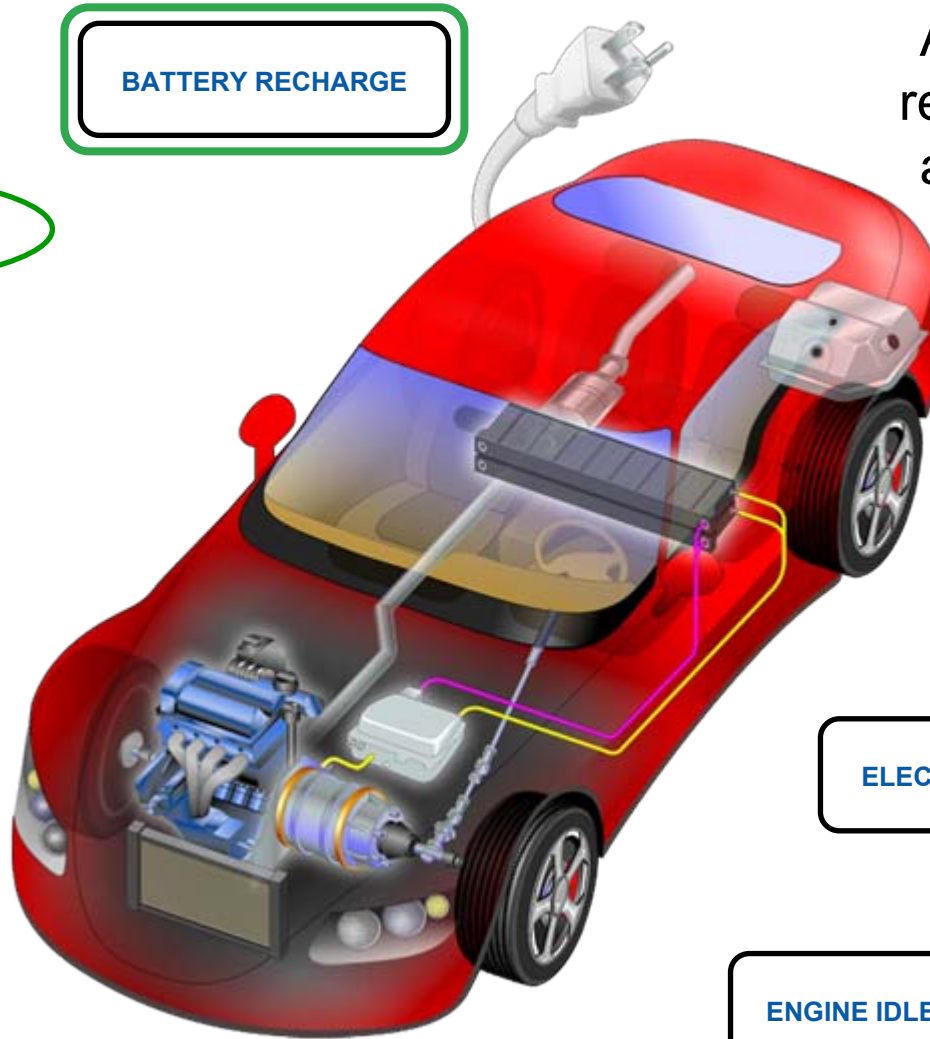
REGENERATIVE BRAKING

ELECTRIC ACCESSORIES

ADVANCED ENGINE

ENGINE IDLE-OFF

ENGINE DOWNSIZING



Vision of Future Transportation

National Renewable Energy Laboratory • Concept - Ahmad Pesaran • Illustration - Dean Armstrong • NREL/GR-540-40698

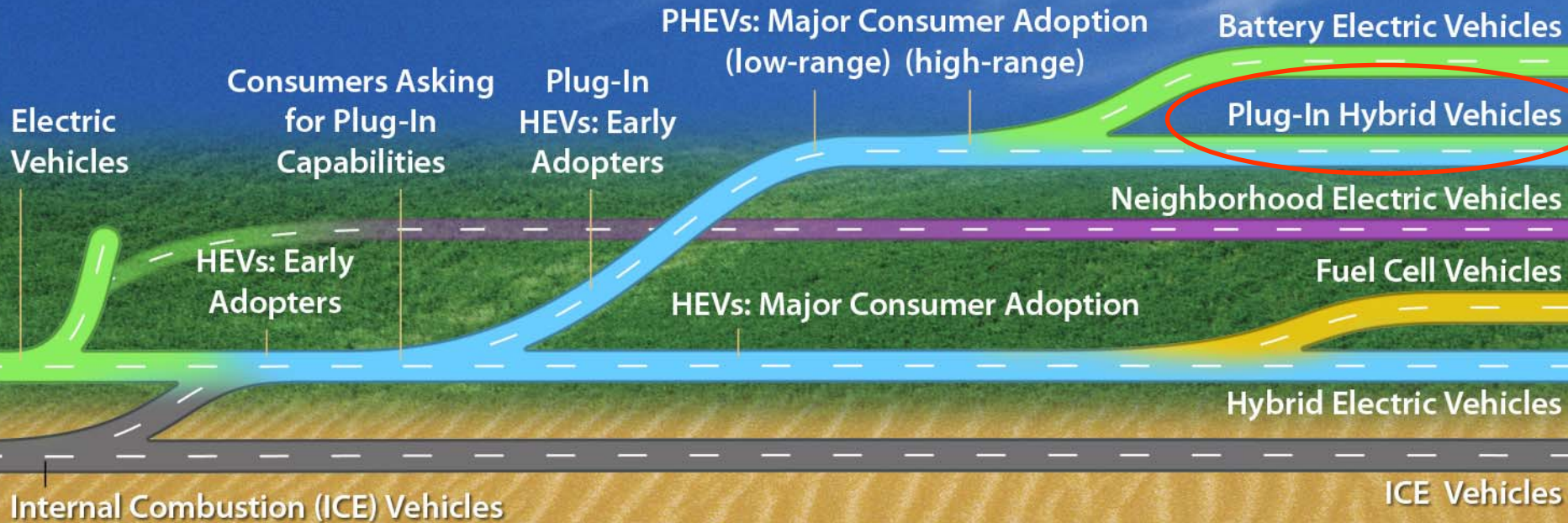


High Power ➤

Battery
Advancement

Affordable High Power, Acceptable High Energy ➤

Affordable High Energy ➤



Gasoline, Ethanol Blends ➤

Diesel, Biodiesel Blends ➤

B20, Biodiesel ➤

E85, Cellulosic Ethanol ➤

Electricity ➤

Hydrogen ➤

Fuels

PHEV Key Benefits and Challenges

KEY BENEFITS



Consumer:


