An Update on Toyota’s Fuel Cell Vehicle Activities

Hydrogen and Fuel Cell Technical Advisory Committee

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Robert Wimmer
Toyota Motor North America
Issues that Influence Automobile Business

**Issues**
- Petroleum Supply
- Climate Change
- Balance of Trade
- Energy Security

**Action**
- Energy & Fuel Diversification
- Life Cycle \( \text{CO}_2 \) Reduction
- Reduce Imported Fuel
- Reduce Imports from Unfriendly Countries

**Potential Solution**
- Biofuels
- Green Electricity
- Natural Gas
- Improved Efficiency
- Low Carbon Fuels
- Fuels from Domestic Feedstocks
- Fuels from Domestic Feedstocks
Hybrid is First Step

**TOYOTA MODELS**

- **Camry Hybrid**
  - Midsize 4 Door

- **Prius**
  - Midsize 5 Door

**LEXUS MODELS**

- **Highlander Hybrid**
  - Midsize SUV

- **GS450h**
  - Premium Sport Sedan

- **RX450h**
  - Luxury SUV

- **HS250h**
  - Midsize Sedan

- **LS600h**
  - Flagship

Averaging over 20,000 hybrids sold per month in 2008
The Big Picture

Cumulative Hybrid Sales

Global Energy Benefits to Date*
- Over billion gallons of gasoline saved
- Over 10 million tons of CO₂ avoided

New technologies must be produced in large volumes to make a meaningful impact

*Toyota Estimate
## Comparison of Energy Efficiency

<table>
<thead>
<tr>
<th>Energy pathway</th>
<th>Well-to-Tank (50%)</th>
<th>Tank-to-Wheel (50% *1)</th>
<th>Well-to-Wheel (20%)</th>
<th>*1</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCHV-adv</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>67% *2</td>
<td>59%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Reforming with membrane separation Hydrogen (70MPa)</td>
<td></td>
<td></td>
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<tr>
<td>EV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>39%</td>
<td>85%</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>Combined cycle power generation Electricity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline HV (Prius)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude oil</td>
<td>84%</td>
<td>40%</td>
<td>34%</td>
<td></td>
</tr>
<tr>
<td>Refine Gasoline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline ICE</td>
<td></td>
<td></td>
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*1 Tank-to-Wheel efficiency: measured in the Japanese 10-15 test cycle  
*2 Difference of Well-to-Tank efficiency between 35MPa and 70MPa: approx. 2%  
(Toyota Calculation)

**FCs are tough to beat for well-to-wheels efficiency**
# Toyota FCHV Progress

<table>
<thead>
<tr>
<th>Technical Challenges</th>
<th>'02 FCHV (lease model)</th>
<th>'05 FCHV (lease model)</th>
<th>'08 FCHV-adv (lease model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cold Start / Driving Capability</td>
<td>Dec. 2002 ~ 0degC ~ 210km</td>
<td>Jul. 2005 ~ 0degC ~ 230km</td>
<td>Present -30degC 500km or more</td>
</tr>
<tr>
<td>2. Actual Cruising Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. FC Stack Durability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Cost reduction</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Toyota is making excellent progress resolving technical challenges
### FCHV-adv

<table>
<thead>
<tr>
<th>Vehicle</th>
<th></th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall length/ width/ height (mm)</td>
<td>4,735/ 1,815/ 1,685</td>
<td>Type</td>
</tr>
<tr>
<td>Max. speed (mph)</td>
<td>96</td>
<td>Pure hydrogen</td>
</tr>
<tr>
<td>Cruising range (mile)</td>
<td>455 *1</td>
<td>Storage system</td>
</tr>
<tr>
<td>Fuel economy (mile/kg H₂)</td>
<td>72.4 *1</td>
<td>High-press. H₂ tank</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Max. storage pressure (MPa)</th>
<th>Tank capacity (kg H₂)</th>
</tr>
</thead>
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<tr>
<td>Storage system</td>
<td>70</td>
<td>6.0 (35 degC)</td>
</tr>
</tbody>
</table>

*1 in LA#4 cycle
Fuel Cell System Technology

Hybrid Technology

Power control unit
Motor
Battery

TOYOTA FC Stack
High pressure hydrogen tank

Fuel Cell System Technology
Key Technical Challenges for FC Vehicles

- A. Cruising range
- B. Freeze start capability
- C. Stack durability
- D. Cost & power density
FCHV-adv has achieved an practical cruising range of well over 300 miles.

FCHV-adv: improved FC system efficiency at all loads

Increased regenerative energy

Improved vehicle efficiency (fuel economy)

On-board H2: +94%

Fuel economy: +23%

Practical fuel economy (mile/kg)

Toyota in-house test cycle

Cruising range

On-board H2 (kg)

FCHV (137 miles, η 46%)

FCHV-adv (329 miles, η 58%)

Test cycle

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<td>LA#4</td>
<td>455 miles</td>
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<tr>
<td>Japanese 10·15 in-house test</td>
<td>516 miles</td>
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FCHV-adv: improved FC system efficiency at all loads

Increased regenerative energy

Improved vehicle efficiency (fuel economy)

