Fuel-Cell-Hybrid Vehicle (FCHV)

IFCBC, February 2009

E. Peled, Tel Aviv University
Outline

• The oil import problem.
• The solution: renewable energy and alternative fuels (hydrogen, alcohols).
• Hydrogen production, distribution and storage
• Higher energy-conversion efficiency and greener technology with the use of fuel cells (FC).
• Development efforts (car industry)
• FCHV safety issues
• FCHV niche market.
• PEM FC cost analysis.
• Market penetration of FCHVs
The Impact of Fuel Cells

Fuel Cells could have a great positive effect on Western society
They would reduce
• Dependence on oil import
• Pollution
Disadvantages
• Currently cost prohibitive
• Require a new hydrogen infrastructure
Basic Operation of a PEM Fuel Cell

- Chemical Reaction Produces Electricity
- Fuel - H₂, O₂
- By-Product - H₂O
- Electrons Released at Anode
- Electrons Collected at Cathode
Possible EV System Configurations: which is the best?

- Direct Methanol FC
- Methanol Reformer
- Gasoline Reformer
- DOE ended funding

- Compressed Hydrogen
- Solid Hydride
- Methanol Tank
- Gasoline Tank
- Methanol Tank
- Hydrogen
- Methanol
- Gasoline
Hydrogen production and supply

Making hydrogen and supplying it to fuel cell vehicles

- Solar/Biomass/Nuclear
- By-product gas
- Coal
- Petroleum
- Natural gas
- Electricity

Wind, Solar

Hydrogen production plant

CO₂ separation and recovery

Tanker truck

CO₂ fixation facility (sequestration)

Hydrogen storage tank

Hydrogen fueling station

Fuel Cell Hybrid Vehicle
HYDROGEN STORAGE

Figure 23 – Specific volume versus weight for a number of hydrogen storage media and US DOE originally set targets [44]
### On-Board H₂ Storage Alternatives

**Short-term Goal: 3 kg H₂ (215 km)**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Storage System Volume [l]</th>
<th>Storage System Weight [kg]</th>
<th>Technology Readiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000 psi (~350 bar) Compressed Hydrogen Tanks</td>
<td>145</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>10,000 psi (~700 bar) Compressed Hydrogen Tanks</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Low Temperature Metal Hydrides</td>
<td>55</td>
<td>215</td>
<td></td>
</tr>
<tr>
<td>Liquid Hydrogen</td>
<td>90</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

### On-Board H₂ Storage Alternatives

**Long-term Goal: 7 kg H₂ (700 km)**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Storage System Volume [l]</th>
<th>Storage System Weight [kg]</th>
<th>Technology Readiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000 psi (~350 bar) Compressed Hydrogen Tanks</td>
<td>320</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>10,000 psi (~700 bar) Compressed Hydrogen Tanks</td>
<td>220</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Aluminate Hydrides</td>
<td>200</td>
<td>222</td>
<td></td>
</tr>
<tr>
<td>Carbon Nanotubes</td>
<td>~130</td>
<td>~120</td>
<td></td>
</tr>
</tbody>
</table>
Electric Vehicle FC system, 2007

The Toyota Fuel - Cell - Hybrid - Vehicle (FCHV)

Weight 1880kg, 5 passengers, 155km/h, Cruising range 330km

Battery - NiMH 21 kW

Fuel cell - 90 kW

Motor - 90kW

350 Atm hydrogen
Honda FCHV (Lithium ion battery)
Proton Exchange Membrane Fuel Cell (PEMFC), Power Output 100kW,
Size (liters)57, Weight (lbs) 148, 288V Lithium ion battery, Driving Range 280 KM
,Fuel Capacity / Tank Pressure 4.1 kg Hydrogen @ 5000psi

Fuel Cell Evolution
A true testament to Honda’s pioneering spirit, the evolution of the FCX Clarity is a story filled with determination and brave, creative solutions.

Honda has come out ahead by putting the first dedicated platform hydrogen fuel cell vehicles on the road and into customers’ hands. A true testament to Honda’s pioneering spirit, the evolution of the FCX Clarity is a story filled with determination and brave, creative solutions to seemingly insurmountable obstacles. And it’s all driven by Honda’s sense of responsibility to pursue clean energy sources that promise bluer skies for our children.
Kia - new Borrego FCHV

- A 115-kW fuel cell system
- A lithium-ion battery in a hybrid-drive system (offers a zero starting capability down to -30°C).
- Maximum speed of 100 mph
- Traveling range of 315 miles.
- The company plans to deploy a small fleet of the fuel cell Borregos on roadways during 2010.
GM HydroGen 4 FCEV

Passed 400,000 miles of testing in the U.S. (where its known as the Chevrolet Equinox Fuel Cell), capable of 0-62mph in around 12 seconds, has a top speed of 100 mph and a range of around 200 miles.
Mercedes' BlueZERO Hydrogen Concept

- The BlueZERO F-CELL (fuel cell) has a range of 400 km on one tank of Hydrogen and 100 km on the 17.5-kWh lithium ion battery.
- It is a "concept" cars and no plans for production have been announced so far.
Safety issues

