Technology Innovation and Challenge for Sustainable Mobility

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Toshio Hirota, Ph.D.
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1972 Engineering Lab., Nissan Motor Co., Ltd.
R&D on Fuel cell electric vehicles
H2 engines, Methanol engines

1990 Engine Development Department
FFV, Emission Technologies,
Production engines

1994 Nissan R&D USA
Ultra low emission vehicles, EVs

1998 Development of FCV

2005 R&D Planning of Environmental technologies,
including EVs, FCVs and ICEs

2014 Retired Nissan Motor Co., Ltd.

2008 Waseda University
Research on EVs and Smart mobility
Technology Innovation and Challenge for Sustainable Mobility

- Conventional technologies
  - ICE: Internal combustion engines
  - HEV: Hybrid electric vehicles

- Alternative fuel vehicles
  - Biofuel engine vehicles
  - FCV: Fuel cell vehicles
  - BEV: Battery electric vehicles

- Smart mobility
  - Renewable energy
  - Harmonized transportation
  - Sustainable mobility
Toshio Hirota, Environmental Research Institute, Waseda University, Japan

*WBCSD: World Business Council for Sustainable Development*

- Ecological footprint with human activity exceeded the Earth’s natural ability to absorb these impacts in the late of 1980s.
- The requirement in 2010 was 50% larger than world bio-capacity.
- Key components: Carbon, Cropland, Grazing land, forest
CO2 Emissions from Gasoline Vehicle

- CO2 emissions per gasoline 1L
  - Vehicle driving: 2.3kg
  - Refinery: 0.5kg
  - Total: 2.8kgCO2/L

For example:
Fuel economy: 10km/L
Mileage: 10,000km/year
- CO2 emissions: 280g/km
- 10,000 km runs a year: 2.8t/year
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Energy Efficiency of Gasoline Engine

- Maximum efficiency of gasoline engine is 30 - 36%.
- Average efficiency under actual driving is around 20% because of low torque driving.
Cycle efficiency improvement

Theoretical efficiency $\eta_{th}$ of internal combustion engine is improved with increasing of the compression ratio $\varepsilon$ and the specific heat ratio.

$$\eta_{th} = 1 - \frac{1}{\varepsilon^{\kappa-1}}$$

Source: Symposium on ICE technologies, Nov. 10, 2010
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
High compression gasoline engine: Mazda Sky active

- Increase the compression ratio causes reduce the output torque because of knocking.
- Modifications of the combustion chamber and fuel injection system realize high compression ratio without knocking.

Source: Symposium on ICE technologies, Nov. 10, 2010
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
Best fuel economy K-car in Japan

Suzuki Alto Eco
Dec. 18, 2013
- Fuel economy 35.0 km/L (JC08 mode)
- Ene-charge (Regeneration system)
- Idling stop
- Eco-cool
- Light weight vehicle

Daihatsu Mira e:S
July 9, 2014
- Fuel economy 35.2 km/L (JC08 mode)
- High compression ratio, Atkinson cycle
- Dual injector fuel injection system
- Adv. regeneration system

Efficiency Improvement by Hybrid System

1. Engine stop mode (Low revolution・Idle range)
2. EV driving mode (Starting・Low speed range)
3. Shifting engine driving range to high efficiency range (Charge the battery with surplus torque)
4. Cooperation recovery of brake energy (Deceleration)
Toyota Hybrid Aqua

- Compact size passenger car
- Start of sale: Dec. 2011
- Hybrid system: THS-Ⅱ
- Fuel economy: 37.0 km/L (JC08 mode)
- Price: 1,748 k-yen
- Top sales model in Japan, 260,000 in 2013

<table>
<thead>
<tr>
<th>Size</th>
<th>3,995 x 1,695 x 1445 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seating capacity</td>
<td>5</td>
</tr>
<tr>
<td>Curb weight</td>
<td>1050kg</td>
</tr>
<tr>
<td>F.E</td>
<td>37.0 km/L (JC08 mode)</td>
</tr>
<tr>
<td>Engine</td>
<td>1.5L Atkinson cycle 54kW/4,800rpm</td>
</tr>
<tr>
<td>Motor</td>
<td>PMAC synchronous motor 45kW, 169N•m</td>
</tr>
<tr>
<td>Battery</td>
<td>Ni-H 6.5Ah</td>
</tr>
</tbody>
</table>

Source: Toyota Website, http://toyota.jp/aqua/
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
Aqua hybrid system

- Hybrid system is basically same as Prius system.
- A lot of efforts are made to install the complex system in the compact engine compartment.
- Engine length is 51 mm shorter and the transmission with 2 motors is 21 mm shorter than previous system.