- Lower “fuel” costs
- Fewer fill-ups
- Home recharging convenience
- Fuel flexibility



Nation:

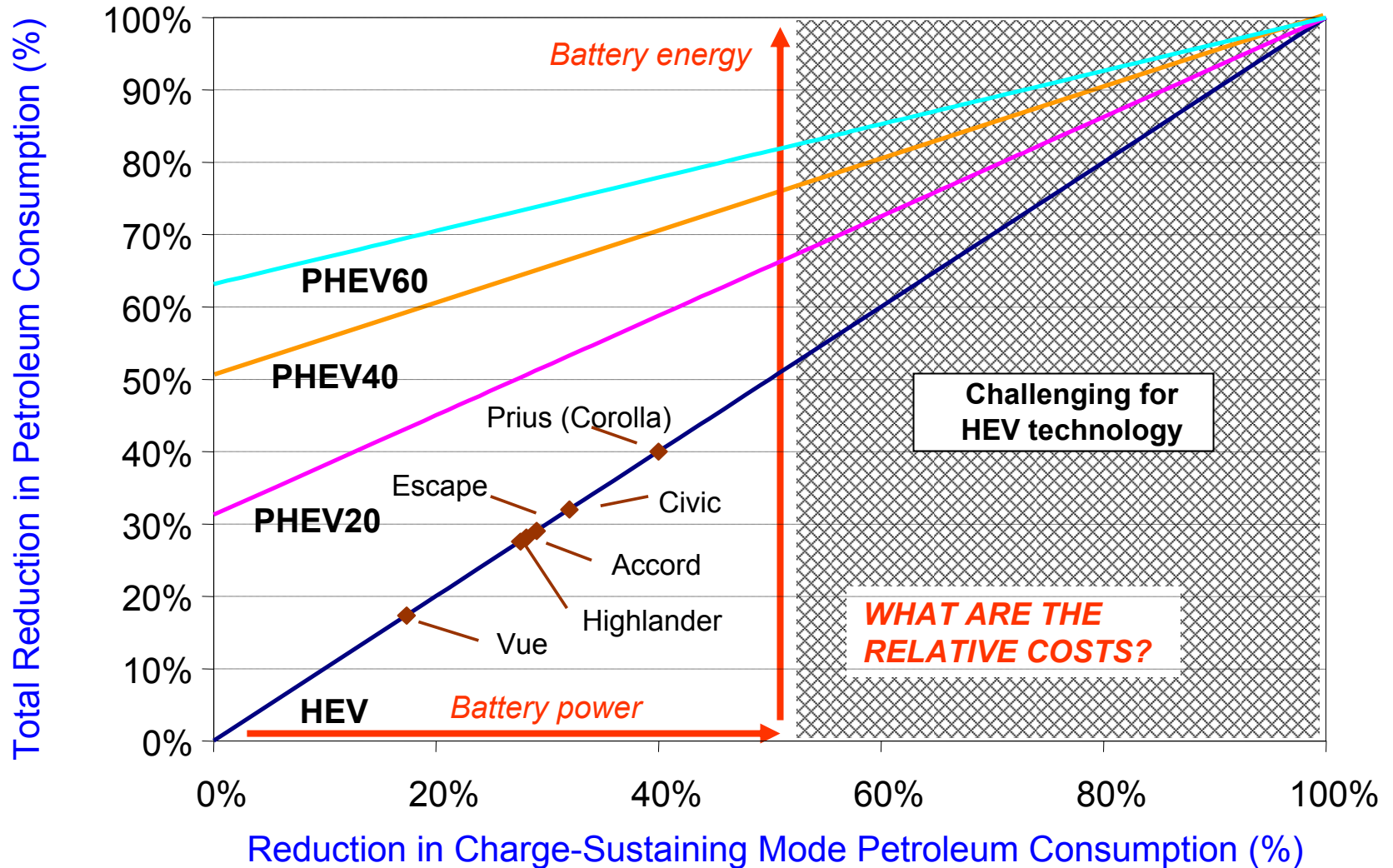
- Less petroleum use
- Less greenhouse and regulated emissions
- Energy diversity/security

KEY CHALLENGES

- Recharging locations
- Battery life 
- Component packaging
- Vehicle cost

Cost-Benefit Analysis

Potential Petroleum Reduction from PHEVs



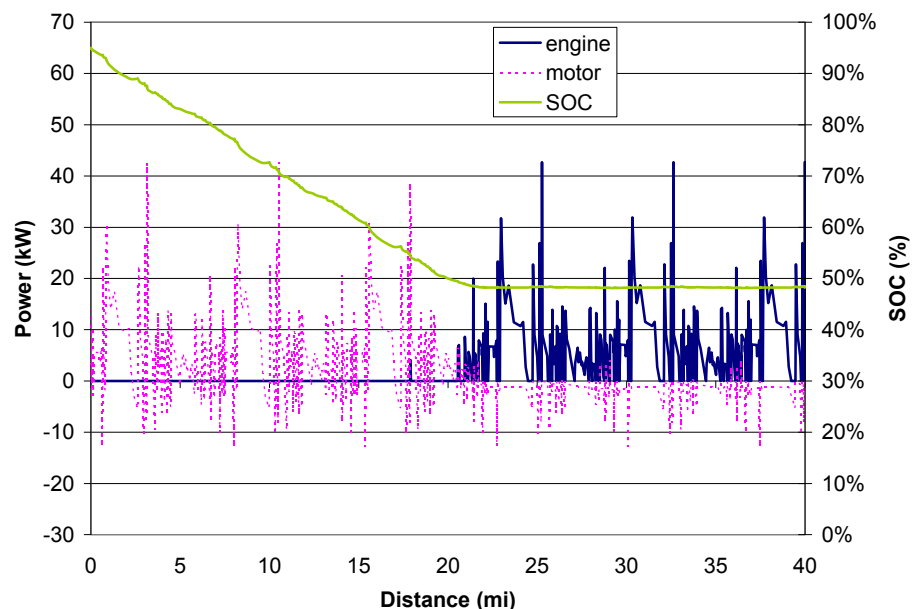
PHEV Study Scope and Approach

Vehicle Configurations

- conventional automatic
- pre-transmission parallel hybrid: HEV or PHEV
- 2 technology scenarios
 - near term and long term

