Plug-in Hybrid Electric Vehicles
Current Status, Long-Term Prospects and Key Challenges

Presented at Clean Cities Congress and Expo
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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!

WHAT’S OUR PLAN?
A “Full” Hybrid

76hp gasoline engine, 67hp electric motor, 1.5kWh battery
A Plug-In Hybrid

Fuel Flexibility

- ADVANCED ENGINE
- ELECTRIC ACCESSORIES
- ENGINE DOWNSIZING
- REGENERATIVE BRAKING
- BATTERY RECHARGE
- PETROLEUM
- ELECTRICITY

76hp gasoline engine, 67hp electric motor, 9.0kWh battery (30mi)
Light Duty Fleet Oil Use - Impact of HEVs on Consumption

This highly aggressive scenario assumes 100% HEV sales from 2010 onwards...

Oil use same as today!

HEVs unable to reduce consumption below today’s consumption level

Produced using VISION model, MBPD = million barrels per day
Oil Use Reduction with PHEVs

Light Duty Fleet Oil Use - Impact of PHEVs on Consumption

This highly aggressive scenario assumes 100% HEV sales from 2010 and 50% PHEV40 sales from 2020 onwards…

PHEVs reduce oil consumption with a transition to electricity

Produced using VISION model, MBPD = million barrels per day
OEM Plug-In Hybrids

2003 Renault Kangoo Elect’road
- up to 50mi electric range
- approximately 500 sold in Europe

DaimlerChrysler Sprinter PHEV
- 15 prototypes being produced for testing in various locations in Europe and North America
- up to 20mi electric range
Other PHEV Prototypes - Industry

EnergyCS Plug-In Prius
HyMotion Escape PHEV
AFS Trinity Extreme Hybrid™

AC Propulsion Jetta PHEV
Esoro AG H301
Design Options
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
Household Travel Survey Data Can be Used to Predict Real-World Benefits of Advanced Technologies

• Provides valuable insight into travel behavior
• GPS augmented surveys supply details needed for vehicle simulation
PHEVs Reduce Fuel Consumption By 50% On Real-World Driving Cycles

227 vehicles from St. Louis each modeled as a conventional, hybrid and PHEV

- 8647 total miles driven
- 100% replacement of sample fleet

- 26 mpg
- 37 mpg
- 58 mpg & 140 Wh/mi
- 76 mpg & 211 Wh/mi

Average Daily Costs

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<td>PHEV40</td>
<td>$1.08</td>
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Assumes $2.15/gal and 9¢/kWh

PHEVs:
- ~40% reduction in operating costs
- ~$460 annual savings

NREL National Renewable Energy Laboratory
HEVs and PHEVs Likely to Reduce Greenhouse Emissions

Figure 2-10
Greenhouse Gas Emissions (CO₂) “Well-to-Wheels” for the Compact Car for the Average Driving Schedule and Charging Nightly

Electrified Miles May Lead to Cleaner Operation

Figure 2-7
NOx Plus HC (Smog) “Well-to-Wheels” Emissions for the Compact Car for the Average Driving Schedule and Charging Nightly

In-Use Simulations Show Reasonable Recharge Times with Standard Household Outlet

- Typical vehicle is used less than 5% of the time
  — Lots of opportunity for recharging
- Both PHEV20 and PHEV40 owners likely to get full recharge overnight with standard outlet
Technical Challenges

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
Technical Challenges
Battery Packaging
Technical Challenges
Vehicle Costs

HOW CAN WE SAVE THE MOST GALLONS AT THE LEAST COST?

Gasoline Savings (%) vs. Incremental Cost (%) for different vehicles:
- Prius (Corolla)
- Civic
- Accord
- Escape
- Highlander
- Vue

HEVs vs. PHEVs?
Conclusions

• Plug-in hybrid technology uses electricity from the utility grid to reduce petroleum consumption beyond that of HEV technology
  — Predicted 50% reduction in in-use consumption based on simulations using travel survey data

• Industry interest is growing and some prototypes have been built
  — Collaboration between labs and industry will likely lead to innovative systems solutions

• The U.S. Department of Energy is expanding its research portfolio to include PHEVs
  — Research will address key remaining barriers to commercial PHEVs including battery life, packaging, and cost