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

from FY05 Milestone Report

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Golden, Colorado
January 19, 2006

NREL/PR-540-39415
Presented to DOE management staff on September 14, 2005 at the DOE headquarters in Washington DC. Content updated January 19, 2006 for final publication.
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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!

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

- High Impact Path

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

Market penetration model not included - vehicle to vehicle comparison
1,000,000 PHEVs Could Save ~10 Million Barrels of Oil Annually

It has taken 5 years to reach 200,000 hybrid vehicles in the market.

Annual US Consumption

Daily US Consumption

Number of PHEVs

Percentage of Fleet

(5%)

(45%)
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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

Battery power sufficient to provide EV-only operation

60 mpg

PHEV10 Mid-Size Sedan (fixed battery energy)
Only a few EV miles but many more blended miles
Battery is < half the original power and 30% cheaper, but fuel economy drop is < 10%
Component Sizing and Control Options

PHEV10 Mid-Size Sedan (fixed battery energy)

Below 20kW battery, lost regen impacts consumption
Component Sizing and Control Options

Cylinder deactivation in large engine could be used to regain efficiency

PHEV10 Mid-Size Sedan (fixed battery energy)
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
• Slope and magnitude of relationship are long-term and debatable
Optimal Depth of Discharge (DOD) is Dependent on Battery Life and Cost, Vehicle Life, Duty Cycle, …

Requires systems approach!

Battery cost and life assumptions highly influential

Battery cost decreases as life increases

Optimum DOD = 73%

Battery life exceeds vehicle life

Energy costs increase as battery weight increases

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

- Maximum cost saving when trip length = AER
- Only includes battery and operating costs, engine and motor costs assumed constant for all vehicles

- Large relative cost penalty when trip length << AER - battery is under-utilized.

**Daily Distance Distribution**
Cost effective solutions capture large percentage of trips
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.

- 8647 total miles driven
- 100% replacement of sample fleet
- 1452 kWh for recharge

PHEV30 saves ~1 gal/day/vehicle

Morning commute electrified!

- 26.6 mpg
- 106 mpg
- 168 Wh/mi

Assumes $2.50/gal and 6¢/kWh

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>50% reduction in operating costs

~$700 annual savings

Assumes $2.50/gal and 6¢/kWh

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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

• 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

Focus on:
• Battery Cost and Life
• Systems Integration
• Hybrid Evolution
Messages (Just a Reminder)

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