• If a collision occurs, sensors in the TOYOTA FCHV’s front, rear and sides detect impact and instantly shut the valves on the high-pressure hydrogen tanks.
• For additional safety, the valves are also closed if leakage is detected by any of the hydrogen sensors placed at multiple locations within the vehicle,
• The high pressure hydrogen tanks are designed for maximum safety to avoid rupture even if the vehicle suffers a rear-end collision.
Overall efficiency of cars (well to wheel)

Overall efficiency (\%) = \text{Fuel efficiency (\%)}_{\text{well-to-tank}} \times \text{Vehicle efficiency (\%)}_{\text{tank-to-wheel}}

\*1 Well-to-tank: Efficiency with which the fuel is obtained, processed, stored and transported to the vehicle's tank.
\*2 Tank-to-wheel: Efficiency with which the fuel in the vehicle's tank is consumed and converted into vehicle motion at the wheel.

Overall (well-to-wheel) efficiency of the TOYOTA FCHV

<table>
<thead>
<tr>
<th></th>
<th>Fuel efficiency (%)_{well-to-tank}</th>
<th>Vehicle efficiency (%)_{tank-to-wheel}</th>
<th>Overall efficiency (%)_{well-to-wheel} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline vehicle</td>
<td>88</td>
<td>16</td>
<td>14%</td>
</tr>
<tr>
<td>Toyota Prius</td>
<td>37</td>
<td>37</td>
<td>32%</td>
</tr>
<tr>
<td>FCV (compressed hydrogen)</td>
<td>58*3</td>
<td>38</td>
<td>22%</td>
</tr>
<tr>
<td>TOYOTA FCHV</td>
<td>50</td>
<td>50</td>
<td>29% With hybrid control</td>
</tr>
<tr>
<td>FCHV (target)</td>
<td>70</td>
<td>60</td>
<td>12%</td>
</tr>
</tbody>
</table>

40-45% on H₂ (from electrolyzer) From gas
Niche FCHV transportation applications:

UMV and all electric airplanes
Scooters, motorbikes and bicycles (Beijing as a sample)
APUs
Material handling (fast charge)
Fuel cell trains
Mobility assistance vehicles

Figure 6: (left) SFC Smart Fuel Cell scooter and (right) Intelligent Energy/Suzuki Crosscage bike
## Summary  Volume and Weight

<table>
<thead>
<tr>
<th>PEMFC Sub-System</th>
<th>Volume (L)</th>
<th>Weight (kg)</th>
<th>DOE 2010 Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack</td>
<td>40</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>Power density² (Wₑ/L)</td>
<td>2,000</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>Specific power² (Wₑ/kg)</td>
<td>1,702</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>Balance of Plant</td>
<td>78</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Water management (enthalpy wheel, membrane humidifier)</td>
<td>14</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Thermal management (radiator, fan, pump)</td>
<td>26</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Air management (CEM, motor controller)</td>
<td>15</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Fuel management (H₂ blower, H₂ ejectors)</td>
<td>5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous and assembly</td>
<td>19</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td><strong>Total System</strong></td>
<td><strong>118</strong></td>
<td><strong>110</strong></td>
<td></td>
</tr>
<tr>
<td>Power density² (Wₑ/L)</td>
<td>678</td>
<td>650</td>
<td></td>
</tr>
<tr>
<td>Specific power² (Wₑ/kg)</td>
<td>727</td>
<td>650</td>
<td></td>
</tr>
</tbody>
</table>

¹ Does not include packing factor, which would lower volumetric power density.
² Based on stack net power output of 80 kW, and not on the gross power output of 86.5 kW
The cost problem of PEM FC - Stack

Platinum and the electrolyte membrane are the major contributors to the stack cost.

**Yr 2001 Fuel Cell Stack Cost Breakdown**
(Stack Cost: $181/kW)

- MEA 84%
- Bipolar Coolant 6%
- Bipolar Interconnect 6%
- Gaskets 2%
- Packaging 1%
- End Plates 1%

**Yr 2001 MEA Cost Breakdown**
(MEA Cost: $152/kW)

- Membrane 37%
- Anode 28%
- Cathode 26%
- Gas Diffusion Layer 9%

*Basis: 50 kWe net, 500,000 units/yr. Not complete without assumptions.

While power density determines the actual amount of material in the system. Parasitic power losses further increase size and cost.
System (stack and BOP) cost

<table>
<thead>
<tr>
<th>PEMFC System Cost(^1) ($/kW)</th>
<th>2005 OEM Cost</th>
<th>2007 Factory Cost(^1)</th>
<th>2007 OEM Cost(^1,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack</td>
<td>67</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Water Management</td>
<td>8</td>
<td>2.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Thermal Management</td>
<td>4</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Air Management</td>
<td>14</td>
<td>7.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Fuel Management</td>
<td>4</td>
<td>3.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>7</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Assembly</td>
<td>4</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>108</strong></td>
<td><strong>57</strong></td>
<td><strong>59</strong></td>
</tr>
</tbody>
</table>

\(^1\) High-volume manufactured cost based on a 80 kW net power PEMFC system. Does not represent how costs would scale with power (kW).

