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

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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)

Fuel Flexibility

- PETROLEUM
- ELECTRICITY

BATTERY RECHARGE

An HEV with wall recharge capability and fuel flexibility

- REGENERATIVE BRAKING
- ELECTRIC ACCESSORIES
- ENGINE IDLE-OFF
- ENGINE DOWNSIZING
- ADVANCED ENGINE

An HEV with wall recharge capability and fuel flexibility

PHEV

ELECTRIC ACCESSORIES

- ELECTRICITY
- PETROLEUM
- AND/OR

FUEL FLEXIBILITY
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

**WHAT ARE THE RELATIVE COSTS?**

**Reduction in Charge-Sustaining Mode Petroleum Consumption (%)**

**Total Reduction in Petroleum Consumption (%)**

- **Battery power**
- **Battery energy**

- **Prius (Corolla)**
- **Civic**
- **Accord**
- **Highlander**
- **Escape**
- **Vue**

**Challenging for HEV technology**

**WHAT ARE THE RELATIVE COSTS?**

NREL National Renewable Energy Laboratory
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

- PHEV range
- kWh/mi (from simulation)
- SOC window
- P/E ratio
- Performance constraints

mass compounding

- kWh usable
- kWh total
- kW<sub>motor</sub>
- kW<sub>engine</sub>
- DOH

Benefit of plugging-in

Total MPG Benefit

Benefit of hybridization

DOH = degree of hybridization

DOH = degree of hybridization
Battery Models (Scaleable)

Battery Design Functions

Specific Energy (Wh/kg)

Specific Power (W/kg)

NiMH (near-term scenario)

Li-ION (long-term scenario)

Battery Cost Functions

Module Specific Cost ($/kWh)

Power-to-Energy Ratio (1/h)

NiMH (near-term)

Li-Ion (long-term)
Results: Battery Specifications

Battery Power vs Energy for PHEVs

Midsize Sedans

P/E = Energy/Total Energy

Total Battery Energy (kWh)

Battery Power (kW)

P/E = 20

P/E = 10

P/E = 6

P/E = 4

US06 all-electric

UDDS all-electric

UDDS blended

P/E = Energy/Total Energy

LI-ION BATTERIES
Results: Incremental Cost of Reduced Consumption

Reduction in Fuel Consumption vs Powertrain Cost Increment - Midsize Sedans

Long-term scenario
LI-ION BATTERIES

Higher battery power
Varying DOH
Lower battery power

~$8K

~50% reduction

Conventional~660 gals

Retail Cost Increment

Reduction in Annual Petroleum Consumption (gals.)

- UDDS AER vehicles

- HEV0
- PHEV2
- PHEV5
- PHEV10
- PHEV20
- PHEV30
- PHEV40
- PHEV50
- PHEV60

- Conventional~660 gals
PHEV Energy Use

PHEV Onboard Energy Use: Long-Term Scenario

- Conventional HEV
- PHEV10
- PHEV20
- PHEV40

Annual Petroleum Consumption (gals)

- Long-Term: Petroleum
- Long-Term: Electricity

Annual Electricity Consumption (kWh)

Performance:
- 23 mpg Long-term scenario
- LI-ION BATTERIES

UDDS AER PHEVs
Near-term HEV Fuel Savings Offset Incremental Cost

Cumulative Vehicle plus Energy (Fuel/Elec.) Costs

- $3.00/gal.
- $0.09¢/kWh (2005 average, not off-peak)

Maintenance costs not included, no discount rate applied.

NIMH BATTERIES

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

Cumulative Vehicle plus Energy (Fuel/Elec.) Costs

Long-term scenario
LI-ION BATTERIES

$3.00/gal.

$0.09¢/kWh (2005 average, not off-peak)

Maintenance costs not included, no discount rate applied
Both Higher Gas Prices and Lower Battery Costs Required for PHEV to Payback Relative to HEV

Cumulative Vehicle plus Energy (Fuel/Elec.) Costs

- Long-term scenario
  - LI-ION BATTERIES

- Maintenance costs not included, no discount rate applied

- $5.00/gal. (future?)
- $0.09¢/kWh (2005 average, not off-peak)
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