Prospects for Hybrid, Diesel and Hydrogen Vehicles

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Technology Breakthrough - or Evolution?

• The popularity of the second generation Prius has caused a major shift in thinking about hybrids, now viewed as a mainstream product.

• The low GHG transportation scenario for the future is often articulated as hybrids being a bridge to the hydrogen-fuel cell engine.

• The hydrogen-fuel cell engine has become accepted as the ultimate answer.

• Should we stand back and take a closer look?
Value of Fuel Savings @ $2/ gallon

- For a one percent reduction in consumption

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Consumer</th>
<th>Vehicle Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Car</td>
<td>$32</td>
<td>$50</td>
</tr>
<tr>
<td>Midsize car</td>
<td>$40</td>
<td>$65</td>
</tr>
<tr>
<td>Compact SUV</td>
<td>$60</td>
<td>$98</td>
</tr>
<tr>
<td>Large SUV</td>
<td>$80</td>
<td>$130</td>
</tr>
</tbody>
</table>
Types of Hybrids

• A large number of “hybrid” designs have been unveiled, each with unique attributes.
• Four types that will be in the US market and span the range of designs
  – Belt drive Alternator Starter (BAS)
  – Crankshaft mounted single motor (IMA/ISAD)
  – Dual Motor “full” hybrids (Prius/Escape)
  – “Full” hybrids with electric 4WD (Lexus 400H)
Common Attributes of Hybrids

- Hybrids must fully exploit all synergies with drivetrain and accessories to provide large improvements in fuel economy.
- Hybrids provide large fuel economy gains only in stop-and-go driving.
- Benefits deteriorate in very hot/cold weather due to space conditioning.
- Hybrids not suited for cargo hauling.
Belt-drive Alternator Starter

• Advantages - Easy to install, relatively low cost, few synergies needed.

• Disadvantages - Hard to install with large engines, automatic transmissions, A/C

• Provides 8 to 10 percent improvement in city driving

• Good solution for low cost small cars?
IMA/ ISAD Hybrid

- Advantages - reasonable cost (~$2000 to $3000), 40% to 50% benefit if all synergies are exploited as in Honda Civic hybrid.
- Disadvantages - no pure electric propulsion, inferior driveability compared to Prius.
- Future designs with ultra-capacitors may be introduced in Europe
- Potentially the little noticed dark horse in the hybrid market race?
Two Motor “Full” Hybrid

• Advantages - 60% to 65% fuel economy benefit with complete package optimization, good driveability, public acceptance in US?

• Disadvantages - future cost will be high (>4000), possible limit to maximum market penetration.

• Electric four-wheel drive improves economics in “soft-road” SUV models
Why look at diesel?

- Unlike a hybrid, the diesel’s fuel efficiency benefit is more robust across all driving conditions.
- Cautious optimism that diesel can meet Tier 2 and LEV 2 emission standards.
- Terrific low-end torque makes it well suited to cargo hauling, towing and rough duty.
- Perfect complement to the Hybrid?
Diesel Costs and Benefits

- Current diesel engines add $1500 (4 cyl.) to 3000 (V-8) for the engine alone and another $700 to 1200 for after-treatment.
- Fuel economy can increase 45 to 50% in combination with other changes.
- Significant additional improvement is possible with a diesel-hybrid combination, with cost reduction in emission control.
- Diesel hybrids likely to emerge in Europe soon.
Hydrogen - Fuel Cell

- Problems of current high cost (> $100K) of fuel cell and difficulty of hydrogen storage are well known.

- Problem of poor fuel economy is NOT well known - current FC cars are getting only 45 to 50 mpg on pure Hydrogen! This also causes poor range (< 200 miles).

- In contrast, first generation electric cars were rated at about 120 mpg (gasoline equivalent).
Are Fuel Cells the only path?

• Most research goals on fuel cells are aiming for huge cost reduction and improved hydrogen storage media.
• Little emphasis to date on poor fuel economy—unless FE is doubled, these vehicles could be a net negative for GHG.
• Technology breakthroughs on Li-Ion and Li-Polymer batteries could make EV a powerful and efficient competitor to fuel cells
Cost Effectiveness of Options

- For a midsize car

<table>
<thead>
<tr>
<th>Option</th>
<th>Benefit</th>
<th>$/percent FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>25</td>
<td>30 to 35</td>
</tr>
<tr>
<td>Conv. + BAS</td>
<td>30 + 2</td>
<td>55 to 60</td>
</tr>
<tr>
<td>IMA (optimized)</td>
<td>47 + 3</td>
<td>60 to 65</td>
</tr>
<tr>
<td>Full</td>
<td>60 + 3</td>
<td>125 to 135</td>
</tr>
<tr>
<td>Diesel</td>
<td>50 + 3</td>
<td>80 to 90</td>
</tr>
</tbody>
</table>
Summary

• Conventional technology improvements continue to be far more cost-effective than alternatives.
• Hybrids can be one element of a future strategy but are NOT suitable for everybody.
• The mild hybrid offers a level of benefit and cost effectiveness that could be more attractive in the market than those for a full hybrid.
• Diesels can be a good complementary strategy for pickups, load haulers and highway drivers.
• The little noticed fuel economy problem for hydrogen - fuel cell vehicles can be a show stopper for GHG emission reductions.
• More attention and analysis are required for a future all electric scenario, given battery development and hybrid success.
• Cost effectiveness will continue to be a problem for all alternatives at least to 2015 from the consumer and societal viewpoint.