Progress and Challenges for TOYOTA’s Fuel Cell Vehicle Development

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1. Comparison of Fuel Cell Vehicle and Battery Electric Vehicle

2. Recent Progress of Toyota’s FCHV
   - Cruising Range
   - Freeze Start

3. Remaining Technical Challenges of FCHV
   - Durability
   - Cost

4. Conditions for FCV’s Mass Introduction
   - H₂ supply, cost and infrastructure
Comparison: Electricity and Hydrogen

- Liquid fuel: Most appropriate for automotive use
- Electricity: Difficult to extend cruising range
- Hydrogen: Can achieve quick charge and long cruising range like conventional vehicles

(Toyota calculation)

- Lithium-ion battery
- High pressure hydrogen (35MPa)
- High pressure hydrogen (70MPa)
- CNG (20MPa)
- Hydrogen-absorbing alloy (2wt%)
- Gasoline
- Ethanol
- Diesel
Comparison: Fuel Cell and Battery

Mass (calculation) required to achieve an practical cruising range of 300 miles

[ Vehicle weight (excluding battery) : 1.4t ] Toyota calculation
As personal mobility, EV is viable for intra-city travel, and FCHV for inter-city travel.
## Comparison of Total Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Energy pathway</th>
<th>Well-to-Tank 50%</th>
<th>Tank-to-Wheel 50% *1</th>
<th>Well-to-Wheel *1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FCHV-adv</strong></td>
<td>Natural gas Membrane separation reform Hydrogen (70MPa)</td>
<td>67% *2</td>
<td>59%</td>
<td>40%</td>
</tr>
<tr>
<td><strong>EV</strong></td>
<td>Natural gas Gas-fired Power generation Electricity</td>
<td>39%</td>
<td>85%</td>
<td>33%</td>
</tr>
<tr>
<td><strong>Gasoline HV (Prius)</strong></td>
<td>Crude oil Refine Gasoline</td>
<td>84%</td>
<td>40%</td>
<td>34%</td>
</tr>
<tr>
<td><strong>Gasoline ICE</strong></td>
<td>Crude oil Refine Gasoline</td>
<td>84%</td>
<td>23%</td>
<td>19%</td>
</tr>
</tbody>
</table>

*1 Tank-to-Wheel efficiency: measured in the Japanese 10-15 test cycle
*2 Efficiency difference between 35MPa and 70MPa: approx. 2%

(Toyota Calculation)

FCHV-adv has great advantage in the Well-to-Wheel efficiency.
### Evolution of TOYOTA FCHV

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Present</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>'02 FCHV (lease model)</td>
<td>Dec. 2002 ~</td>
<td>'08 FCHV-adv (lease model)</td>
</tr>
<tr>
<td>'05 FCHV (lease model)</td>
<td>Jul. 2005 ~</td>
<td></td>
</tr>
</tbody>
</table>

#### Technical Challenges

1. **Cold Start / Driving Capability**
   - Present: 0degC
   - 2015: -30degC

2. **Practical Cruising Range**
   - Present: 300mile or more
   - 2015: 15 years or more

3. **FC Stack Durability**
   - Present: 1/10 or less (design / materials)

4. **Cost reduction**
   - Present: |

- Actual cruising range and cold start / driving capability has been significantly improved.
- Toyota continues efforts especially on FC stack durability and FC system cost reduction targeting commercialization in 2015.

*FCCJ* Target on starting commercialization (Decision making)

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*FCCJ: Fuel Cell Commercialization Conference of Japan*
<table>
<thead>
<tr>
<th>Vehicle</th>
<th></th>
<th>Fuel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall length/ width/ height (mm)</td>
<td>4,735/ 1,815/ 1,685</td>
<td>Type</td>
<td>Pure hydrogen</td>
</tr>
<tr>
<td>Max. speed (mph)</td>
<td>96</td>
<td>Storage system</td>
<td>High-press. H₂ tank</td>
</tr>
<tr>
<td>Cruising range (mile)</td>
<td>455 *1</td>
<td>Max. storage pressure (MPa)</td>
<td>70</td>
</tr>
<tr>
<td>Fuel economy (mile/kg H₂)</td>
<td>72.4 *1</td>
<td>Tank capacity (kg H₂)</td>
<td>6.29 (15 degC)</td>
</tr>
<tr>
<td>Seating capacity</td>
<td>5</td>
<td>Curb weight</td>
<td>4145 lbs</td>
</tr>
</tbody>
</table>

*1: in LA#4 cycle
Joint evaluation of FCHV-adv was performed on June 30th, 2009 on mixed traffic condition in Southern California.

