Toyota’s Approach to Fuel Cell Vehicles

June 25, 2014

Toyota Motor Corporation
The first automobiles

Steam-powered vehicle (1769)

Electric vehicle (1899)

Gasoline vehicle (1886)

Benz Patent-Motorwagen

<table>
<thead>
<tr>
<th></th>
<th>Price</th>
<th>Engine</th>
<th>Max. speed</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>2,750 marks (approx. $1,000)</td>
<td>Single-cylinder horizontal 984 cc/400 rpm/0.9 hp</td>
<td>16 km/h</td>
<td>313 kg</td>
</tr>
</tbody>
</table>

Source: Toyota Automobile Museum; Wikipedia
The electric engine starter

Manual engine starter

Electric engine starter (1911)

Source: Cadillac 1912 Instruction Book
The assembly line

Ford Model T assembly line

Advent of mass production (1913)

Price reductions due to innovations in production methods

$850 (1908)
(Rival companies: $1,800)

$780 (1910)

$290 (1924)

Sources: Ford Motor Company; Wikipedia; Utah Division of State History; Amerika jidosha kogyo no kenkyu (Setsuo Kotani, 2001)
The road network in the U.S.

**Interstate Highways** (Dwight D. Eisenhower National System of Interstate and Defense Highways)

- Built under the Federal-Aid Highway Act of 1956
- Combined length of approx. 66,000 km, at a total cost of 25 billion dollars over 13 years
- Funded with Highway Trust Fund (Gasoline tax in 1956: 3 cents/gallon)

Sources: U.S. Department of Transportation Federal Highway Administration; Cato Handbook on Policy, 6th Edition
History of gasoline

1901: Oil fields discovered in Texas
1907: First gas station opens in the U.S.
1913: Thermal cracking allows greater quantities of gasoline to be obtained from petroleum
1929: 300,000 stores selling gasoline in the U.S.

Lucas gusher, Spindletop Hill, Texas (1901)

Drive-in gas station (1913)

Sources: Sekiyu no seiki (Daniel Yergin, Yoshiki Hidaka, Naotake Mochida, 1991); The Paleontological Research Institution, Gulf Oil
The simultaneous development of technologies, roads and fuel gave rise to the age of gasoline-powered automobiles.
What the automobile has achieved

- Enhanced mobility (for people and for goods)
- Freedom and convenience (“anytime, anywhere”)
- Mobile personal spaces

Economic, social, and cultural growth = New possibilities created by enhanced mobility
Problems caused by gasoline-powered automobiles

Growth of global industry and technology in the 20th century

Increase in number of vehicles

Surge in fossil fuel consumption

Concern over future oil supply

CO₂ emissions leading to global warming

Air pollution
Developing non-conventional resources will increase the global oil supply.

Global liquids supply by type

- Crude oil (conventional oil fields)
- Liquid natural gas
- Oil sands
- Tight oil
- Deep-sea oil fields
- Biofuels
- Others

Crude and condensate resources

Remaining resources

Cumulative production through 2040

Source: IEA; ExxonMobil
Increase in distance traveled

Distance traveled has increased due to economic growth

Source: WBCSD Mobility 2001

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The world in 2050

- Global population of 9.6 billion
- 70% of the world’s population living in cities

Rapid increase in overall/urban population and economy leading to
Intensified environmental problems
(climate change, global warming, air pollution)
What is a sustainable mobility society?

One that allows us all to move freely in comfort and safety, in an environment-friendly, sustainable manner.
A sustainable society

A society which uses diverse energy sources, with electricity and hydrogen infrastructures

- Electricity storage facilities
- Thermal power generation
- Power generation units
- Automotive fuel
- Hydrogen storage facilities
- Electrolysis
- Power generation units
- Energy Flow: Electricity, Hydrogen, Fossil fuels

Renewable Energy
- Wind power
- Photovoltaic generation
- Biomass
- Wastewater

Hydrogen-Electricity Conversion
- EVs/PHVs
- Urban/residential
- Urban/residential
- Urban/residential
- Refineries/chemical plants
- Chemical plants

