Perspectives on Disseminating Next Generation Vehicles for Sustainable Mobility beyond 2030 and towards 2050

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Research Council
Waseda University
Serious Issues associated with mobility

< Environment >
- Global warming
- Air pollution

< Energy >
- Oil dependence
- Renewables

< Traffic Congestion >

< Traffic Accidents >

< Natural Disasters >
Three important measures to resolve or mitigate vehicle-related environmental and energy issues

1. Reducing exhaust gas emissions and improving fuel economy in conventional gasoline and diesel vehicles

2. Developing and disseminating alternative power systems, fuels and energy, including hybrids, EVs, plug-in hybrid, FCVs, etc.

3. Changing the way we use the automobile, by means of ITS, ICT, modal shift using mass transit, eco-driving, social and community planning, tax incentives, public awareness, etc.
Greenhouse Gases Reduction by each Country according to the Paris Agreement, Nov., 2015

<table>
<thead>
<tr>
<th>Country</th>
<th>Reduction</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>60 - 65% per GDP by 2030</td>
<td>2005</td>
</tr>
<tr>
<td>E U</td>
<td>40% by 2030</td>
<td>1990</td>
</tr>
<tr>
<td>India</td>
<td>33 - 35% per GDP by 2030</td>
<td>2005</td>
</tr>
<tr>
<td>Japan</td>
<td>26% by 2030</td>
<td>2013</td>
</tr>
<tr>
<td>Russia</td>
<td>70 - 75% by 2030</td>
<td>1990</td>
</tr>
<tr>
<td>USA</td>
<td>26 - 28% by 2025</td>
<td>2005</td>
</tr>
</tbody>
</table>

☆President Trump announced that the United States would withdraw from the Paris climate accord on June 1st, 2017
Energy Related CO₂ Emission Reductions in 2030 for the Paris Agreement, Japan

[ Unit: Million t-CO₂ ]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>429 (457)</td>
<td>401 / ▲6.5 (▲12.3)</td>
</tr>
<tr>
<td>Business, etc.</td>
<td>279 (239)</td>
<td>168 / ▲39.8 (▲29.7)</td>
</tr>
<tr>
<td>Household</td>
<td>201 (180)</td>
<td>122 / ▲39.3 (▲32.2)</td>
</tr>
<tr>
<td>Transportation</td>
<td>225 (240)</td>
<td>163 / ▲27.6 (▲32.1)</td>
</tr>
<tr>
<td>Energy Conversion</td>
<td>101 (104)</td>
<td>73 / ▲27.7 (▲29.8)</td>
</tr>
<tr>
<td>Total</td>
<td>1,235 (1,219)</td>
<td>927 / ▲24.9 (▲24.0)</td>
</tr>
</tbody>
</table>
Crude Oil Price Significantly Changed. (US EIA, 2015)

☆Such oil shocks must be avoided or overcome by improving vehicle efficiency, disseminating lower carbon energy vehicles and making mobility smarter.
## Comparison of LDV Fuel Economy Standards based on NEDC, ICCT 2015

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>km/L</th>
<th>L/100 km</th>
<th>CO₂ g/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>2020</td>
<td>22.1</td>
<td>4.52</td>
<td>105</td>
</tr>
<tr>
<td>E U</td>
<td>2021 (2030)</td>
<td>24.4 (31.7)</td>
<td>4.10 (3.1)</td>
<td>95 (73)</td>
</tr>
<tr>
<td>USA</td>
<td>2025</td>
<td>22.5</td>
<td>4.44</td>
<td>103</td>
</tr>
<tr>
<td>China</td>
<td>2020 (2025)</td>
<td>19.8 (25.0)</td>
<td>5.05 (4.00)</td>
<td>117 (93)</td>
</tr>
<tr>
<td>India</td>
<td>2021</td>
<td>20.5</td>
<td>4.88</td>
<td>113</td>
</tr>
</tbody>
</table>

( ): Proposed  
NEDC: New European Driving Cycle  
ICCT: The International Council on Clean Transportation
**Future Passenger Car Fuel Economy Targets**

