Current Status and Future View of EV/PHEV with Charging Infrastructure in Japan

by

Tatsuo Teratani

Toyota Motor Corporation

Background paper for the IFP/IEA/ITF Workshop on “Developing infrastructure for alternative transport fuels and power-trains to 2020/2030/2050: A cross country assessment of early stages of implementation”

OECD, 30th November 2012
1. Environmental Change around Automobiles

Automotive environment today is about to go through a large change. There are “5 automotive major environments”, two of which have newly emerged: “energy issue” created by new rising powers and their dramatic market change followed by young generation’s new life-style and values, and “natural resource issue” such as in rare earths, water and food (Fig.1).

Also rapidly evolving factors are “increased use of electronics”, “electrification” and “system integration”. In the history of 126 years of automobiles, the last 40 years have seen a remarkable development of electronics, and the major focus of interest today is on the EV and PHEV.

![Fig. 1 Environmental change around automobiles](image)

2. Environmental and energy issue over automobiles

The most important environmental and energy issue of automobiles for sustainable societies are, respectively, reduction of carbon dioxide that leads to less global warming and shift to new energy resource for less dependence on oil (Fig.2).

The majority of energy resources that we use today come from the solar energy stored in the earth’s history of 46 billion years. We must again come back to the first principle and consider the energy use for cyclical energy society. One of the
candidates for realistic solutions will be EV/PHEV where electrical energy from power stations with low carbon dioxide emission will be used as a secondary destination. The spread of EV/PHEV will depend upon the development of infrastructure and high-capacity, low-cost batteries (Fig.3).

<table>
<thead>
<tr>
<th>Diversification of Automotive Fuels and Powertrains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Energy</td>
</tr>
<tr>
<td>Oil</td>
</tr>
<tr>
<td>Natural gas</td>
</tr>
<tr>
<td>Coal</td>
</tr>
<tr>
<td>Plant</td>
</tr>
<tr>
<td>Uranium</td>
</tr>
<tr>
<td>Hydro, solar, biofuel</td>
</tr>
</tbody>
</table>

**Fig.2 Diversification of fuels and powertrains**

**Total Energy Management (TEM)**

- Electrical energy: 1.2 TWh/year (1.8 × 10<sup>9</sup> W) in Japan
- Power generation cost (Electricity cost in BAUs per kWh): Solar: 246, Wind: 25, Thermal: 47
- Sun (Nuclear fusion)
- Tidal energy source
- Solar, wind, thermal energy
- Power generation cost (Electricity cost in BAUs per kWh): Solar: 46, Wind: 26
- Nuclear G: 3, 6 G: 10, 24
- Nuclear G: 3, 6 G: 10, 24

**Total Energy Management**

**Fig.3 Total energy management**

In selecting automotive fuels, it is one of important things to select the fuels with high energy density. This figure shows energy density per unit volume of typical fuels compared with gasoline 10. Ethanol is 6. Gaseous fuel is 1 to 3. Batteries and Li-ion battery is about 0.2 (Fig.4).

That is to say, energy density of Li-ion battery is 1/50 compared to gasoline. For gaseous fuels and batteries, we have to install the huge fuel tank and batteries, and so there will be no space and car becomes too heavy.
Liquid fuels have still remained the advantage about energy density in automobiles.

3. Connection of EV/PHEV to national grid

Automotive OEMs are seriously planning mass-production of EV and PHEV from 2012 and therefore they will need to consider electrical power infrastructure in their mind because their vehicles will be connected to the national grid (Fig.5). Consequently, we will need to develop “total energy management” as shown in Fig.6, where “energy supply” and “energy store” are newly added to the conventional “vehicle energy management”.

![Energy Density Diagram](image-url)
Fig. 5 History of electric propulsion vehicles in Japan

Fig. 6 Total energy management with infrastructure
4. PHEV (Plug-in Hybrid Vehicle) in Japan

Since 2009, Toyota has been testing of Prius PHV (Plug-in Hybrid Vehicle) used by 600 vehicles and fleet-users worldwide with many field data results. And since 2012, mass-production PHVs have been launched to the market. Figure 7 shows the concept of plug-in hybrid vehicle. PHV will run as an electric vehicle on the charged electricity for short trips and as a conventional hybrid vehicle for long trips. The best advantage is there is no drive distance limitation (Fig.8).

Fig.7 The concept of Prius Plug-in Hybrid

Fig.8 AC normal charging of Prius PHV
2012 marked an increased activity of international standardization of electric vehicles followed by launch of Prius PHEV and certification of AC normal charging by JARI (Japan Automobile Research Institute), kicking off social design that secures “safety/assurance” and “compatibility” for customers (Fig.9). Japan’s proposal and contribution is expected for international standardization meeting such as IEC/ISO. It is also important that Japan, US, EU and China cooperate together to enhance spread of EV/PHEV to meet their regional infrastructure development situations and needs.

