What’s the Deal with Hybrid and Electric Cars?

Day 2: An in-depth look at Electric Powertrains

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Outline

1. Ways in which hybridization improves efficiency.
2. Hybrid Architectures-Overview.
3. Hybrid Powertrain Case Studies
4. An Outlook at the Future
5. Plug-in hybrids
Urban Drive Cycle Energy Balance
2005 3 L Toyota Camry

POWERTRAIN

Fuel Tank: 100%

<table>
<thead>
<tr>
<th>Engine</th>
<th>16%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Loss: 76%</td>
<td></td>
</tr>
<tr>
<td>Driveline Losses: 3%</td>
<td></td>
</tr>
<tr>
<td>Standby: 8%</td>
<td></td>
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</tbody>
</table>

VEHICLE-Related

| Aero: 3% |
| Rolling: 4% |
| Braking: 6% |

Rolling: 4%
Braking: 6%
Highway Drive Cycle Energy Balance
2005 3 L Toyota Camry

Fuel Tank: 100%

Engine

Engine Loss 77%

Standby: 0%

Driveline

Driveline Losses: 4%

23%

19%

Aero: 10%

Rolling: 7%

Braking: 2%
Introduction to Engine Map

SI Engine Brake Efficiency Map

Torque (Nm)

Speed (rpm)

MAX TORQUE
Engine Operating Points vs. Efficiency

Engine Operation Over an Urban Driving Cycle

- Torque (Nm)
- Speed (rpm)
- max torque curve
- output shaft
- op. pts
Opportunities for Energy Savings

Micro Hybrid Eliminates

Fuel Tank: 100%

Full Hybrid Reduces
- Engine downsizing
- Decoupling of engine and wheel

POWERTRAIN

Engine Loss 76%

Standby: 8%

16%

13%

Engine

Driveline

Driveline Losses: 3%

Vehicle-Related

Aero: 3%

Rolling: 4%

Braking: 6%

Mild Hybrid Reduces
Classification of Hybrids

1. By Architecture:
   a. Series
   b. Parallel
   c. Series/parallel

2. By Relative Size of Electric Part
   a. Start/Stop- Micro Hybrid
   b. Mild Hybrids
   c. Full Hybrids

3. By Connection Topology (next slide)
Series Hybrid

Source: SAE 2003-01-0083

Pros: Engine Optimization

Cons: Unnecessary Electric Losses, Battery Size
Parallel Hybrid Architecture

Pros: Most Efficient Power source directly to wheels

Cons: Tough Engine Optimization

Source: SAE 2003-01-0083
Parallel/Series Architecture

Figure 2: Toyota Hybrid System (THS) Layout
Micro Hybrids-The Saturn VUE
Courtesy: Dr. Keim, LEES MIT, Dr. Rinderknecht, Getrag
One Parallel Implementation-Honda IMA

2010 Honda Insight Hybrid with Integrated Motor Assist (IMA)

Parallel Only Implementation-Honda IMA

Engine

Motor

Transmission

Cutaway model of the New Honda IMA System
Parallel Only Implementation-Honda IMA

Pros: Simple, cheap, easy packaging, most of the fuel savings.

Cons: Engine Optimization, Regen. Braking
Engine Fuel Consumption Map

Torque (N-m)

Engine RPM

Torque

- Torque
- 250g/kWh
- 280g/kWh
- 310g/kWh
- 340g/kWh
- 370g/kWh
- 100 kph cruise

Courtesy: Dr. Keim, LEES MIT
Transmission Effects

Shift Diagram-Toyota 2005 2.5L Camry

Torque (Nm)

Engine Speed (RPM)

Downshifting Line

Upshifting Line

Downshifting

Upshifting

Constant P=20kW
Efficient Continuously Variable Transmission in the Horizon?