- **CO₂:** 116, 77.4, 58.0, 46.4 g/km

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Fuel Economy, km/L</th>
<th>CO₂: 116</th>
<th>CO₂: 77.4</th>
<th>CO₂: 58.0</th>
<th>CO₂: 46.4</th>
<th>Relative Fuel Consumption, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td></td>
<td>52</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>20%</td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>40%</td>
</tr>
<tr>
<td>2040</td>
<td></td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>60%</td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>80%</td>
</tr>
</tbody>
</table>

- **Annual fuel economy improvement:** 4% and 5%

- **20.3 km/L**

By Y. Daisho
Ensuring efficiency, durability and cost reduction are essential to comply with more stringent diesel emission regulations to be in effect in Japan, the EU and the USA in 2010s to 2020s.
The Volkswagen emissions scandal called "dieselgate" started on 18 September 2015.

VW decided to shift from diesel to EVs. Some large cities in Europe have prohibited drivers from driving in a diesel passenger car. In 2017, France and the UK announced that selling diesel passenger cars will be prohibited after 2040.
Solutions to Achieve a 50% Brake Thermal Efficiency in ICEs

“Innovative Combustion Technologies” by the Strategic Innovation Program (SIP), JST, FY2014-18

Mechanical losses

- 4% Exhaust losses
- 35% Cooling losses
- 28~30% Brake work (Target)

- 20% Brake work
- 16~18% Brake work

- 38~41% Brake work

✓ Reducing mechanical losses by 50%

✓ Utilizing exhaust gas energy
  • Increasing turbocharging efficiency
  • Using a thermoelectric device

✓ Reducing heat losses by improving combustion

✓ Enhancing indicated work by improving combustion in both engines

★ Brake Thermal Efficiency Baseline:
  - Gasoline engines ⇒ 38%
  - Diesel engines ⇒ 41%

≪ Energy Balance ≫

☆ The high efficiency engine is essential for increasing hybrids’ fuel economy.
Variations of Electrified Vehicles

- EVs in 1970s to 2000s
- Advanced Technologies
  - Batteries, Electronic Control, Lightweight Materials, Devices, and Engines
- Recent EVs
- Fuel Cell Vehicles
- Hybrid Vehicles
Three Hybrid Systems

(Integrated starter and generator, Power assistance, 48V system)

<Parallel (Mild)> 【20-50%】

<Series (Full)> 【50-100%】

<Series/Parallel (Full)> 【50-100%】

<Hybrid type>

【Improved fuel economy, %】

M: Motor  G: Generator
C/I: Controller / Inverter
B: Battery unit
T: Transmission  C: Clutch
Ps: Power splitter
Pi: Plug-in

→ : Drive / Power generation
← : Regeneration

(FCVs adopts the similar system. Nissan’s Note e-Power takes this system.)
Various HVEs Sold Recently in Japan

- Prius, Toyota
- Plug-in Prius, Toyota
- Plug-in Outlander, Mitsubishi
- Solio, Mild hybrid (ISG), Suzuki
- Note, e-Power, Series Hybrid, Nissan
- Fit Hybrid, Dual Clutch Transmission, Honda
- Diesel Parallel Hybrid Truck, Isuzu
- Diesel Parallel Hybrid Bus, Hino
A Variety of Electric Vehicles in 2017-2019

- Chevrolet Bolt, GM
- i3, BMW
- E-Golf, VW
- Leaf, Nissan
- Model 3, Tesla
- Honda Urban EV Concept
- E-Canter, Mitsubishi
- Semi in 2019?, Tesla
The number of EVs will increase by 24% annually based on BAU policies of each country, reaching 4 million in 2020 and 21.5 million in 2030. The number EVs in circulation will reach 13 million and 125 million in 2030, counting for 10% in the light duty vehicle categories.

Enhanced policies will make the global EV stock number 220 million in 2030.
Devices for Storing Electricity

After 2030

High reliability and durability and low cost are essential.