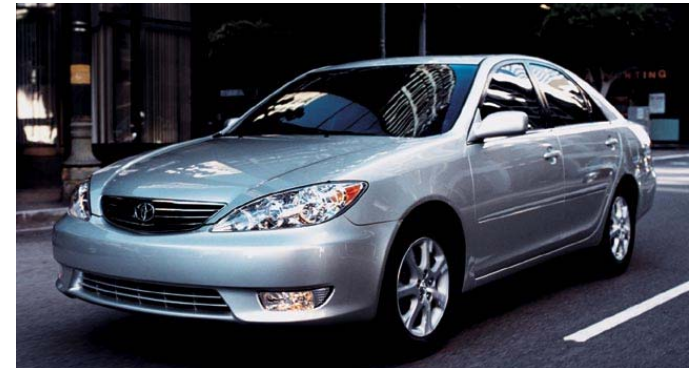
Approach

- Dynamic, power-flow simulation
- Calculates component sizes and costs
- Iterative mass-compounding
- Measures fuel/electricity consumption using NREL-proposed revisions to SAE J1711
- *Battery definition is key input to the simulation*



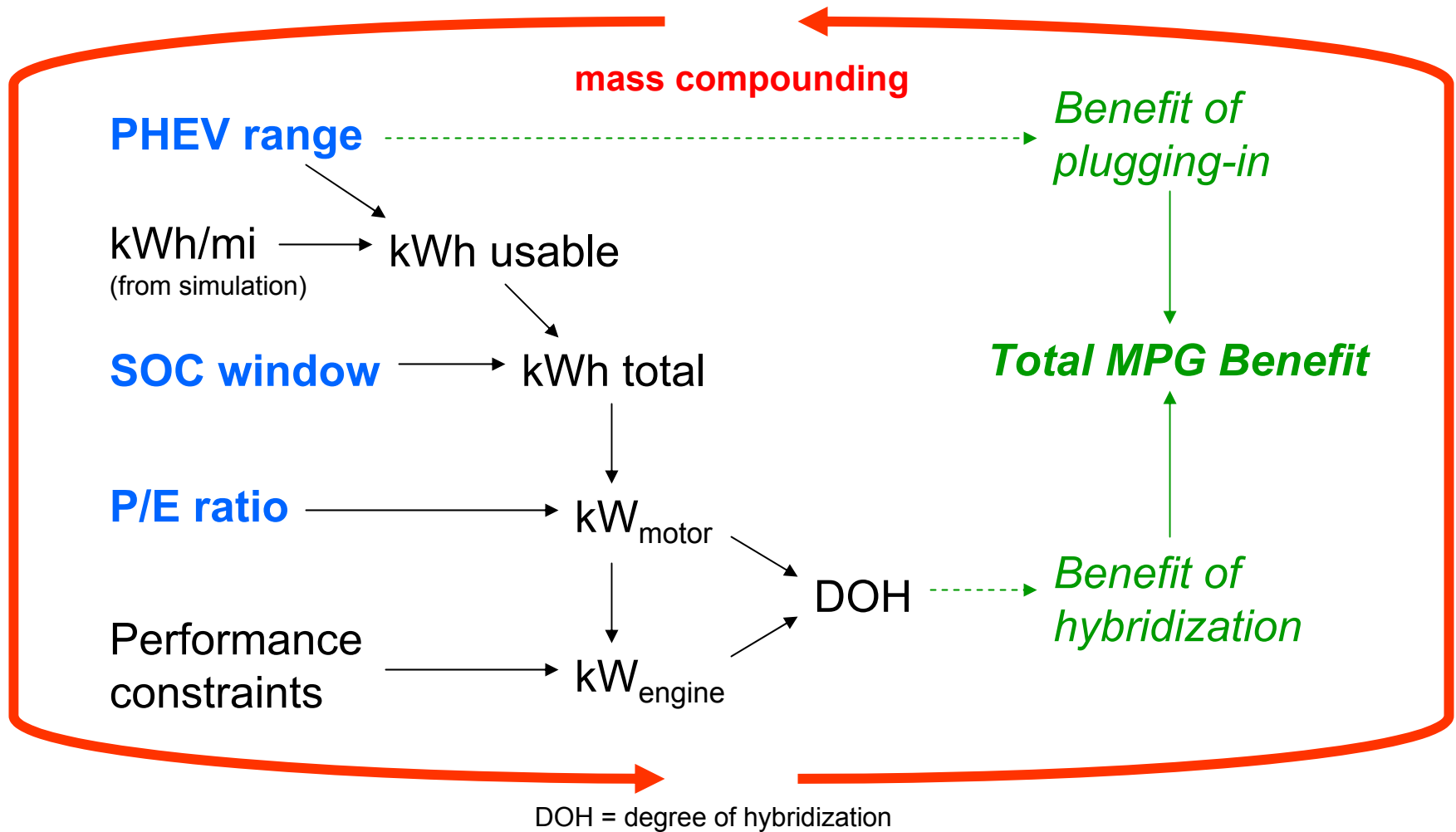
Key Study Assumptions

- Usable State of Charge window varies from 40% for HEV0 to 70% for PHEV60
 - Based on battery life of 15 years and daily travel distance probability
- Mid-size car platform (Malibu/Camry)
 - High volume vehicle
 - Performance equivalent to existing vehicles
 - No platform engineering and no engine technology improvements
 - » Isolate the PHEV technology impacts
- Battery attributes scale with Power/Energy ratio



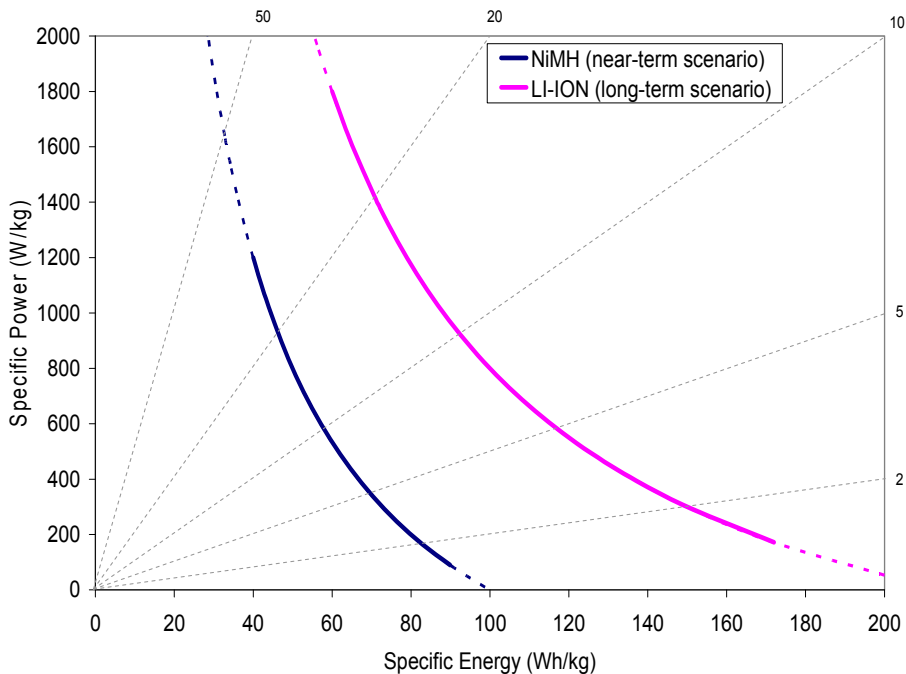
Battery Definition as Key Input to Simulation