Conventional CVT

New (Toroidal) CVT
Toyota Prius 2010

Source: http://www.autobloggreen.com/photos/possible-leakage-2010-toyota-prius/1100518/
Toyota Parallel/Series Architecture

Source: ADVISOR documentation
Figure 3: Relationship of Component Speeds of Japanese Prius

Component Speed Relationship:

\[ \frac{1}{R} \times \text{Gen + Motor} = \left[1 + \frac{1}{R}\right] \times \text{Engine} \]

\[ \text{Motor} = 38.75 \times (\text{Vehicle Speed in km/h}) \]
Hybrid Architecture/Control Strategy
Fiat Hybrid

Source: http://www.autobloggreen.com/2008/04/14/fiat-going-hybrid-with-home-grown-system-within-the-next-3-years/
IVECO Hybrid System
Bosch-Getrag Hybrid System
GM/Daimler/BMW Hybrid System

2009 GMC Yukon 2 Mode Hybrid

GM/Daimler/BMW Hybrid System
Possible Future Hybrid Architecture Pathways

• “Actively” Optimizing
  ➢ Power-Split Architecture (parallel/series)-Electric CVT
  ➢ Parallel Architecture-Mechanical CVT. Gearbox Efficiency critical.
  ➢ Parallel Architecture- “Special Manual/Automatic Transmission”

• Non “Actively” Optimizing
  ➢ Parallel Architecture with Manual/Automatic transmissions (Honda)
  ➢ Start/Stop (Micro Hybrids) with Boosted Efficient Engines

• The issue of relative electric system-What is Optimum?. 
Chevrolet Volt

Source: http://www.nytimes.com/2008/09/14/automobiles/14AUTO.html?_r=1&oref=slogin
Series Hybrid

Source: http://www.advancedenergy.org/corporate/initiatives/heb/hybrid_tech.php
Can it get over 100 mpg?
Tesla Roadster
Tesla Roadster

**ELECTRIC RIDE**
The Tesla Roadster puts the charge back into supercharged. The all-electric, high-performance sports car is powered by the same batteries that run your laptop. Wired got the first guided tour. — J.O.

**MOTOR**
At the heart of the AC electric motor is a high-efficiency motor. The breakthrough: it's made of brazed copper, which is more conductive than conventional aluminum rotors.

**COOLING**
The inverter's transistors produce very little heat, allowing the car to use lightweight, energy-efficient air cooling, which vents through a tailpipe.

**HEATING**
Since there is no conventional engine to provide cabin heating, the Roadster has an electric heater. One bonus: it delivers heat immediately — no waiting for an engine to warm up.

**PARTS**
Tesla has deals with various manufacturers to supply the windshield wipers, brakes, suspension, and other components — there's no need to reinvent the high-performance windshield wiper.

**BATTERY PACK**
The power supply is split into 11 sectors of 622 lithium-ion cells. Each sector is controlled by its own processor, which monitors the charge and discharge rate of every cell.

**SAFETY MONITORS**
An accelerometer, smoke detector, voltage meter, temperature gauge, and water sensor can detect a crash or other failures and shut the batteries down to prevent fire or explosion.

**INVERTER**
The inverter uses 72 insulated transistors to transform the battery's dc energy into ac power. It delivers almost 80 percent more power than gas's 20 percent.

Source: www.treehugger.com
DIY Conversions

Motor

Fixed gear transmission

DMOC (Digital Motor Controller)

Azure Dynamics (former Solectria) AC24LS kit
All-Electric conversion

1995 Chevrolet S-10
~$12,000 not including labor

Source: http://www.cnn.com/2008/TECH/ptech/08/14/electric.cars/index.html
All-Electric Truck Conversion

Source: Azure Dynamics
Plug-in Hybrid Truck Conversion

Post-transmission motor mounted on transaxle

Source: http://www.converdantvehicles.com
Hybrid to Plug-in Hybrid Conversion

Hymotion/A123 L5 Li-Ion plug-in hybrid conversion kit

Purchase price is $9995 (plus a $400 “destination fee”) for a 5 KWh pack with a 4.5 hour charge time, 30-40 PHEV miles, and adding 180 pounds.