- Li-ion Battery
- Metal Air Battery?
- All-solid-state Battery?
- Lead Acid Battery
- Ni-MH Battery
- Capacitor
- Electric Double Layer Capacitor

Power density W/kg

Energy Density Wh/kg

2010~2030

Li, Co, Mn, Ni, Graphite, etc. ⇒
Issues on Rapid Recharging Systems for EVs and PHEVs in Japan

- The effect of stopping all nuclear power stations in March 2011 on increased CO2 emissions in Japan
  - 340g/kWh in 2010
  - 610g/kWh (1.8 times) in 2014 (average)

- Revised CHADEMO standards for rapid EV recharging, announced in March 2017
  - Increasing power capacity for EVs and reducing recharging: 50 kW ⇒ 150kW (2017) ⇒ 350kW (2020)
  - Issues on how to manage electricity supply and demand for transportation, business and household sectors
    - Smart grid and demand response systems are necessary.
    - Power management systems are also necessary to store and generate electricity

Reduced recharging time
30 min
10 min
50kw ⇒ 150kw

Smart Grid System

- Offices and shops
- Plants
- Power stations
- Schools and hospitals
- Housing
- EVs and PHEVs
- PV
- Wind
ZEV regulations is tightened in California.

- ZEV sales: 4.5% in 2018, stepwisely 22% in 2015
- GM, Ford, FCA, Toyota, Honda, Nissan, VW, BMW, Daimler, Hyundai/Kia and Mazda have to comply.
- ZEVs include BEVs, FCVs, TZEVs (Transitional ZEV, PHV) excluding hybrids.
- Nine states follow California.

NEV (New Energy Vehicle) policy starts in China.

- ZEVs sales: 10% in 2019, 12% in 2020
- Hybrids are excluded.
- PHEVs having more than 50 km EV range are included.
- EV and battery technologies are expected to advance.
- Will EV sales decrease after EV’s purchase incentives are expired in 2020?
- China will become the mightiest EV nation, producing 7 million EVs out of 35 million vehicle production along with “Made in China 2025.”
- Disseminating EV will not have any significant effect on reducing CO2 or improving air pollution in all megacities in China.
Chinese Li-ion Battery Makers dominate the market.

Automotive Li-ion battery shipment ranking in 2017 (高工産業研究院, China/Nikkei, May, 2018)

BYD plans to produce 60 GWh/year no later than 2000 (July, 2018)

- 10 GWh for 250,000 EVs (40 kWh)
- Will mass production reduce the costs?
- Reduced EV sales will cause over-production of battery units.
Issues on Rapid Recharging Systems for EVs and PHEVs in Japan

- The effect of stopping all nuclear power stations in March 2011 on increased CO₂ emissions in Japan
  - 340g/kWh in 2010
  - 610g/kWh (1.8 times) in 2014 (average)

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  - Increasing power capacity for EVs and reducing recharging: 50 kW ⇒ 150kW (2017) ⇒ 350kW (2020)
  - Issues on how to manage electricity supply and demand for transportation, business and household sectors
    ✓ Smart grid and demand response systems are necessary.
    ✓ Power management systems are also necessary to store and generate electricity.

Reduced recharging time:
- 30 min to 10 min
- 50kW ⇒ 150kW
Advanced Electric Micro-Buses with an Wireless Power Supply System for Community Transportation (Sponsored by NEDO and MOE, 2004-2016)

<Specifications>

- Base: Hino Motors’ Poncho
- Length: 6.29 m, Width: 2.08 m, Height: 3.10 m
- Occupancy: 20-30 passengers
- Drive range: 45 km (fully charged)

- An advanced rapid inductive charging system is developed to reduce the capacity of batteries.
- Zero emissions, high efficiency and low CO2 emission characteristics
- A demand system is possible for regional transportation.
- Low noise, smooth acceleration and comfortable ride for elderly and handicapped passengers

By Waseda University, Hino Motors and Showa Aircraft
An Inductive Power Supply System for Rapid Recharging EV’s Batteries

Primary coil
Secondary coil
AC source
Tuning capacitor
Communication system
Battery management system
AC/DC converter
Battery unit
Electric load
Communication coil
Commercial power
High frequency power
DC power
Communication line

Maximum power: 50 kW

Waseda University
Showa Aircraft Industry Co., Ltd.
“Waseda’s Future Vehicle” (2000-2014)

★ The vehicle has been converted to a fuel cell vehicle

- Occupancy: two passengers
- Weight: 750 kg
- Fuel economy: 35 km/L (10-15 mode)

660 cc gasoline engine
Li-ion battery unit
CFRP lightweight body
Dual type hybrid system
Low rolling resistance tires
Small Electrified Vehicles for Personal Mobility
Y. Daisho and Y. Kamiya, Waseda University

- FCV for elderly passengers (2009-)
- FC bike (MOE, -2007)
- Two-seater EV 7 kW IPS (2008-)
- Plug-in hybrid (2008-)
- FC carrier for market place (NEDO, 2007-)
"Mirai" is the world-first mass production fuel cell passenger car sold worldwide.