### Standardization for AC Normal Charge

1. **Charging Connector**
   - Type 1: AC connector; developed by Japan and standardized.

   ![Charging Connector Diagram]

   - SAE J1772 (adoption);
   - IEC: from Japan (Type 1);
   - IEC: from Germany (Type 2) (mennekes type);
   - IEC: from Italy (Type 3).

   - **AC single phase:** 3 phase
   - **DC charge possible:** Pm-dedication type

2. **Control pilot function**
   - Each OEM has to correspond to charging cable and charger with control pilot function.
   - Since 2011/11, AC charging method has been unified and reflect the charging infrastructure guideline published in Japan.
   - Since 2012/4, JARI has started to certificate AC normal charger.

Fig.9 Standardization for AC normal charge

<4-1> Work done for domestic spread of charging system in Japan

Japan is working on equipping infrastructure for charging as a national policy. “Next generation automobile strategy 2010”, which was formulated in 2010 by joint efforts of government and industry, states the target volume of 5000 quick-charge and 2 million normal charge machines by 2020 (Fig.10).

There are about 1300 quick-charge machines installed right now on all over Japan from Hokkaido to Okinawa. Electric outlets at homes also count as normal charging machines and therefore it is difficult to estimate the number of normal charging machines but there believed to be around a couple of hundred thousand.
This is thanks to the introduction of EV and PHEVs in various models and the financial aid by the government through the purchase promotion system, and also the certification system that provides measures to assure compatibility and safety of the charging equipment.

Meanwhile, energy-saving technologies for conventional vehicles are also advancing as seen in direct-injection, down-sizing, turbo-charging, idle-stop and lowered power consumption of onboard systems. Even so, the European carbon dioxide regulation for 2020 is another step stricter and further electrification of vehicles is inevitable. We therefore expect steady spread of electric vehicles.

5. EV (Electric Vehicle) in Japan

<5-1> Purchase promotion system
The government or local authorities will provide financial support when purchasing EV and the charging equipment if a set condition is met. The government support provides up to 1 million yen through Next Generation Vehicle Promotion Center for
vehicle purchase. They will also pay half the equipment price for DC quick charging and AC normal charging stand with fixed charging cable (Mode III) with upper limit. Refer to the center’s webpage for details. Local authorities have their own systems and need to consultation for details (Fig.11, Fig.12).

Short time charging is possible.

**Specification**
- Sw.: Constant C. P. w. r.
- Input: 3 P a s e 2 0 0 V
- Max. output: 5 0 k W
- Max. output V o l. 5 0 0 V
- Max. output C u r.: 1 0 0 A

<table>
<thead>
<tr>
<th>Driving Range with SOC 8 0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 0 k m/5 M in. 6 0 k m/1 0 M in.</td>
</tr>
</tbody>
</table>

Fig.11 DC quick charging stand at Shopping–center

Rent- a- car in Okinawa

( Photo by Teratani  2011.9.9 )

Nissan Leaf

Quick Charging ; 25min.
- 80% Charge; 130km
- IC card; Rent fee 20 €
- In Conv. Store; 5 €/1)

High-way SA; Free fee

Fig.12 Nissan Leaf of Rent–a-car in Okinawa
The importance of infrastructure for charging has already been explained earlier and the certification system will assure the compatibility and safety. As for the DC quick charging (Fig.13), CHAdeMO committee reviewed the design but there was no similar body for AC normal charging. Accordingly, Japan Automobile Research Institute (JARI), Registration Body has started product certification since April 2012.

The AC normal charging product certification is given to cable type with charging communication function (Mode II) and to stand type (Mode III). This certification consists of plant and product certification and covers various development stages from product design up to final product function check and is world–first, full–scale certification of charging equipment. This certification is conducted by third party organization and does not have law enforcement power but it does assure the safety and communication of various combinations of different EV and PHEVs and is therefore very valuable in reality. Refer to the details in the webpage of JARI.

6. Current Status and Future Target of EV/PHEV/HV in Japan

There are already many mass–production HVs in Japanese market, and PHEVs and EVs in use have been launched to the market as Fig.14.
Figure 15 shows the roadmap targets of electric vehicles (EV) in Japan. For increasing of PHEVs and EVs, charge points of electric vehicles (EV) are planned for 2020 in Japan (Fig.16).