Final Topic: Policies for EVs

- Economics of EVs and HEVs
- Options for Promoting EVs
  - Market Incentives
  - State and Local Incentives
- Obama and EVs
- Project Better Place

http://graphics8.nytimes.com
http://www.evworld.com
http://www3.allaroundphilly.com
# Cost of Driving: EV vs. Conventional

**Battery Electric Vehicle**

<table>
<thead>
<tr>
<th>On-board energy consumption</th>
<th>300 Wh/mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging Efficiency</td>
<td>90%</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>333 Wh/mile</td>
</tr>
<tr>
<td>Electricity Cost</td>
<td>10 cents/mile</td>
</tr>
</tbody>
</table>

**Driving Cost (electricity only)**: 3.3 cents/mile

At 15,000 miles/year, you would save $700/year on fuel.

The estimated price range for advanced batteries is $500 - $1,000 per kWh.

~ buying 1 kWh of battery energy (~3 miles of electric range) each year.

**Conventional Gasoline Vehicle**

<table>
<thead>
<tr>
<th>Fuel economy</th>
<th>25 MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cost</td>
<td>$2.00/gallon</td>
</tr>
</tbody>
</table>

**Driving Cost (fuel only)**: 8.0 cents/mile
## Economics of Hybrids Available Today

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Hybrid Premium</th>
<th>Payback time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toyota Prius</td>
<td>$2,303</td>
<td>4.2</td>
</tr>
<tr>
<td>Chevrolet Malibu Hybrid</td>
<td>$535</td>
<td>4.6</td>
</tr>
<tr>
<td>Toyota Camry Hybrid</td>
<td>$1,381</td>
<td>4.8</td>
</tr>
<tr>
<td>Ford Escape Hybrid</td>
<td>$2,310</td>
<td>5.0</td>
</tr>
<tr>
<td>Saturn Vue Green Line</td>
<td>$1,774</td>
<td>5.8</td>
</tr>
<tr>
<td>Honda Civic Hybrid</td>
<td>$2,734</td>
<td>7.4</td>
</tr>
<tr>
<td>Nissan Altima Hybrid</td>
<td>$2,221</td>
<td>8.4</td>
</tr>
<tr>
<td>Saturn Aura Green Line</td>
<td>$1,095</td>
<td>9.4</td>
</tr>
<tr>
<td>Lexus GS450h</td>
<td>$2,280</td>
<td>10.8</td>
</tr>
<tr>
<td>Lexus RX400h</td>
<td>$4,767</td>
<td>11.7</td>
</tr>
<tr>
<td>Toyota Highlander Hybrid</td>
<td>$6,986</td>
<td>22.8</td>
</tr>
</tbody>
</table>

Primary Options to Advance EVs

1. Market incentives
   • Federal tax credit for energy efficient vehicles of the Energy Policy Act of 2005
   • State tax credits
   • Regional and local incentives

1. R&D

1. Demonstration and deployment
Federal Plug-in Electric Drive Vehicle Tax Credit of 2008

Tax Credit Value
- Battery Cost (Low)
- Battery Cost (Mid)
- Battery Cost (High)
- Electric Range (Estimate)
Regional Incentives

Use of HOV lanes
    AZ, CA, FL, GA, NJ, NY, UT, VA
Free parking
    Select cities in CA, MI, MD, TX
State Tax Credit or Rebate
    CO, IL, OR, PA, SC, WV
Partial Sales Tax Exemption
    CT, ME, NM, TN, WA
Battery Manufacturing Incentives
    MI

http://www.toyota.com

http://www.treehugger.com
Better Place plans to bring an entire EV infrastructure

Business plan like that of mobile phone

Better Place owns the batteries, the consumer pays for energy (miles)

Plan includes charging stations and battery swapping

So far: Israel, Denmark, Australia, California, Hawaii, and Canada
Obama and EVs: promises and decisions

Promises
• Put 1 million Plug-In Hybrid cars on the road by 2015

Decisions
• Attach strings to automaker bailouts?
• Allow states to establish GHG limits?
• Establish new CAFE standards?
In conclusion; you now know more than most about EVs, PHEVs, and HEVs

- Introduction to EVs
- EV Issues and Terminology
- Batteries for EVs
- Electric Motors for EVs
- EV and HEV Powertrains
- EV and PHEV Conversions
- Policies and Initiatives for EVs

For more information:
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Questions?