Specifications
- 70MPa (2 tanks)  • Range: 700 km  • Max. speed: 170 km/h
- Power density: 3 kW/L (100 kW)  • Cold startability: -30°C
- Vehicle efficiency: 65%

Almost all related patents will be opened.
Price. 7.23 Million yen (Tax incentive: 2 million yen)
Annual production schedule: 700-1,000 in 2014-15, 2,000 in 2016 and 3,000 in 2017

"Mirai" is the world-first mass production fuel cell passenger car sold worldwide.
A Variety of Toyota’s FCVs, 2014-2017

“Mirai” December, 2014

FC Bus with two Mirai’s FC systems sold to the Tokyo Metropolitan Government, February, 2017

FC Forklift, January, 2017

The truck has two “Mirai’s FC systems, 12kWh battery unit and 500kW power motor unit with 1,800N·m torque. The gross vehicle weight is 36 tons.

Other automakers are expected to follow or collaborate with Toyota.

- Number of registered FCVs:
  - 40,000 by 2020
  - 200,000 by 2025
  - 800,000 by 2030
  (3-6 million in 2040, 8-16 million in 2050)
- FCVs should include not only passenger cars but also forklifts, trucks, buses, vessels, etc.
- Number of hydrogen stations:
  - 160 by 2020
  - 320 by 2025
  (720 in 2030)
- Hydrogen should be CO2 free in terms of production, transportation, storage and usage by 2040.
- Hydrogen carriers including organic hydride, ammonia and liquefaction are the most promising measures to store and transport hydrogen. (SIP)
- Technological and economical issues should be discussed and overcome to introduce renewable hydrogen.
Electricity Sources Proposed for the Paris Agreement by METI, Japan, 2018

Reducing the consumption of fossil fuels in electric power stations is effective to decrease CO₂ emission from all sectors.
Options for Decarbonizing Electricity and Hydrogen

- **Renewables**
  - Solar
  - Wind
  - Geothermal
  - Hydraulic
  - Biomass

- **Nuclear Power**

**Electricity**
- Electric Vehicle
- Plug-in Hybrid
- Fuel Cell Vehicle
- Hybrid & IC Engine Vehicles

**Hydrogen**
- (Water Electrolysis)
- (Fuel Cell)
- (Reforming)
- (Water Pyrolysis)

- Hydrogen handling, storage and supply

☆ Hydrogen is produced mainly from fossil fuels such as oil and natural gas.
☆ Carbon-free hydrogen must be realized by 2040 taking into production, transportation, storage and supply processes. (Japan)
☆ Overall LCA and cost evaluation should be made on these fuels and energy.
## Comparison of Next Generation Vehicles

<table>
<thead>
<tr>
<th>Category</th>
<th>Emissions</th>
<th>Low carbon</th>
<th>Drive range</th>
<th>Recharging time</th>
<th>Cost</th>
<th>Potential and issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline vehicle</td>
<td>◯</td>
<td>△</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>increasing efficiency</td>
</tr>
<tr>
<td>Hybrid vehicle</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>□</td>
<td>lowering costs</td>
</tr>
<tr>
<td>Electric vehicle</td>
<td>◯</td>
<td>◯</td>
<td>△</td>
<td>▲</td>
<td>△</td>
<td>Lowering costs, Decarbonizing electricity</td>
</tr>
<tr>
<td>Plug-in hybrid</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>□</td>
<td>△</td>
<td>lowering costs, decarbonizing electricity</td>
</tr>
<tr>
<td>Fuel cell vehicle</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>▲</td>
<td>decarbonizing hydrogen locating hydrogen stations</td>
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<tr>
<td>Clean diesel vehicle</td>
<td>□</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>◯</td>
<td>reducing emissions hybridization</td>
</tr>
<tr>
<td>Natural gas vehicle</td>
<td>◯</td>
<td>□</td>
<td>△</td>
<td>◯</td>
<td>□</td>
<td>locating NG stations Increasing efficiency</td>
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</tbody>
</table>
### Market Share Targets for Passenger Cars in 2020-2030 proposed by METI