Input parameters that define the battery in BLUE

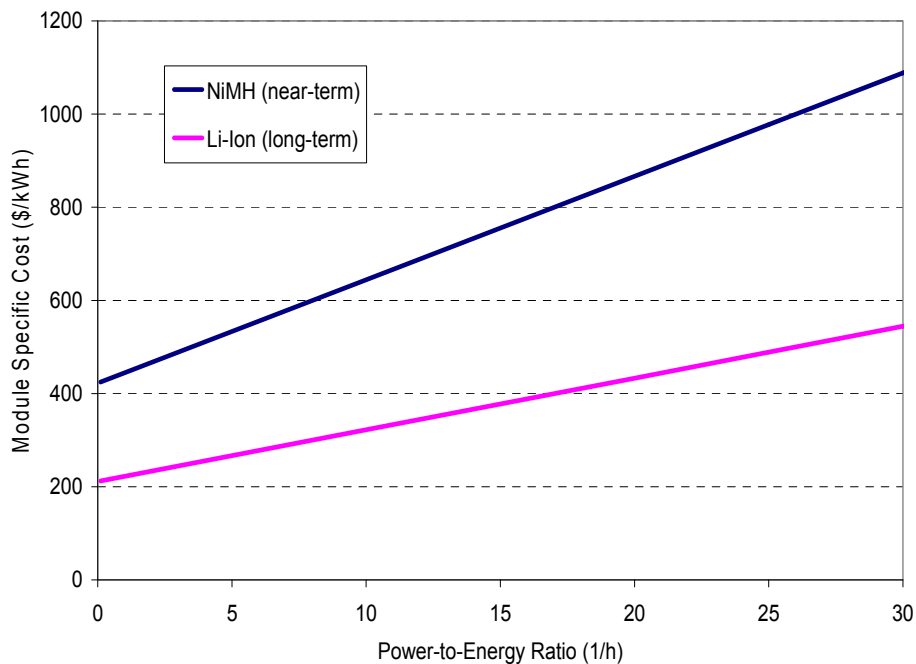


Battery Models (Scaleable)