Actual on-road range evaluation of Toyota’s FCHV with DOE, NREL and SRNL

Trip distance: 331.5 miles
Fuel Economy: 68.3 mile/kg\(\text{H}_2\)
Calculated full-tank range: 431 miles
Cold start and driving performance of the TOYOTA FCHV-adv was verified to be equivalent to gasoline-ICE vehicles.
First, we aim to reduce the cost to 1/10 of the current level by design and materials improvement.
(1) Design:
  1. System simplification
     - FC system, H$_2$ tank system, etc.
  2. FC stack
     - Simplifying design
     - Downsizing & downweighting,
       Reducing Pt amount
       (to reduce the materials used)

(2) Materials:
  Reducing the cost of FC-system-specific materials
  → Important to cooperate with materials manufactures

(3) Mass Production technology
  - FC stack, H$_2$ tank, etc.
Cost Reduction of High-pressure Hydrogen Tank Body

(1) Reduce CFRP by reducing the wall thickness
   - Optimize laminar structure (hoop winding / helical winding)
   - Selection of tank type (type III, IV)    - Optimize L/D
   - Optimize boss size

(2) Reduce cost of CFRP
   - Aviation grade → general-purpose grade
   - Develop low-cost CFRP for high-pressure tank
Development of Mass Production Technology

(1) Web handling technology

(2) One-by-one handling technology

(3) High speed winding of 70 MPa hydrogen tank

Slide 14: TOYOTA
Conditions for FCV’s mass introduction

Self-sustaining increase of FCV sales together with H₂ supply network

Customers
Purchase and drive FCV

Green-conscious + economic advantage (Vehicle cost, fuel cost)

Profitability (vehicle manufacturing & sales)

Auto OEMs
Manufacture & sell FCV

Energy suppliers
Produce & sell H₂

Profitability

For mass introduction of FCVs, profitability of every stakeholder is essential.
Challenges of Infrastructure Development, Hydrogen Pathways

**Optimum hydrogen infrastructure building from the perspective of right timing, right place, and right methods**

**H₂ Production**
- Excess by-product H₂
- Solar /Biomass
- Electricity
- Coal
- Petroleum
- Natural gas

**H₂ Transport / Storage**
- Gaseous H₂
- Liquid H₂
- Chemical hydrides etc.

**H₂ Supply**
- Trigeneration Station
- Electricity/Hot water/H₂
- Onsite H₂ Production
- Home Refueling
- Trigeneration Electricity/Hot water/H₂

**Refueling**
- Station
- High-Pressure H₂
- Liquid H₂

**In short term:** by-product H₂, fossil-fuel-based H₂
**In mid- & long term:** renewables, biomass, nuclear power → water electrolysis, direct water splitting

- 1. Pipeline (Short-distance) close to H₂ production plant
- 2. Truck (Mid- & long distance)
- 3. Truck (remote area)

**FCHV**

*Today For Tomorrow*
Breakdown of Hydrogen Station Cost  (Case of Japan)

On-site NG reformation
100Nm³/h (96 vehicles/day), 35MPa

H₂ station cost
(Aichi Expo)

(2005 results)

Total
$2.9M

Gasoline station
ave. building cost

Approx. $1M (8 nozzles)

$1 = 100 Yen based

For popularization, development of Hydrogen Station’s cost reduction technology is essential.
Infrastructure building needs to be coordinated with vehicle placements.
Auto OEMs and Energy Suppliers are working in line toward expected start of 2015 FCV commercialization in Japan.
Toward future mass introduction of FCVs

<Conditions for mass introduction>
- Profitable Business cases for Customers, Auto OEMs and Hydrogen suppliers is important. In other words, low-cost FC vehicle and sufficient supply of low priced hydrogen should be available.
- Both Fuel Cell vehicles and Hydrogen infrastructure should be durable and reliable in practical use. ( Durability, safety, etc. must be proven in the real world. )
- It took seven years even for “successful” HV vehicles to reach 100k/year global sales.

<Request to CARB in regards to Fuel Cell Vehicles>
- Close observation of technology progress and surrounding condition to determine potential ZEV Phase 4 regulation. ( Just a large number of mandate will not work to realize mass introduction. )
- Variety of Incentives for real mass introduction of Fuel Cell vehicles together with Hydrogen supply network.
- To enhance study of Low-cost supply network of Hydrogen by Energy Companies.
Summary

1. Fuel Cell vehicle is more suitable for longer-range, larger vehicle applications compared to EVs.

2. Toyota’s FCHV technology has been steadily moving forward including more than 300 miles of practical range and –30degC freeze start capability.

3. Toward 2015 target of larger scale introduction, Toyota is making maximum efforts to overcome remaining technical challenges of FCHV such as Cost reduction and Durability improvement.

4. Conditions for FCV’s Mass Introduction
   - Low-cost and easy-access H₂ supply network are a must.
     Further technical development and study of profitable business case are necessary.
   - Variety of governmental incentives are critical to form initial market beginning around 2015-2020.

5. Request to CARB/Government
   - Align ZEV requirement with technical, infrastructure and market readiness.
   - Study of various potential governmental incentives.
Today for Tomorrow