(A Strategic Research Committee for Next Generation Vehicles, METI, 2010, The following Committee, METI, 2018)

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>2017 (data)</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional vehicles</td>
<td>63.97%</td>
<td>50～80%</td>
<td>30～50%</td>
</tr>
<tr>
<td>Next generation vehicles</td>
<td>36.02%</td>
<td>20～50%</td>
<td>50～70%</td>
</tr>
<tr>
<td>HEV</td>
<td>31.2%</td>
<td>20～30%</td>
<td>30～40%</td>
</tr>
<tr>
<td>EV / PHEV</td>
<td>0.41 / 0.82%</td>
<td>15～20%</td>
<td>20～30%</td>
</tr>
<tr>
<td>FCV</td>
<td>0.02%</td>
<td>～1%</td>
<td>～3%</td>
</tr>
<tr>
<td>Clean diesel</td>
<td>3.52%</td>
<td>～5%</td>
<td>5～10%</td>
</tr>
</tbody>
</table>

- 4.386 million passenger cars were sold in Japan, in 2017.
- Percent market share of passenger cars is lower than 5% in the other major countries in 2017 as follows.  
  - USA: 4.0%  
  - Germany: 3.0%  
  - France: 4.8%  
  - China: 3.0%  
  - India: 0.03%
Projected Next Generation Passenger Vehicles’ Share Worldwide and Relative Importance for R&D

- Decarbonized electricity and hydrogen (EV, PHEV, FCV)
- Advanced batteries and electrification (EV, HEV, PHEV, FCV)
- Advanced engine technologies (ICEV, HEV, PHEV)
- Reduced vehicle weight
Drivers, cars and roads are connected using advanced ICTs to achieve safe, eco-friendly and convenient mobility (ITS Japan).

Roles of Intelligent Transport Systems

- Car Navigation
- ETC
- Safe Driving Assistance
- Traffic Management
- Road Management
- Mass Transit Management
- Commercial Vehicle Management
- Pedestrian Assistance
- Ambulance Vehicle Management
Smart Mobility, Housing and Community

Big Data

Cloud (Internet)

We, drivers must also be smarter!

Smart House (HEMS)
(Smart Telecommunication)

Smart Probe Car

Smart Community with Smart Grids

Smart Mobile Phone

ITS ICT IT AI IoT

Twitter
Autonomous Drive and Car Sharing

- **Google Car**
- **Car Sharing (Daimler)**
- **Robot Taxi (DeNA, ZMP, Japan)**
- **Autonomous Ride Sharing (Uber, Volvo)**
- **Autonomous Shuttle Bus “WEpod” (The Netherlands)**
Projected Long-term Reduction in Motor Vehicle CO$_2$ Emission in Japan

【Measures】

- **<Fuel Economy Improvements>**
  - Efficient power systems, Hybridization, Vehicle weight reduction

- **<Use of Low Carbon Fuels and Energy>**
  - Electricity, Biofuels, H$_2$

- **<Improvements in Vehicle Use>**
  - ITS, ICT, Modal shift, Change in car lifestyle

(By Y. Daisho)
Issues for Developing and Disseminating Next Generation Vehicles

- Social activities for sustainable mobility in terms of environmental protection, energy security, economy, convenience, safety, comfort and resiliency to disasters.
- Continued governmental support and collaboration between industry, academia and government for developing advanced mobility technologies.
- Strengthening global competitiveness for transportation-related technologies.
- Developing and disseminating technologies related to renewable fuels and energy such as electricity, bio-fuels, hydrogen etc.
- Creating new environmentally friendly car lifestyles.
- Developing technologies related to ITS, IT and ICT for us to drive conveniently, efficiently and safely.
- Technological and policy contributions to emerging economies.