Battery Design Functions



Battery Cost Functions



Results: Battery Specifications

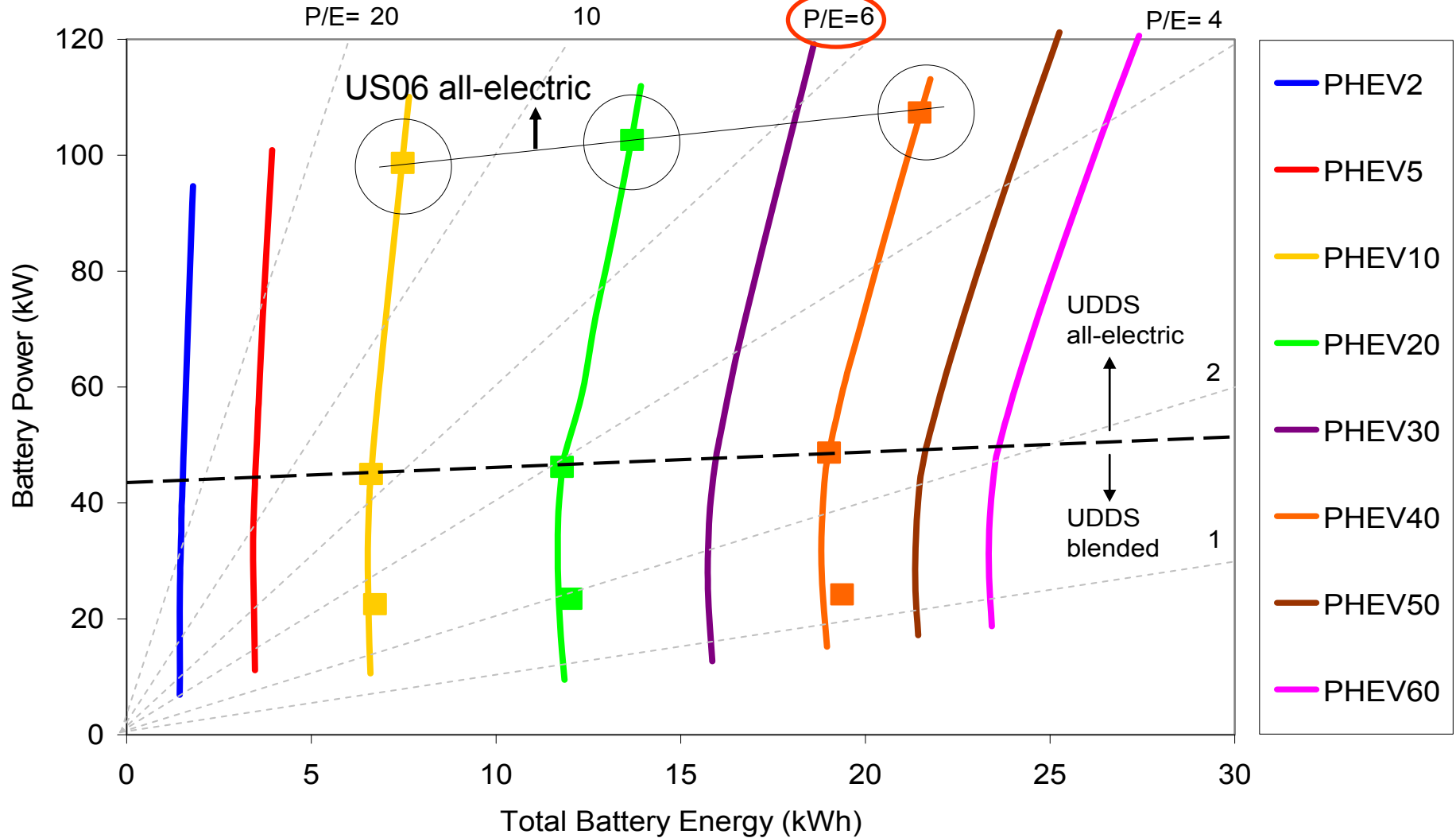
P/E = Energy/Total Energy

Battery Power vs Energy for PHEVs

Midsize Sedans

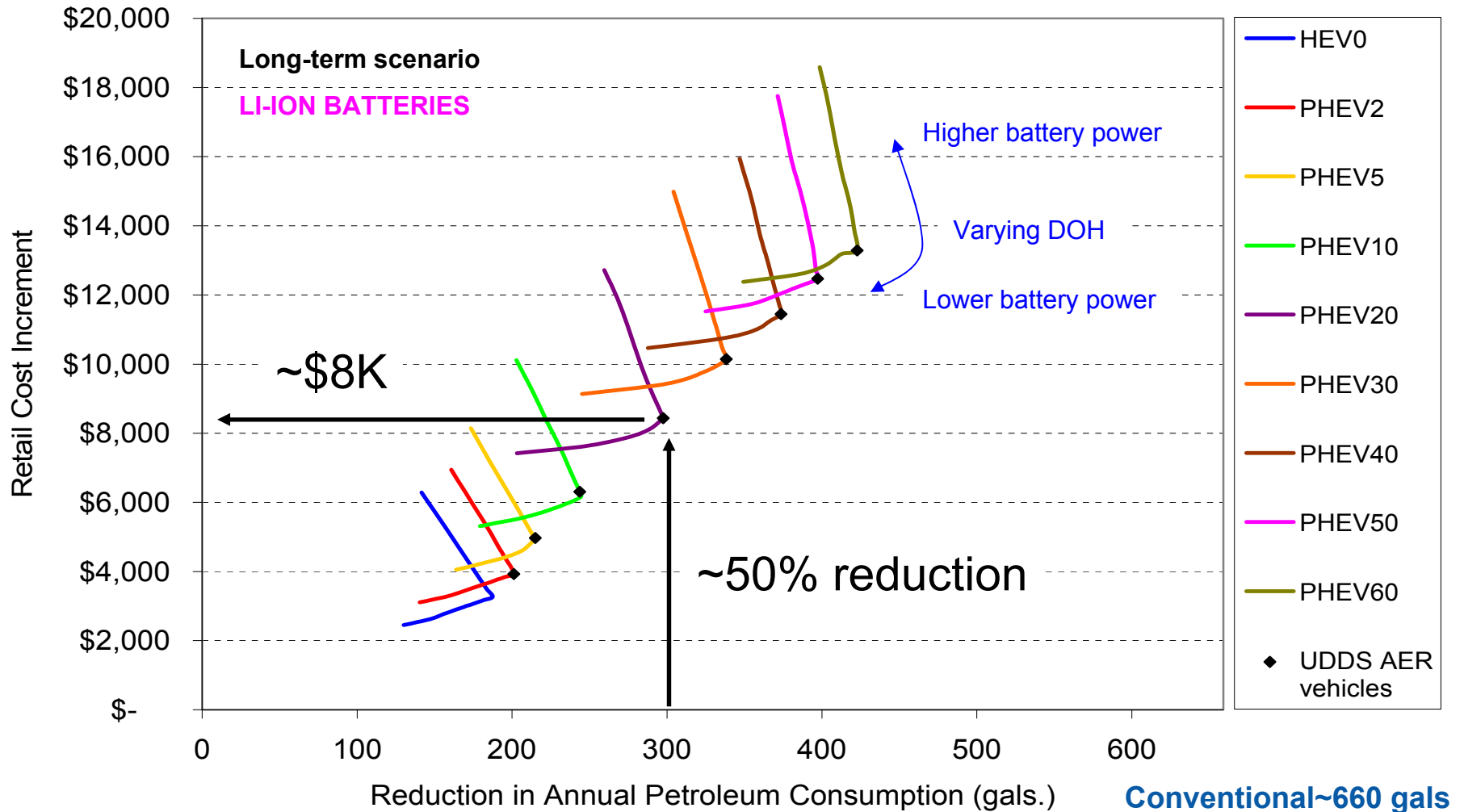
Long-term scenario

LI-ION BATTERIES



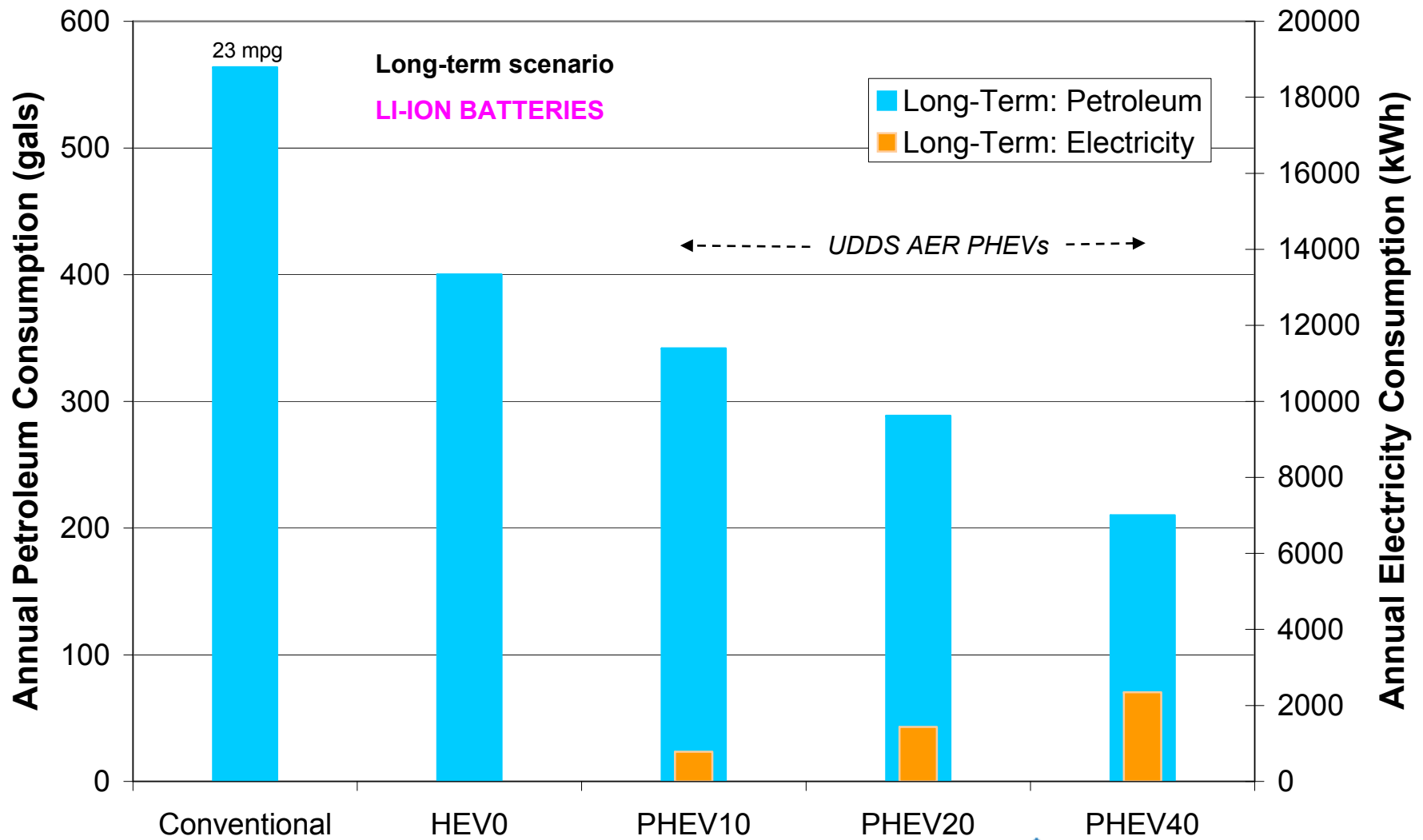
Results: Incremental Cost of Reduced Consumption