Hydrogen Grid
- High-volume, long-term storage
- Urban/residential
- FCVs/FC buses

Electricity Grid
- Industry
- Fossil Fuels

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Toyota’s environmental principles

- Embracing diverse energy sources
- Developing efficient, low-emission vehicles
- Driving real and positive change by popularizing these vehicles
Primary energy sources, automotive fuels and powertrains

Primary energy source
- Oil
- Natural gas
- Coal
- Plants
- Uranium
  - Hydro, solar, geothermal electricity generation

Automotive fuel
- Gasoline
- Diesel

Powertrain
- Conventional and hybrid vehicles
- PHVs
- EVs
- FCVs

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Toyota has introduced hybrid models in all vehicle categories as of May 2014.

<table>
<thead>
<tr>
<th>Category</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact</td>
<td><img src="compact_models.jpg" alt="Image" /></td>
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<tr>
<td>Medium</td>
<td><img src="medium_models.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Large</td>
<td><img src="large_models.jpg" alt="Image" /></td>
</tr>
<tr>
<td>SUV</td>
<td><img src="suv_models.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Minivan</td>
<td><img src="minivan_models.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Commercial</td>
<td><img src="commercial_models.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>

As of May 2014
Hybrid vehicle sales

HV global sales
• 2012: Achieved 1 million annual units sales for the first time
• Dec. 2013: Cumulative sales passed 6 million units

As of May 2014

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TOYOTA
Development of hybrid technology

Hybrid technology underpins Toyota’s PHVs, EVs and FCVs
## Characteristics of alternative fuels

<table>
<thead>
<tr>
<th></th>
<th>Electricity</th>
<th>Hydrogen</th>
<th>Biofuel</th>
<th>Natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EV</td>
<td>FCV</td>
<td>Internal combustion engines</td>
<td>Internal combustion engines</td>
</tr>
<tr>
<td>Well-to-wheel CO₂</td>
<td>Poor to Excellent</td>
<td>Poor to Excellent</td>
<td>Poor to Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Supply volume</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Cruising range</td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>Fueling/charging time</td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Dedicated infrastructure</td>
<td>Good</td>
<td>Poor</td>
<td>Excellent</td>
<td>Good</td>
</tr>
</tbody>
</table>
Fuel diversity and uses

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Electricity</th>
<th>Gasoline, diesel, biofuels, CNG, synthetic fuels, etc.</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel distance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVs</td>
<td>HOME DELIVERY VEHICLES</td>
<td>SHORT-DISTANCE COMMUTER VEHICLES</td>
<td>PERSONAL MOBILITY</td>
</tr>
<tr>
<td></td>
<td>EVs</td>
<td>HVs</td>
<td>PHVs</td>
</tr>
<tr>
<td></td>
<td>FCV BUSES</td>
<td>FCV BUSES</td>
<td>FCV BUSES</td>
</tr>
<tr>
<td></td>
<td>HOME DELIVERY TRUCKS</td>
<td>FULL-SIZE TRUCKS</td>
<td></td>
</tr>
</tbody>
</table>

**EVs: Short-distance, HVs & PHVs: Wide-use, FCVs: Medium-to-long distance**
The importance of PHVs

PHVs can be used safely and without limitations, at all times

Next-generation electric vehicles for widespread use

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# Pros and cons of EVs

## Advantages
- Zero emissions when driven
- Quiet
- Rechargeable from household outlet

## Disadvantages
- Shorter range
- High battery costs
- Long charging time
- Need for quick charger infrastructure

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**EVs are appropriate for short-distance commuting and fleet use**
About hydrogen

- Hydrogen is found in abundance in water and fossil fuels
- It is colorless, odorless, and tasteless at room temperature and normal atmospheric pressure; it is extremely light and diffuses rapidly
- It is a reactive element with numerous chemical/fuel uses; fuel cells increase the electricity generation efficiency of hydrogen
Primary uses of hydrogen

Hydrogen has been used for over 200 years

- Urban areas: gas lamps
- In homes: utility gas (water/coal gas)
- In manufacturing: fertilizer (ammonia), oil refining (desulfurization, etc.)
- As an automotive fuel