Electric vehicles (EV) in use

<table>
<thead>
<tr>
<th>Type</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery electric vehicles (BEV)</td>
<td>28,000</td>
</tr>
<tr>
<td>Plug-in hybrid electric vehicles (PHEV)</td>
<td>9,000</td>
</tr>
<tr>
<td>Hybrid electric vehicles (HEV)</td>
<td>1,500,000</td>
</tr>
</tbody>
</table>

Fig. 14  Current number in use of electric vehicles (EV) in Japan

Roadmap targets

<table>
<thead>
<tr>
<th>Type</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV</td>
<td></td>
<td>15-20%</td>
<td>20-30%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHEV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEV</td>
<td>20-30%</td>
<td></td>
<td>30-40%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 15  Roadmap targets of electric vehicles (EV) in Japan

Charge points

<table>
<thead>
<tr>
<th>Type</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow charge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast charge</td>
<td>20 thousand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid charge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5000</td>
</tr>
</tbody>
</table>

Fig. 16  Charge points of electric vehicles (EV) in Japan
7. Wireless Charging Method

Wireless charging method (the mat type) is being reviewed for wireless charging standardization. Electrical power will be transmitted through an air gap of more than 100mm. Magnetic resonance type is promoted (Fig. 17).

The standard is the only one (ISO-IEC61980-1) where the standardization work has started. The wireless charging is still in the phase of research and development and has many issues to be solved and therefore we believe we will need more time until commercialization.

Fig. 17 Wireless charging system (R&D Phase) of Prius PHV
( Nov. 2012 ; TBS-TV on air in Japan)

8. Future Vision for Sustainable Mobility Society

In Japan today, the electrification of automobiles, i.e. HEV, EV, PHEV, FCEV has advanced and the development has come to mass-production phase. The development of cooperative infrastructure and low-cost technologies will play a key role for spread of EV/PHEV. The contribution of HEV and EV in the aftermath of
Great East Japan Earth quake became the evening news’ spotlight and boosted the development of emergency power supply and future V2H (Fig.18).

In Japan, since last year 3.11, namely “East Japan Disaster” electric power problem has been treated with close-up. In Tohoku with the disaster, EV and HV have contributed to supply electricity from on-board battery to home electric-loads, for example, light, water, refrigerator, air-conditioner, TV and so on. For this power supply, we call V2L and V2H. This slide shows the future energy management, V2H. Now, for near future, V2H and HEMS are investigated in Japan. and for them Toyota has started the verification test in Toyota city. It is important to be visible for green electric power in future.

Figure19 shows Toyota’s expected portfolio for future mobility products, in the post-oil age. EVs will first be used for short-distance travel and FCVs for middle-to-long-distance, while HVs or PHVs will come to replace most of today’s vehicles.

Of course, electric propulsion vehicles (HEV, PHEV, EV and FCEV) have been
continuously developed in the world, but its developing speed depends on the performance of battery and infrastructure for them.

Fig.19 Image of future mobility portfolio by Toyota

In the sales of mass-production EV/PHEV, we have recognized strongly that it is important to think about three view points (1. Future view, 2. User’s view, 3. Maker’s view) for expansion of EVs. Especially, User’s view and User’s acceptance for EV/PHEV is the most important in the market (Fig.20).
9. Conclusion

The Great East Japan Earthquake shocked us deeply and gave impact on our fundamental value on energy. We were faced with lack of risk management against natural disasters, collapse of our “100% safe” myth of nuclear power, shortages and distribution issue that became apparent in planned power cut, and finally the supply–chain weakness that hit manufacturing industry. With this experience in mind, our direction now is clear; we need to look outwards than inwards with brave mind for change and open mind for cross–industrial information sharing. We will change a crisis into a chance.

Technological innovations to focus on for electrification of vehicles are battery (increased performance, lower cost of Li ion and post–Li material), power semiconductors (commercialization of SiC and GaN) and power network (realization of smart grid).
Summary

1. **Environmental Change ; 「5 Trends 」**
   → • Environment, Safety, Market + Energy, Resource

2. **Total Energy Management Era is coming with Infra.**
   → • "Post Oil"; Alternative Fuel, Electricity, Hydrogen
   • PHV (Plug-in Hybrid) is one of the realistic solutions.

3. **Wireless Charging System ; R&D Phase in Japan**
   → • Since 2012, Start of certification for AC normal charger
     (METI Target: 2 millions AC chargers until 2020)
   • DC quick chargers over 1300 have located in Japan.
     (METI Target: 5000 DC chargers until 2020)

4. **HV, PHV, EV, FCV become very attractive.**
   → • Short; EV, Short/ middle/ long; PHV, HV, Long; FCV