Reduction in Fuel Consumption vs Powertrain Cost Increment - Midsize Sedans



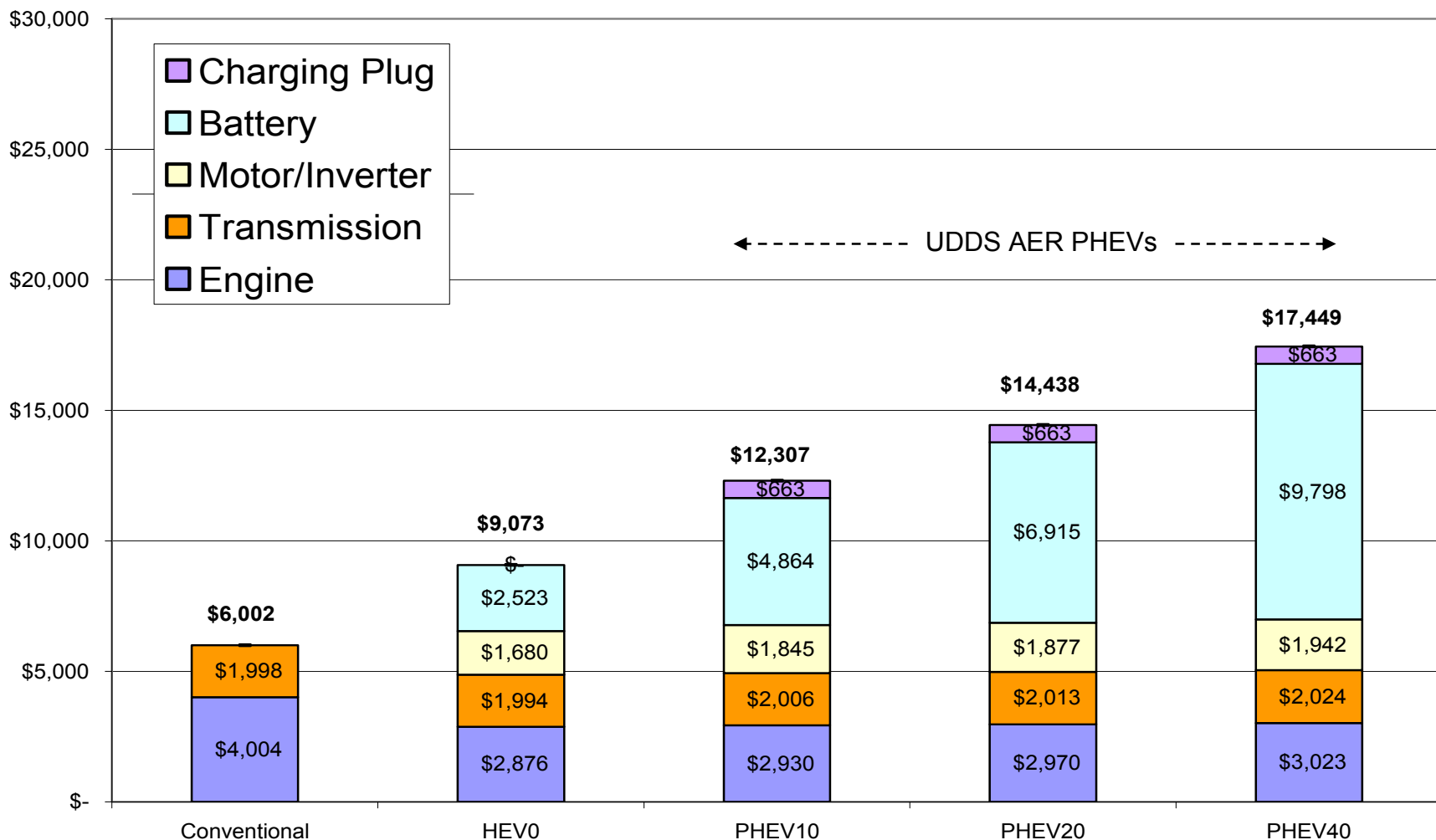
PHEV Energy Use

PHEV Onboard Energy Use: Long-Term Scenario



