FCEV Technology: Stack Technology

Technology developments to enable FCEV manufacturing at scale?

2016.9.27

Toyota Motor Corporation
1. Toyota Environmental Challenge
2. MIRAI Technologies
3. Future challenge
   3-1. New FCEV technologies
   3-2. Hydrogen Infrastructure
   3-3. Customer first
1. Toyota Environmental Challenge

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Toyota Environmental Challenge 2050 (Oct. 2015)

Challenge 1: New Vehicle Zero CO₂ Emissions Challenge

Challenge 2: Life Cycle Zero CO₂ Emissions Challenge

Challenge 3: Plant Zero CO₂ Emissions Challenge

Challenge 4: Challenge of Minimizing and Optimizing Water Usage

Challenge 5: Challenge of Establishing a Recycling-based Society and Systems

Net Positive Impact Challenge

Challenge 6: Challenge of Establishing a Future Society in Harmony with Nature

Zero Environmental Impact Challenge

Contributing to a Better Society through Net Positive Impact

Challenge of Achieving Zero
Electrification would increase dramatically after 2020.
Toyota has developed all the technologies not only conventional vehicles but also Zero Emission Vehicles.
HEV expansion and CO$_2$ reduction in US

3.0M* HEVs in 15 years in US, resulting in 20M ton CO$_2$ reduction.

*achieved 9.0M HEVs in global
Development of Hybrid Technology

Hybrid technology as core, common crossover technology for PHEV, BEV and FCEV
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FCEV “MIRAI” was launched in US, October 2015
(Volume production started in Japan, 2014)
Newly developed components

**FC stack**
- Innovative flow channel structure and Electrodes of cells for higher output
- Output/volume: 3.1kW/L

**High pressure H₂ tank**
- The light weight structure of carbon fiber reinforced plastic enabled
- Storage: 5.7wt%*

**No external Humidifier system**
- Internal water circulation

**FC boost converter**
- Reduced number of cells in FC stack
- Common use of hybrid units

*H₂ mass/Tank mass

In-house development of FC main components to achieve world leading performance
FC Stack with high power density

- Higher performance, smaller size -

Achieved 2.2 times higher power density from previous (2008) model

New FC stack (MIRAI)
Titanium
3D fine-mesh flow field (cathode, world-first)

Volume power density 3.1 kW/L

World top level

2002 model
Molded carbon, straight channel

2008 model
Stainless steel, straight channel

Mass power density [kW/kg]
High Performance of New Cells

**Gas diffusion layer:**
- Lower density and thinner base material
- Gas diffusion performance more than doubled

**Electrolyte membrane:**
- Thinned to one-third Proton conductivity increased by 3 times

**Catalyst layer:**
- Highly reactive Pt/Co alloy catalyst. Activity increased by 1.8 times

**Cell voltage [V]**

- **2008 model cell**
- **New cell**

**Current density [A/cm²]**

- Current density 2.4 times higher

**World top level**

**High performance FC with thinner electrolyte membrane and high-activity catalyst. They provided humidifier-less system.**
**Main specification**

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Nominal working pressure</strong></td>
<td>70 MPa (approx. 700 bar)</td>
</tr>
<tr>
<td><strong>Tank storage density</strong></td>
<td>5.7 wt% (world top level)</td>
</tr>
<tr>
<td><strong>Tank internal volume</strong></td>
<td>122.4 L (front: 60.0 L, rear: 62.4 L)</td>
</tr>
<tr>
<td><strong>Hydrogen storage mass</strong></td>
<td>Approx. 5.0 kg</td>
</tr>
</tbody>
</table>

**Weight is reduced by innovation of carbon fiber-reinforced plastic layer structure. Tank storage density of 5.7wt% achieved, a world top level**
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Uncertainties

There are many uncertainties for the future expansion

Vehicle Technology
- Cost/benefit improvements
- Deployment rates
- Fleet sales mix

Govt Policies
- Incentives
- Flexibilities
- Other regulations (safety, fuels, etc.)
- State mandates

Customers
- Preference
- Affordability
- Awareness of FE Technologies
- Acceptance of Technologies
- Investment payback

Fuels
- Price
- Availability
- Quality/Specs
- Infrastructure

Economic Conditions
- GDP
- Unemployment rate
- Income levels
- Health of Auto Industry

There are many uncertainties for the future expansion
Key point of further FCEV expansion

Technology development

• Cost reduction
• Downsizing
• Cruising range (Fuel efficiency)

Infrastructure

• Easy access
• High reliability

Customer first

• Fuel price
• Incentives
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Future challenges of FCEV

**FCEV volume target (around 2020 and later):**
- Global: More than 30,000/year
- Japan: Approx. 1,000/month, plus 100 buses in total

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**Cost Reduction**
- High performance and downsizing
- High cost materials
  - Platinum, PEM, CFRP etc.
- Production Volume Efficiency

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**Downsizing**
- FC and BOP
- Hydrogen Storage

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**High Spd&Volume Manufacturing**
- FC cell production
- Hydrogen Tank production

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**Cruising Range, Fuel Efficiency**
- Further Cruising Range
- Fuel Efficiency Improvement

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Environmental challenge 2050, Oct. 2015
Fuel cell system costs have been reduced significantly. Effort of cost reductions has continued.
Toyota’s approach

