PHEVs Component Requirements and Efficiencies

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Phil Sharer, Aymeric Rousseau
Argonne National Laboratory
Sponsored by Lee Slezak

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Project Overview

Timeline
- Start – July 2008
- End – September 2009
- 75% Complete

Budget
- DOE
  - FY08 $ 200k
  - FY09 $ 400k

Barriers
- Set targets for the different technical teams
- Perform cost benefit analysis

Partners
- U.S. EPA
- ANL Battery’s group
Main Objectives

- Define targets for the different technical teams.
- How does each assumption influence the component requirements?
- Can we lower a component requirement without significant fuel economy loss?
- What are the most appropriate battery energy/power to maximize fuel displacement?
- What is the best control strategy philosophy for different battery characteristics?
- What should the cost targets be to have specific payback?
Milestones

- Implement RWDC
- Define Assumptions (performance, cost)
- Define Vehicles
- Develop Analysis Methodology
- Run Simulations
- Analyze Fuel Efficiency
- Perform Cost Benefit
- Write report
Approach

Real World Drive Cycles

Automated Sizing

Analysis (Distribution)

Motor Power for Cycle
- Battery Power
- Engine Power
- Battery Energy

Vehicle Assumptions

>110 Trips
One day in Kansas City

Midsize Vehicle

Only Hot Conditions Assumed, no Grade!
Battery Power and Usable Energy Requirement as a Function of Vehicle Mass

**Battery Power vs Vehicle mass for Small SUV**

- SI Split HEV
- SI Split PHEV
- FC HEV
- FC PHEV
- EV

**PHEV Battery Energy vs Vehicle mass for Midsize**

- SI Split PHEV10
- SI Split PHEV20
- SI Split PHEV30
- SI Split PHEV40
Engine Power Requirements Provided to the Engine Tech. Team

Engine Power per vehicle classes

Engine Power per vehicle configuration

ICE Power vs Vehicle curb weight for Power Split PHEV

ICE Power vs Vehicle curb weight for a Large car

- Midsize
- Small SUV
- Midsize SUV
- Pickup

- Pre-Tx
- Pwr Split (Single mode)
- Pwr Split (2 mode)
- Ser-Eng
Different PHEV Powertrains and Battery Sizes

Powertrain Configuration
- Power Split PHEV
- Series PHEV

Battery Energy
- 4 kWh
- 8 kWh
- 12 kWh
- 16 kWh

PHEV Class
- Low Energy PHEV
- High Energy PHEV
Kernel Density Used to Compare Options

Distribution Fuel Consumption Conventional Vehicle

- histogram
- kernel density estimation

Mean Value
One Control per Configuration was Selected Based on a Fuel Economy and Number of Engine Starts - Criteria

Mean Values

Fuel Consumption [l/100km] vs Electrical Consumption [Wh/km]

- PHEV 16 kWh Series Thermostat Control
- PHEV 12 kWh Series Thermostat Control
- PHEV 8 kWh Split Optimum Engine Power
- PHEV 4 kWh Split LoadEngPwr 10miCD
- Split HEV
- Conventional

\[ \Delta \text{Fuel Consumption per added kWh} \]

Linear relation between Electrical and Fuel Consumption

Non Linear

Preliminary results
Fuel Consumption Lowers with Increasing Battery Energy

Preliminary results

- Conventional (mean = 6.53 l/100km, std = 0.30)
- HEV Split (mean = 4.85 l/100km, std = 0.46)
- PHEV 4kWh Split (mean = 3.31 l/100km, std = 0.77)
- PHEV 8kWh Split (mean = 2.36 l/100km, std = 0.89)
- PHEV 12 kWh Series (mean = 0.91 l/100km, std = 0.82)
- PHEV 16 kWh Series (mean = 0.67 l/100km, std = 0.67)
Battery Usage Linked to Usable Energy ->
Different Impact on Life for Different Energies

Most cycles use low energy consumption

These configurations offer range of battery energy usage

Most cycles use high energy consumption

- PHEV 4kWh Split
  - mean = 52.43 Wh/km, std = 28.88
- PHEV 8kWh Split
  - mean = 91.74 Wh/km, std = 35.16
- PHEV 12 kWh Series
  - mean = 128.45 Wh/km, std = 20.14
- PHEV 16 kWh Series
  - mean = 138.32 Wh/km, std = 17.38
4kWh Battery Energy Provides 50% of the Gains Achieved with 16 kWh Battery
Used Battery Energy as a Function of Driving Distance

For medium distance, we see largest energy consumption difference due to driving characteristics.

For short distance, we have similar electrical consumption -> Linked to low power demand?

Same control for series independently of battery energies.

Preliminary results
Constant Payback Period Requires Longer Driving Distances for Bigger Battery Packs

- Equation for break even lines with conventional vehicle:

\[
t_{\text{break even}} = \frac{C_{\text{Veh2}} - C_{\text{Veh1}}}{c_{\text{fuel}} \times \left[\text{Cons}_{\text{fuel, Veh1}(d)} - \text{Cons}_{\text{fuel, Veh2}(d)}\right] + c_{\text{elec}} \times \left[\text{Cons}_{\text{elec, Veh1}(d)} - \text{Cons}_{\text{elec, Veh2}(d)}\right]}
\]

The further you drive, the better the payback

\[
C_{\text{elec}} = 0.07 \text{ $/kWh}
\]

\[
C_{\text{fuel}} = 3\text{ $/gallon}
\]

Preliminary results
Fuel Price Significantly Influences Payback Period

Break Even Lines of the Split 4kWh configuration with the Conventional Vehicle for different Fuel Prices

- Spikes due to small number of data points for long distances
- Benefit of 1$ increase non-linear

Payback [years]

Daily Distance [miles]

C_{elec} = 0.07$/kWh

C_{battery} = 4128$

(1000$/$kWh)

C_{base} = 30791$

Preliminary results
Future Activities

- Update the cost assumptions based on literature search and expert discussions (D. Santini & A. Vyas).
- Complete fuel efficiency and cost analysis
- Add HEV vehicle
- Perform cost benefit analysis based on several scenarios to define the most appropriate vehicle for different options (i.e., battery energy, battery cost, distance, fuel cost...).
- What is the impact of assuming the vehicle can be charged during the day?
- How does the results based on the RDWC compare with the latest J1711 Procedure (using both National and RWDC Utility Factors).
- Perform MonteCarlo analysis on the control strategy parameters to provide an uncertainty value.
Summary

- **Impact of RWDC on Fuel Efficiency**
  - Several vehicles with different powertrain configurations and battery energies were simulated.
  - A single control strategy was selected for each option based on a combination of fuel efficiency and engine ON/OFF criteria.
  - The fuel efficiency was compared with a conventional vehicle to assess the potential fuel displacement over the Kansas City RWDC.

- **Impact of RWDC on Cost Benefit Analysis**
  - With current pricing, long payback period due to high battery cost
  - Increasing fuel price significantly influences payback period and is a major factor for the rentability of a PHEV
  - Benefits of price reduction on payback nonlinear
  - You should regularly drive longer than what your AER theoretically allows
**References**