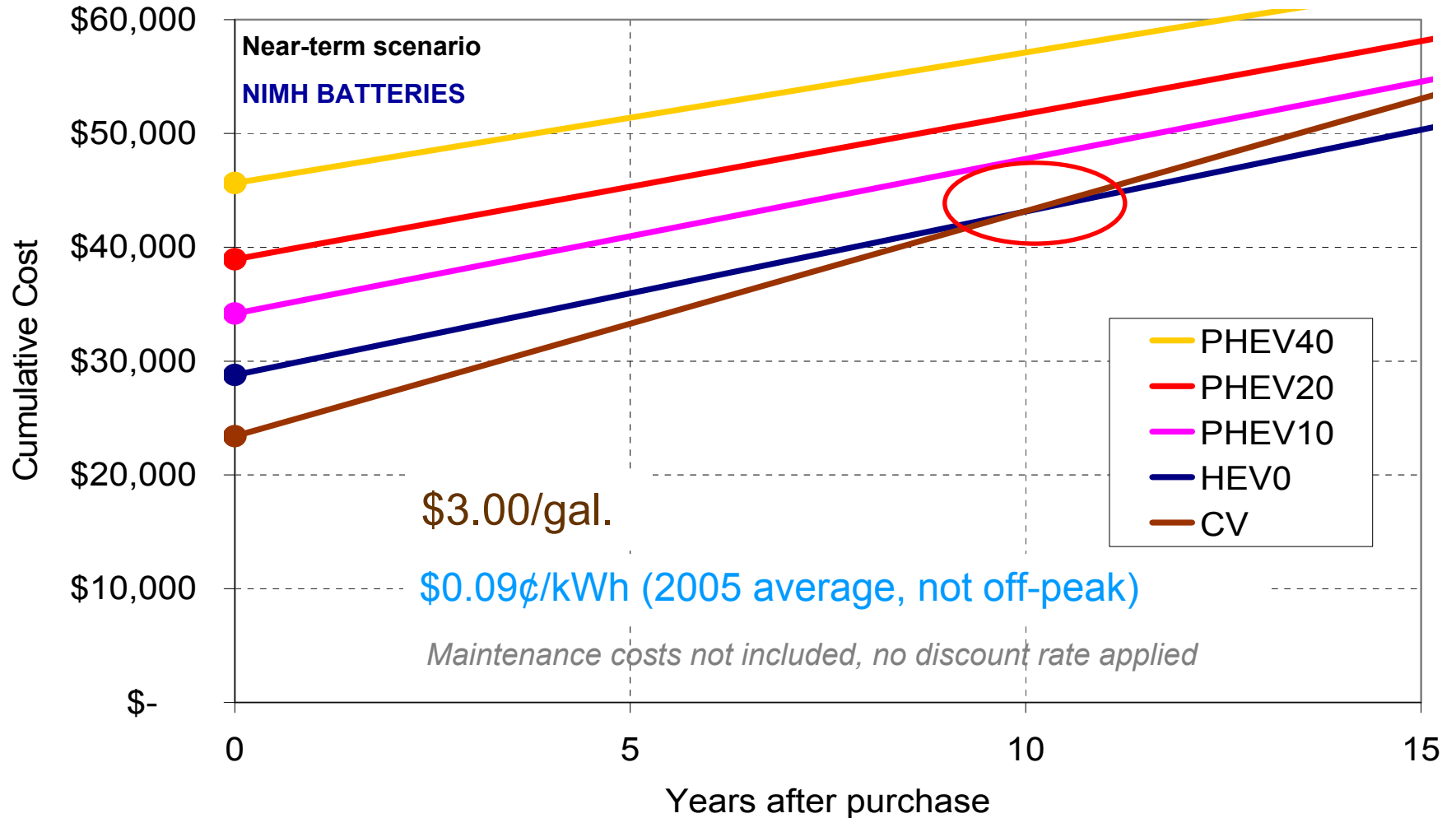
Powertrain Costs Comparison – Long Term

Powertrain Costs (incl. retail markups)



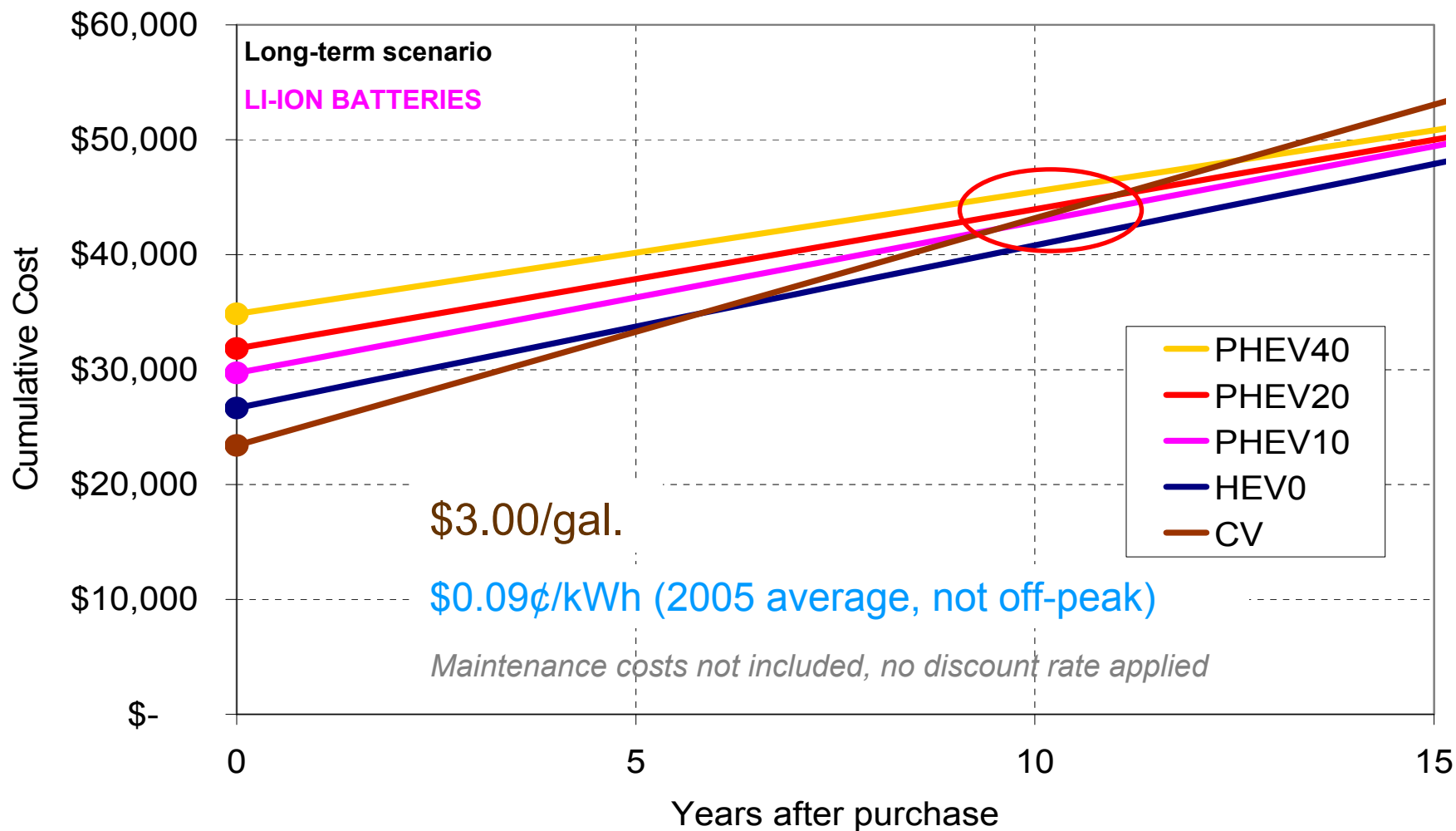
Near-term HEV Fuel Savings Offset Incremental Cost