Source: Toyota Website, http://toyota.jp/aqua/
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High thermal efficiency engines

- Toyota Crown hybrid
  - Sept. 2012
  - Thermal efficiency: 38.5%
  - Atkinson cycle, Cooled EGR

- Honda Accord hybrid
  - June. 2013
  - Thermal efficiency: 38.9%
  - Atkinson cycle DOHC i-VTEC

Source: Toyota Website, Honda Website
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
Toyota Hybrid Vehicle sales

Source: Toyota Presentation Material on FCV, June 25, 2014
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
Plug-in hybrid vehicle

- Equipped a large capacity battery and a charger by grid power
- Driven by a motor with battery at short distance driving and driven by a hybrid system with engine and motor at long distance driving.
Honda Accord Plug-in Hybrid, Jan. 2013

- Honda developed a series hybrid system for passenger car.
- The system is consist of 2 motors, 100kW generator and 120kW motor, a clutch, and a lithium-ion battery.
- An engine drives wheels through electric transmission.
- Under high speed driving condition, an engine drives wheels mechanically through a clutch and reduction gears.
- AER, all electric driving range, is 13 miles with 6 kWh battery.

Source: Response, Jan. 17, 2013
http://response.jp/article/img/2013/01/17/189002/517835.html
Improvement of plug-in hybrid vehicles
VW 1 liter car "XL1"

- Prototype model for advanced technology
- 2 seat plug-in hybrid vehicle
- Fuel consumption: 0.9L/100km (111km/L)
- CO2 emission: 24g/km
- EV drive range: 35km

- Power unit
  - Max torque 140N•m
- 2 cylinder diesel engine
  - 800cc, 48PS
- Motor: 20kW
- Max speed: 160km/h
- Acceleration: 11.9 seconds (0-100km/h)

Toshio Hirota, Environmental Research Institute, Waseda University, Japan
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Fuel cell vehicle

Advantages
■ Zero CO2 emission
■ High energy efficiency
■ Quiet and smooth driving

Need to improve
■ Cost reduction of FC and hydrogen storage tank
■ Hydrogen infrastructure
PEMFC: Proton exchange membrane fuel cell

- Hydrogen resolves into protons and electrons at an anode electrode
- Proton moves to cathode side through a membrane
- Proton and oxygen react at cathode side to generate water

Source: JHFC website
http://www.jhfc.jp/fc_fcv/about_fc/index.html
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
Toyota Reveals Exterior, Japan Price of Fuel Cell Sedan
News release, June 25th, 2014

- Toyota will introduce FCV in Japan before April 2015.
- The price of the FC sedan is approximately 7 million yen.
- The FCV features performance similar to a gasoline engine vehicle, with a cruising range of 700 km (JC08) and a refueling time of 3 minutes.
- FCVs contribute to the diversification of automobile fuels, emit no CO2 or harmful substances during operation.

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Electric Vehicle LEAF
Acceleration of electric vehicle

- Significant improvement in acceleration

**Motor**

- High Torque Motor
- Motor Control Technology

**Situation:** First-in-line at green light

Source: Takaaki Karikomi, JSAE paper, May 2011

Toshio Hirota, Environmental Research Institute, Waseda University, Japan
Improvement of Handling Performance

- Quick and linear response to driver’s steering operation with motor torque control
- Torque up at the beginning and torque down at the end of turn

Source: Yuuki Shiozawa, JSAE, May 2011
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
EV, PHEV Market introduction in Japan

Source: Next generation vehicle PC: EV, PHEV stock data
http://www.cev-pc.or.jp/NGVPC/data/index.html
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
EV Charging infrastructure in Japan

- Increasing number of EV charging stations

July 18, 2014

- Normal Charging
  7,580 stations
- Quick Charging
  2,706 stations

Kamakura city area
Kanagawa prefecture

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**Power-train efficiency**

- We should evaluate not only the power-train technologies but also energy for automotive application.