Maximum HEV technology application yields cost reduction

HEV Technology
- Power Control Unit
- Motor
- Battery

FCEV Technology
- FC Stack (electrolyte membrane, separator)
- High pressure hydrogen tank (Carbon fiber)
Reduction of high cost materials may achieve both higher FC power density and cost reduction.
Multi-approaches for material reduction

Precious metal reduction ex.: Core Shell Catalyst

- Higher catalyst activity with metal alloy
- Better Pt/support interaction for higher catalyst activity
- Smaller Pt amount with core shell structure
- suppress Pt dissolution
- new catalyst support with good anti-corrosion

Development for higher performance and downsizing

Volume power density [kW/L]

Mass power density [kW/kg]

1) Material development: ex) alloy, core shell structure catalyst
2) Performance improvement and downsizing

Material/cost reduction
Multi-approaches for material reduction

Precious metal reduction ex.: Core Shell Catalyst

1) Material development: ex) alloy, core shell structure catalyst
2) Performance improvement and downsizing

Development for higher performance and downsizing

Volume power density [kW/L]

Mass power density [kW/kg]

1.0
0.5
0.0
0.5
1.0
1.5
2.0
2.5

2002 model
2008 model
MIRAI

Pd
Pt

Material/cost reduction

Rewarded with a smile
Real time observation of Pt behavior

Direct reaction observation via transmission electron microscope (TEM)

Phenomenon observed (schematic diagram)

Platinum nanoparticle (~few nm)

Coarsening

0 sec. → 337 sec. → 620 sec.

Recreate a fuel cell catalyst chemical reaction in a TEM and observe real-time catalyst coarsening
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Hydrogen refueling

Fueling time of approximately 3 minutes has been achieved with new fueling standards (same in the US, Japan and Europe).
Stations number is growing, forecasted 50 in 2017
Further deployment is necessary for wide FCEV expansion
Global deployment of hydrogen stations

- **California**: 20 sites
- **Northeast states**: 0 site
- **Germany**: 25 sites
- **UK**: 8 sites
- **Nordic countries**: 15 sites
- **Japan**: 80 sites

**Areas where infrastructure development can be expected from early 2016**

**Areas where infrastructure development can be expected after 2016**

**150+ public stations in global, deployment has just started**
## Approach in Japan

**Strategic Roadmap for Hydrogen and Fuel Cells, 2016.3.22**

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2016 (present)</th>
<th>2020 (target)</th>
<th>2025 (target)</th>
<th>2030 (target)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FCEV number</strong></td>
<td>–</td>
<td>–</td>
<td>40,000</td>
<td>200,000</td>
<td>800,000</td>
</tr>
<tr>
<td><strong>Station number</strong></td>
<td>84 sites</td>
<td>100 sites are open</td>
<td>160</td>
<td>320</td>
<td>900</td>
</tr>
<tr>
<td><strong>Capex/Opex</strong></td>
<td>$3.9M/$400k</td>
<td>–</td>
<td>half of 2014 level</td>
<td>same level as US/Europe</td>
<td>–</td>
</tr>
<tr>
<td><strong>Fuel cost</strong></td>
<td>same as HEV ($10/kg)</td>
<td>–</td>
<td>&lt; $10/kg</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Gross profit</strong></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>$5/kg</td>
</tr>
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H₂/FC roadmap was revised by METI* in March 2016 mid and long term targets were set under government leadership

*Ministry of Economy, Trade and Industry
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Gas prices impact ZEV sales and fuel price have strong correlation.
1. "Cool", "advanced" FCEV
   Better price, better product

2. Hydrogen station deployment for the customers
   Access within 5-10min.

3. Customer first
   Equal or less fueling price as HEV
   Incentive for ZEV affordable

Key point of FCEV expansion

Responsible to auto industry

Government, Energy Stakeholder corporation are necessary
**Fuel diversity and uses**

- **HEV/PHEVs**
  - Passenger cars
  - Short-distance commuter vehicles
  - Personal mobility

- **BEVs**
  - Home delivery vehicles
  - Short-distance vehicles
  - Personal mobility

- **HEVs**

- **PHEVs**

- **FCEVs**
  - FC buses
  - Full-size trucks
  - Home delivery trucks

**Fuel diversity and uses**

- **Electricity**
- **Gasoline, diesel, biofuels, CNG, synthetic fuels, etc.**
- **Hydrogen**

**HEV & PHEV:** Wide-use,  **BEV:** Short-to-mid distance,  **FCEV:** Medium-to-long distance
Fun to drive experience

Excellent usability

Refueling time: Approx. 3 minutes

Cruising range: 312 miles

EPA-rated miles, world top level

“The Toyota Mirai breaks 24-hour fuel-cell electric mileage record (1,438 miles!) in California”

TrueZero, Green Car Congress 09/17/16
New value-chain, new energy storage and sustainable society with hydrogen
Cooperation with all stakeholders is required to reduce CO$_2$. 

Cooperation with all stakeholders 

New Vehicle CO$_2$ Zero Challenge 

Government 

Energy Supplier 

Auto Industry 

Customers
• TOYOTA will continue to develop all the technologies from conventional to zero emission vehicles against challenging global warming.

• TOYOTA launched FCEV “MIRAI” in US, October 2015, and keeps developing new technologies.

• Corporation with all stakeholders is necessary for the FCEV expansion and better future for our children.
Thank you