Cumulative Vehicle plus Energy (Fuel/Elec.) Costs



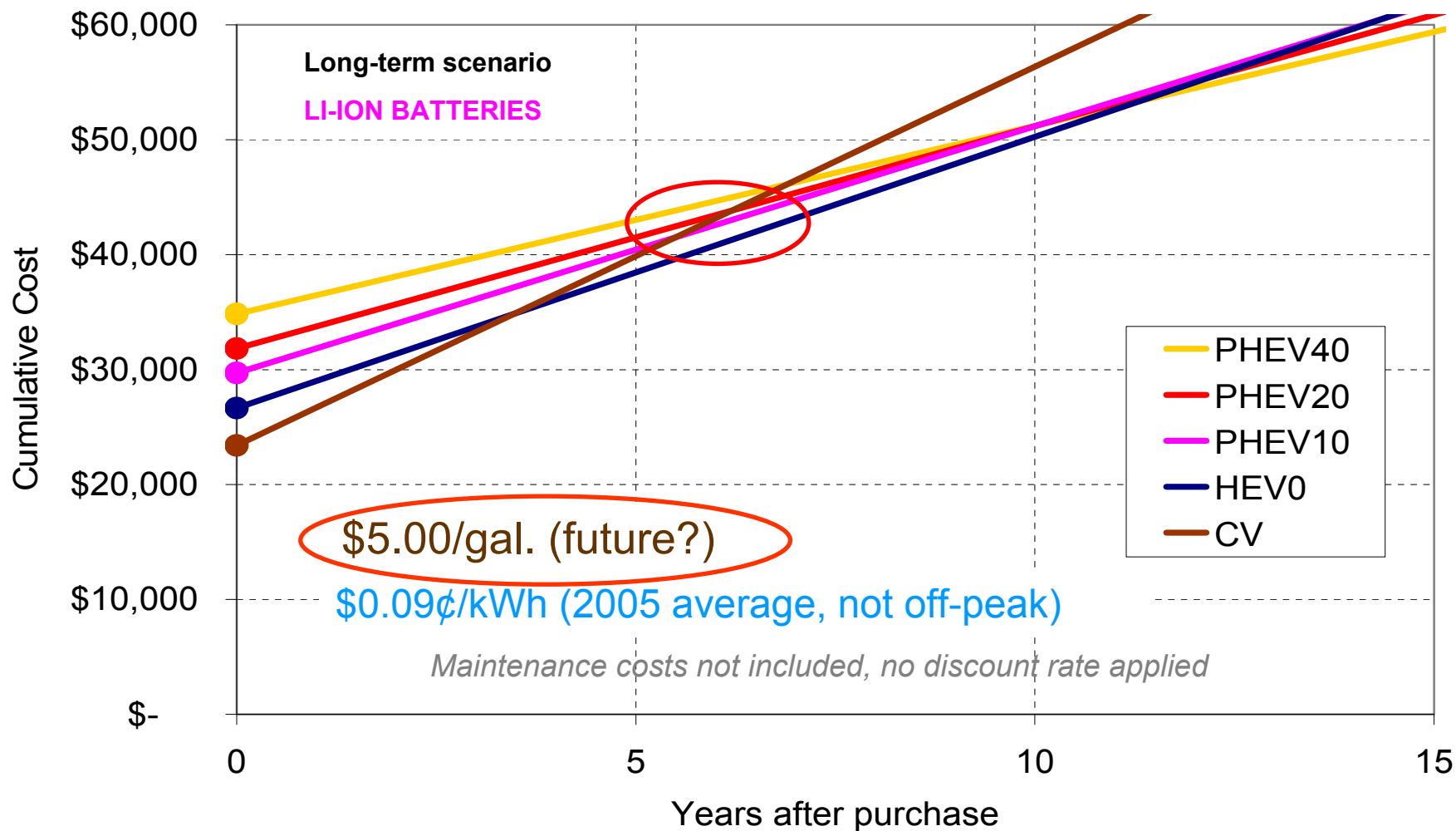
Long-term Battery Cost Reductions Alone Insufficient For PHEV to Payback Relative to HEV

Cumulative Vehicle plus Energy (Fuel/Elec.) Costs



Both Higher Gas Prices and Lower Battery Costs Required for PHEV to Payback Relative to HEV

Cumulative Vehicle plus Energy (Fuel/Elec.) Costs



Why Consumers Might Pay More for PHEVs?

1. Green image, “feel-good factor”
2. Of-peak charging
3. Tax incentives
4. Reduced petroleum use, air pollution and CO₂
5. National energy security
6. Less maintenance
7. Reduced fill-ups
8. Convenience of home recharging (off-peak)
9. Improved acceleration (high torque of electric motors)
10. Alternative business models

Conclusions

1. Systems simulation extremely important and valuable for quickly exploring the broad HEV/PHEV design spectrum.
2. **Key factors** in the HEV/PHEV cost-benefit equation include:
 - **Battery costs**
 - **Fuel costs**
 - **Control strategy** (particularly battery SOC window)
 - **Driving habits** (annual VMT and trip-length distribution)
3. Based on the assumptions of this study:
 - HEVs can reduce per-vehicle petroleum use by approximately 30%.
 - **Per-vehicle petroleum use reduced by up to 50% for PHEV20s and 65% for PHEV40s.**
 - Long-term powertrain cost increments are predicted to be **\$2k-\$6k for HEVs, \$7K-\$11k for PHEV20s and \$11K-\$15k for PHEV40s**
4. Based on overall costs (powertrain plus energy):
 - **HEVs become the most cost-competitive EITHER if gasoline prices increase OR projected battery costs are achieved.**
 - **PHEVs become cost-competitive ONLY if projected battery costs are achieved AND fuel prices increase.**
 - Tax incentives and/or alternative business models (e.g. battery lease) may be required for successful marketing of PHEVs