<table>
<thead>
<tr>
<th>Power-train Technologies</th>
<th>Gasoline Diesel Oil</th>
<th>Natural Gas NG</th>
<th>Bio-fuel</th>
<th>Hydrogen H2</th>
<th>Electricity</th>
<th>Power-train Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ICE</strong></td>
<td><img src="Ice.png" alt="Image" /></td>
<td><img src="NaturalGas.png" alt="Image" /></td>
<td><img src="Biofuel.png" alt="Image" /></td>
<td><img src="Hydrogen.png" alt="Image" /></td>
<td><img src="Electricity.png" alt="Image" /></td>
<td>20 ⇒ 30%</td>
</tr>
<tr>
<td><strong>HV</strong></td>
<td><img src="HybridVehicle.png" alt="Image" /></td>
<td>NG-ICE/M</td>
<td>Bio-ICE/M</td>
<td>H2-FCV/BAT</td>
<td>Depend on bat. capacity</td>
<td>30 ⇒ 40%</td>
</tr>
<tr>
<td><strong>PHV</strong></td>
<td><img src="Plug-inHybridVehicle.png" alt="Image" /></td>
<td>NG-ICE/M/BAT</td>
<td>Bio-ICE/M/BAT</td>
<td><img src="FuelCellVehicle.png" alt="Image" /></td>
<td>40 ⇒ 60%</td>
<td></td>
</tr>
<tr>
<td><strong>FCV</strong></td>
<td><img src="FuelCellVehicle.png" alt="Image" /></td>
<td>NG-FCV</td>
<td><img src="FuelCellVehicle.png" alt="Image" /></td>
<td><img src="FuelCellVehicle.png" alt="Image" /></td>
<td>70 ⇒ 80%</td>
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<tr>
<td><strong>Bat-EV</strong></td>
<td><img src="BatteryElectricVehicle.png" alt="Image" /></td>
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</tbody>
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ICE: Internal Combustion Engine  
HV: Hybrid Vehicle  
PHV: Plug-in Hybrid Vehicle  
FCV: Fuel Cell Vehicle  
Bat-EV: Battery Electric-drive Vehicle  
G: Gasoline  
D: Diesel fuel  
NG: Natural Gas  
Bio: Biomass fuel  
H2: Hydrogen  
M: Motor
Increase energy efficiency and sift energy for 90% reduction of fossil fuel consumption
Smart House

- Solar Energy is utilized for appliances and EV
- EV battery is used for stabilizer of home power line.

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Improvement of PV utilization with EV

- **V2H**, Vehicle to Home, system improves PV utilization of a smart house to reduce gap between solar generation and electricity consumption.
- CO2 emissions of house and EV are reduced with lower CO2 intensity.


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**EV battery for energy storage**

- Effective use of renewable energy by storing fluctuated power into the battery of EV
- Reduce energy consumption and shift to renewable energy from fossil fuels for Smart house system

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**NEC Smart House System**

- Solar power
- Electric Vehicle

**Honda Smart Home System**

- Gas engine co-gen system
- Stationary battery
- Home energy management system

Source: http://www.nec.co.jp/environment/energy/house.html
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Micro Electric Vehicles

Toyota COMS  |  Nissan NMC  |  Honda MC-β

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Micro mobility sharing in Yokohama city

- Yokohama city and Nissan started a EV sharing feasibility program at Minatomirai and central area of the city Oct. 2013.
- 100 micro EVs and 70 sharing stations for the program
- Easy to access with smartphone and one way rental

New mobility concept:
- 1-2 passengers
- Lithium ion battery
- Vehicle weight: 500 kg
- Max. speed: 80 km/h

Electric Bus for Public Transportation
FY2011-2013 Waseda University

- Field test incl. cold condition in Nagano city for 3 years
- Environmental friendly, low noise and low vibration
- Ready for practical usage as public transportation with government support

- Vehicle weight: 5620kg
- Vehicle size: 6.99×2.08×3.10m
- Number of passenger: 31 persons
- Permanent magnet AC synchronous motor
- Lithium-ion battery: 44 kWh
- Inductive charging system and conductive charging system
Smart Mobility/Smart Community

Source: METI, EV/PHV Town Concept, 2009
Toshio Hirota, Environmental Research Institute, Waseda University, Japan
Yokohama Smart City Project

- Field test program in 3 areas, 2010 - 2014
- Target: 64,000 ton-CO2 reduction with 27MW PV, 4,000 HEMS, and 2,000 Electric vehicles

*HEMS: Home energy management system

Source: Yokohama city press release
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Yakushima CO2 Free Island Project

- Introducing electric vehicles with renewable electricity in Yakushima.
- Local government provides incentives for EVs and charging infrastructure.

*Yakushima island is famous with a natural World Heritage Site.
Low Carbon and Sustainable Mobility

- Technology: Vehicle, Energy and Mobility
- Electrically-Drive Technologies
  Hybrid/Plug-in Hybrid, FCV, Battery EV
- Multiple approaches: Technology, Policy, Behavior Change

<table>
<thead>
<tr>
<th>1970</th>
<th>1990</th>
<th>2010</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
</table>

Vehicle Technologies

- ICE Vehicle
- Fossil Fuel
- Public Transportation

Energy Technologies

- ICE
- Bio-ICE
- FCV

Carbon Neutral Energy

Harmonization of Personal/Public Trans.

Mobility Innovation