\(^2\) Assumes 15% markup to the automotive OEM for BOP components.

BOP component costs represent ~ 46% of the PEMFC system cost in 2007,
Results  BOP Economies of Scale

At low production volumes (100 units/year), the pilot plant scenario yields the lowest BOP cost of $340/kW, while at high volumes (≥ 80,000 units/year), the full-scaled scenario yields the lowest BOP cost of $26/kW.

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BOP Factory Cost (\$$/kW)

- Full-Scaled
- Semi-Scaled
- Pilot Plant

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1 High-volume manufactured cost based on a 80 kW net power PEMFC system. Does not represent how costs would scale with power (kW).
**Stack & System Costs vs. Annual Production Rate**

- Power Density = 525 mW/cm²
- Catalyst Loading = 0.21 mg/cm²

<table>
<thead>
<tr>
<th>DOE Target</th>
<th>Stack Cost</th>
<th>$/kWₑ (net)</th>
<th>2007 Status</th>
<th>2008 Status</th>
<th>2007 Status</th>
<th>2008 Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study Estimate</td>
<td>Stack Cost</td>
<td>$/kWₑ (net)</td>
<td>$50</td>
<td>$42</td>
<td>$27</td>
<td>$27</td>
</tr>
<tr>
<td>DOE Target</td>
<td>System Cost</td>
<td>$/kWₑ (net)</td>
<td>-</td>
<td>-</td>
<td>$45</td>
<td>$45</td>
</tr>
<tr>
<td>Study Estimate</td>
<td>System Cost</td>
<td>$/kWₑ (net)</td>
<td>$94</td>
<td>$81</td>
<td>$66</td>
<td>$80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ($)</td>
<td>6,480</td>
<td>3,920</td>
</tr>
</tbody>
</table>
Each line represents market potential versus price for a simple market in 2010 where HEV 0 and conventional models are available in each mid-size model, or HEV 20 and conventional models compete. The six points on each line are calculated with a common methodology. The two enlarged points on each line show the base case range (before government or automaker incentives). The base case range assumes costs using 100,000 HEVs per year and also reflect different methods of estimating the retail price estimate.
Commercialization of fuel cell vehicles and hydrogen stations to commence in 2015 (FCCJ)
July 4, 2008

Under the leadership of major member companies on its board of directors, the Fuel Cell Commercialization Conference of Japan* (FCCJ, President: Taizo Nishimuro, Advisor to the Board Toshiba Corp.) held repeated consultations on scenarios for full scale commercialization of FCVs and development of hydrogen stations, beginning in late 2006. These have finally led to an agreement on a timeline and the requirements for commercialization of FCVs and hydrogen stations in 2015.

[Diagram: Commercialization Scenario]

Technology development and other activities for commercialization of FCVs, which run on hydrogen,
Summary

• Most large auto manufacturers are developing FCHV (billion dollars per year).
• Hydrogen cost will be at least twice that of gasoline. Thus FCHV efficiency must be twice higher (as expected).
• FC system cost must be reduced to about $50/kW (20% higher than that of ICE; major cost items are the membrane and the catalysts)
• Durability must exceed 5000 hours (twice that of today).
• The FC system size and weight (including fuel tanks) must equal (or be closed to) that of gasoline car (seems possible).
• FCHV safety (including the battery) must be demonstrated.
• Early commercialization is expected to start at 2016, full commercialization at 202x.
Thank you all for your attention!
פיעלות המרכז

מתןיעוץ ושרוחים אפויים של רכיבי תאי דלק ותאי דלק
לתועשי ולמוסדות המחק.

מתןיעוץ ושרוחים אפויים של רכיבי תאי דלק ותאי דלק.

מתןיעוץ וביתוח ייעודי של רכיבי תאי סוללות, קבליל, בכיל, תאי סוללות ותאי סוללות מתקדמים. תוארי סולמות וחומרים משחילים: חומרים ננומטרים, פולימרים מוליכים שניים, חומרים ומלחים חושניים.

מידות אנליסיות, אלкатורכימיות מבניות ומישחתות.

יועץ מחוקעיلغישה ולחקירת start-up
לרכז את השתיים עם קבוצות תעשיות ואקדמיה לזרד
קידומים מורפי.

ערוך בפורים בעיות קורורות ברחביה הארצ.

הכשרת תלמידי מחקר ושלטנים בחר הזStreamWriter.

עריכות ימי עיוון.
Cost and performance Issues

• ICE cost is $40/kW, FCs must meet this cost.
• In order to meet it membrane cost must be $30/m² or less (today $600) and platinum catalyst loading must be about 0.1 mg/cm² (or $5/kW), today it is 0.5 mg/cm².
• Hydrogen cost will be at least twice that of gasoline. Thus FC efficiency must be twice higher.
• ICEs delivers about 1kW/l, the FC system must meet this value (it is about 0.7kW/l).