Thanks to past experience and recent research, hydrogen can be used as safely as gasoline or natural gas.
Advantages of hydrogen

- Zero CO₂ emissions during use, helping to achieve a low-carbon society

- Can be obtained from a variety of primary energy sources
  - From fossil fuels such as natural gas, as well as from unused sewage sludge
  - From water using natural energy sources such as solar or wind energy

- Higher energy density than batteries, and is easier to transport and store; can be used to resolve uneven distribution of regional energy, and to compensate for fluctuations in supply from renewable energy sources

- Wide range of uses, from home to automotive fuel and power generation
We believe hydrogen will be a leading energy source in the future
Toyota’s FCV development to date

1992: Start of development

A Toyota FCV took part in a parade in Osaka. The vehicle featured a fuel cell stack and metal hydride hydrogen tank.

1996: Parade in Osaka

“EVS13” in Osaka (Oct.1996)
Toyota’s FCV development to date

2002: FCHV (Dec 2002-)
World-first limited sale in the U.S. and Japan

2005: FCHV (July 2005-)
Achieves vehicle type certification from the Japanese government

2008: FCHV-adv (June 2008-)
Range and cold start capabilities improved

Toyota has leased over fuel cell 100 vehicles to date, and these have driven over 2 million km in the U.S. and Japan

<table>
<thead>
<tr>
<th>Max speed</th>
<th>155 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>830 km</td>
</tr>
<tr>
<td></td>
<td>(10-15 test cycle)</td>
</tr>
<tr>
<td>Occupancy</td>
<td>5</td>
</tr>
<tr>
<td>Max pressure of tank</td>
<td>70 MPa</td>
</tr>
<tr>
<td>Fuel cell output</td>
<td>90 kW</td>
</tr>
</tbody>
</table>
Advantages of FCVs

Energy diversification
- Hydrogen can be produced from a variety of primary energy sources

Zero emissions
- Zero CO₂ emissions during driving

Driving pleasure
- Smooth and quiet operation
- Smooth start and good acceleration at low and medium speeds

Performance
- High cruising range (approx. 700 km under JC08 cycle; Toyota measurements)
- Low refueling time (approx. 3 min.)
- Cold-start capability (-30ºC)

Large power supply capability for emergencies
- Power supply capabilities 4-5 times greater than EVs; can supply power to an average household for more than a week

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The potential of FCVs

FCVs contribute to a sustainable mobility society by:

- contributing to the diversity of automotive fuels
- only emitting water vapor during driving
- offering the convenience of existing gasoline-engine automobiles

FCVs are ideal eco-cars
Fuel cell system development

- Over twice the output power density of the Toyota FCHV-adv ➞ 3.0 kW/L
- Output power over 100 kW
- Size reduction ➞ Key system components can be placed under seats

The new fuel cell system is smaller and performs better
High-pressure hydrogen tank development

- Tank storage density improved by approx. 20% compared to Toyota FCHV-adv
- Number of tanks per vehicle halved from four to two
- Different materials and manufacturing process used

Top-level

- 5.7 wt%
- Reduced costs

(70MPa)

High-pressure hydrogen tank performance has increased while costs have decreased
Fuel cell system development

- No humidifier ➔ Enhanced reliability; reduced size, weight, and cost
- Use of boost converter ➔ Fewer cells, smaller motor

Significant progress has been made in fuel cell system development
Fuel cell system cost reduction

Fuel cell system costs have decreased significantly, and will continue to decrease.
Toyota’s FCV sedan: exterior

(as of June 25, 2014)
Toyota’s FCV sedan: Japan sales (as of June 25, 2014)

Going on sale before April 2015
(in the summer of 2015 in the U.S. and Europe)

Sold at Toyota and Toyopet dealerships
(Initially, sales will be focused on dealerships in areas where hydrogen infrastructure is being developed)

Approximately 7 million yen
(Approximate MSRP; excludes consumption tax; U.S./European pricing not yet decided)