64%
FCHV-adv Real-World Range

Rush Hour in Los Angeles
- 2 FCHVs
- Over 400 miles / tank
- 68.3 miles/kg of H2

Fairbanks to Vancouver
- 2300 miles
- Over 300 miles / tank
- No mechanical problems
Key Technical Challenges for FC Vehicles

A. Cruising range
B. Freeze start capability
C. Stack durability
D. Cost & power density
Demonstrated Cold Start Capability

Ambient Air Temperature at Timmins

Yellowknife, Canada

Cold weather performance similar to conventional vehicles
Cold Start Countermeasures

Management of water when starting at subfreezing temperature

Measures important for cold start capability:
A) Optimum purge to reduce remaining water
B) Increase of water storage capacity
C) Accelerating stack temperature rise
Key Technical Challenges for FC Vehicles

A. Cruising range
B. Freeze start capability
C. Stack durability
D. Cost & power density
MEA durability is steadily improving under real-world conditions.
FC System Durability

Graph showing the relationship between running distance and system output. The graph indicates a linear degradation to the equivalent of 25 years.

Driving Cycle Pattern of Test:
- Average speed: 40 mile/h
- 30 min / cycle
- 312,000 mile; 25 years equivalent

Testing indicates linear degradation to the equivalent of 25 years.
Degradation During Start-up & Shutdown

1. Degradation due to potential change at starting

Voltage at start-up and shutdown must be managed.
Cold Start Degradation

Must minimize degradation from cold starts
FC Stack Durability Summary

Confirmed system durability of FCHV-adv:

- 25-year equivalent durability on crossover
- Approximately 70% of initial performance after the equivalent of 25 years operation

Next steps:
Develop countermeasures to enhance durability

- Reduce start/stop and cold start degradation
- Confirm correlation between laboratory and field test data
Key Technical Challenges for FC Vehicles

A. Cruising range
B. Freeze start capability
C. Stack durability
D. Cost & power density
FCHV Cost Reduction

Reducing costs
By innovative design, material, manufacturing engineering

Resolving technical issues

'05 Model FCHV
'08 Model FCHV-adv
Model generation
Model generation

By mass production

1/10
1/10
Approaches to FCHV Cost Reduction

(1) Design
   1. Simplify the system
   2. Downsize and reduce weight of FC stack

(2) Materials:
   Reduce the cost of FC-system-specific materials
   => Important to cooperate with materials manufacturers

(3) Improve production technology
FC Stack Cost Reduction

(1) Design: Downsize & reduce weight (minimize materials)
1. Increase output density
2. Reduce number of parts
3. Improve joint/seal method
4. **Decrease Pt catalyst loading**

(2) Material: Improve durability & reduce cost
1. Electrolyte membrane
2. Separator (incl. surface treatment)
3. GDL, etc.

Current Density [A/cm²]

Cell Voltage [V]

Current density x2 with ½ electrode area → Halve cell materials used

Max. output
Electrode Catalyst “Trilemma”

- Improvement of catalyst activity
- Crossover reduction
- Contact resistance reduction
- Improvement of proton conductivity
- Improvement of gas diffusivity
- Water management

**Goal**

- Improvement of gas diffusivity
- Water management

**Current Status**

**Trilemma of Electrode Catalyst**

1. Reduction of precious metal amount (Pt 1/10)
2. Higher performance
   - (High voltage / High output density)
3. Durability improvement
   - (200,000km for 15 years or more)

**Efficiency**

**Current Density (A/cm²)**

**Power Density**

Must solve electrode catalyst “trilemma” to achieve FC stack cost targets
(1) Reduce CFRP used (by making thinner)
   - Optimize laminar structure (hoop winding / helical winding)
   - Optimize L/D
   - Optimize boss size

(2) Reduce cost of CFRP
   - Aviation grade => general-purpose grade
   - Develop low-cost CFRP for high-pressure tank
(1) Web handling technology

- Transfer direction
- Slip @ transfer speed 50m/min.
- Revolution indicator

Development of Production Technology
Progress of FC Technology Development

Valley of death
Source of pictures: each automaker’s web site (excluding TOYOTA FCHV)

FC development is more than half way over the “Valley of Death”
Steps for Commercialization

**Production**
- Solar / biomass
- Coal
- Petroleum
- Natural Gas
- Electricity

**Issues**
- Production
- Storage method
- CO₂ Stabilization
- Cost

**Delivery, Supply**
- Hydrogenated compounds
- Transportation Method
- Infrastructure Development
- Codes & Standards
- Hydrogen Delivery Cost

**Vehicle**
- Stack Durability
- Power Density
- Freeze Start Capability
- Driving Range
- Vehicle Cost

**Government, Energy Suppliers**

**Car makers**
California Infrastructure Concern

Assumption:
One $H_2$ station serves 25 FC vehicles

Expected FC Vehicle# based on current ZEV requirement

By the 2012, the demand for $H_2$ stations will far exceed supply if station deployment is not accelerated
Conclusions

• Hydrogen is one of the future fuels Toyota is pursuing

• We continue to devote considerable resources to bringing a FC vehicle to market in the 2015 time frame
  – Cold start & range issues are mostly resolved
  – Durability & cost challenges remain

• “Green” fuels and high volumes are required for meaningful GHG benefit

• Deployment of hydrogen refueling infrastructure must accelerate for fuel cell vehicles to succeed
Thank You!