# Current Status and Future Prospects of Electric Power as Automotive Fuel

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## Summary

The deployment of electric vehicles and plug-in hybrid vehicles on the premise of using low-carbon power sources (renewable energy and nuclear power) is expected to not only contribute to a stable energy supply by lowering dependence on oil (dependence on foreign supply sources) as fuel but also help to reduce $CO_2$ emissions. Moreover, the use of night-time electricity is likely to help spread the use of electric vehicles for commuter use by reducing energy cost. However, it is important to remember that if conventional electricity, mainly generated by coal-fired power plants, is to be used as a power source, the deployment of electric vehicles and plug-in hybrid vehicles may not necessarily be effective in reducing $CO_2$ emissions.

It is also true that compared with vehicles powered by an internal-combustion engine, electric vehicles still have some shortcomings, such as their short driving range, some 100 km on a single charge of the battery, and the long battery-recharging time. To significantly increase the use of electric vehicles in the future, the key will be to develop a low-cost, high-performance battery. It will also be necessary to further reduce the cost of wind and photovoltaic power generation.

As the use of electric vehicles spreads, it will become necessary to conduct a quantitative study on the optimization (cost minimization) of the power source mix (cost minimization), including additional power sources for automobiles.


## 1. Overview

### 1-1 Status and Outlook of Diffusion of Electric Vehicles

An electric vehicle runs on an electric motor that is driven by electricity supplied from an on-board electricity storage battery. Although the history of electric vehicles began before the history of vehicles powered by an internal combustion engine, their use did not become widespread, due to their short driving range and supply infrastructure-related constraints, such as difficulty in securing power sources and power supply stations. Ever since motorization began in the United States in the 1920s, vehicles driven by an internal combustion engine using gasoline or diesel for fuel have remained the mainstay types of vehicles. However, the reduction of $CO_2$ emissions arising from the use of fossil fuels has become a focus of attention as a measure to combat global warming in recent years. As a result, the deployment of the electric vehicles is attracting interest as


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a way to reduce $CO_2$ emissions.

**Table 1-1　Number of Electric Vehicles Owned in Japan**

(Vehicles)

| | | | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|---|---|
| Electric vehicles | Passenger cars | Ordinary size | 35 | 30 | 26 | 18 | 15 | 11 |
| | | Small | 412 | 374 | 331 | 296 | 258 | 222 |
| | Trucks | | 78 | 63 | 48 | 27 | 17 | 11 |
| | Buses | | 2 | 2 | 1 | 1 | 1 | 1 |
| | Special vehicles | | 23 | 20 | 16 | 14 | 13 | 12 |
| | Mini-vehicles | Passenger cars | 133 | 157 | 167 | 174 | 126 | 93 |
| | | Commercial vehicles | 577 | 528 | 467 | 345 | 217 | 155 |
| | Motor vehicles | Four-wheel | 1,248 | 1,522 | 1,963 | 2,236 | 2,282 | 2,068 |
| | | Two-wheel | 2,143 | 2,895 | 4,658 | 5,357 | 6,999 | 6,848 |
| | Total | | 4,651 | 5,591 | 7,677 | 8,468 | 9,928 | 9,421 |

Source : Next Generation Vehicle Promotion Center

Electric vehicles are not nearly as popular in Japan as gasoline-electric motor hybrid vehicles, which have already been established as commercial vehicles. While only about 9,400 electric vehicles (many of which are actually bicycles using electricity as a supplementary power source) were in use in Japan in 2006 as shown in Table 1-1, the development of electric vehicles has come into full swing in recent years.

Due to an improvement in battery performance and the development of a battery system that enables fast recharging, commuter-type electric vehicles (mini-vehicle models) for short-range, town driving are scheduled to be brought to the market one after another in 2009 through 2010. In addition, commercial models of plug-in hybrid vehicles are also expected to be launched by the end of 2009.

Table 1-2 shows major global automakers' development plans for electric vehicles (including plug-in hybrid vehicles).

**Table 1-2　Global Automakers' Electric Vehicle Development Plans**

| Manufacturer | Type | Plan |
|---|---|---|
| Toyota Motor | PHEV | To start sales in Japan, U.S. and Europe by the end of 2009, initially for corporate and rental use |
| Nissan Motor | EV | To start sales in 2010 or later in Japan and U.S. |
| | | Aiming to start volume sales in the global market in 2012 |
| Mitsubishi Motors | EV | To start sales of the i MiEV in Japan by the end of 2009<br>(at around ¥3 million; annual production target for 2011 at around 10,000 vehicles) |
| Fuji Heavy | EV | To start sales of two models in 2009 for use by local governments in Japan |
| | | Aiming to commercialize the STELLA in 2010 |
| GM | PHEV | To launch the Chevrolet Volt PHEV in 2010 (production to start in the second half of 2010) |
| | | Announced production of the Saturn Vue Green Line of PHEV (2008) |
| Ford | PHEV | Co-developing a PHEV with Southern California Edison |
| VW | PHEV | Started test runs of the Golf Twin Drive PHEV |
| Daimler | EV | To raise the standard of EV technology close to mass production level<br>Aiming to start production in 2012 with annual volume of around 10,000 vehicles |
| | EV | ・Supplied 100 EVs for use by police and public organizations London in 2007 (public road tests)<br>・To introduce 100 units of the EV version of the Smart in Berlin by the end of 2009<br>・To introduce EV versions of Benz models starting in early 2010 |
| Chrysler | EV(PHEV) | Announced a plan to start sales in North America in 2010;<br>Co-developing battery-related technologies with GE |
| BMW | EV | Started demonstration tests of an EV based on the Mini in U.S. in January 2009 |
| Volvo and Saab | PHEV | Co-developing a PHEV |
| Opel | PHEV | Planning to start full-fledged sales in Europe in late 2011 |

| Electric Vehicles | | |
|---|---|---|
| Manufacturer | Mitsubishi Motors | Fuji Heavy |
| Model Name | i MiEV | Subaru Plug-in STELLA Concept |
| Photo image |  |  |
| Length x Width x Height | 3,395×1,475×1,600mm | 3,395×1,475×1,660mm |
| Weight | 1,080kg | 1,060kg |
| Passenger number | 4 persons | 4 persons |
| Maximum speed | 130km/h | 100km/h |
| Driving Range | 160km | 80km |
| Motor type | Permanent magnet synchronous motor 47kW | Permanent magnet synchronous motor 40kW |
| Battery | Lithium-ion battery 16kWh | Lithium-ion battery 9.2kWh |

| Plug-in hybrid vehicle | |
|---|---|
| Manufacturer | Toyota Motor |
| Model Name | Toyota Plug-in HV |
| Photo image |  |
| Length x Width x Height | 4,445×1,725×1,490mm |
| Weight | 1,360kg |
| Passenger number | 5 persons |
| Engine displacement | 1,496cc |
| Motor type | Alternating current synchronous motor |
| Battery | Nickel-hydrogen battery 6.5Ah×2(13Ah) |
| EV performance | EV driving range　13km<br>EV maximum speed 100km/h |

Note :　EV : Electric vehicles
　　　PHEV : Plug-in hybrid electric vehicles

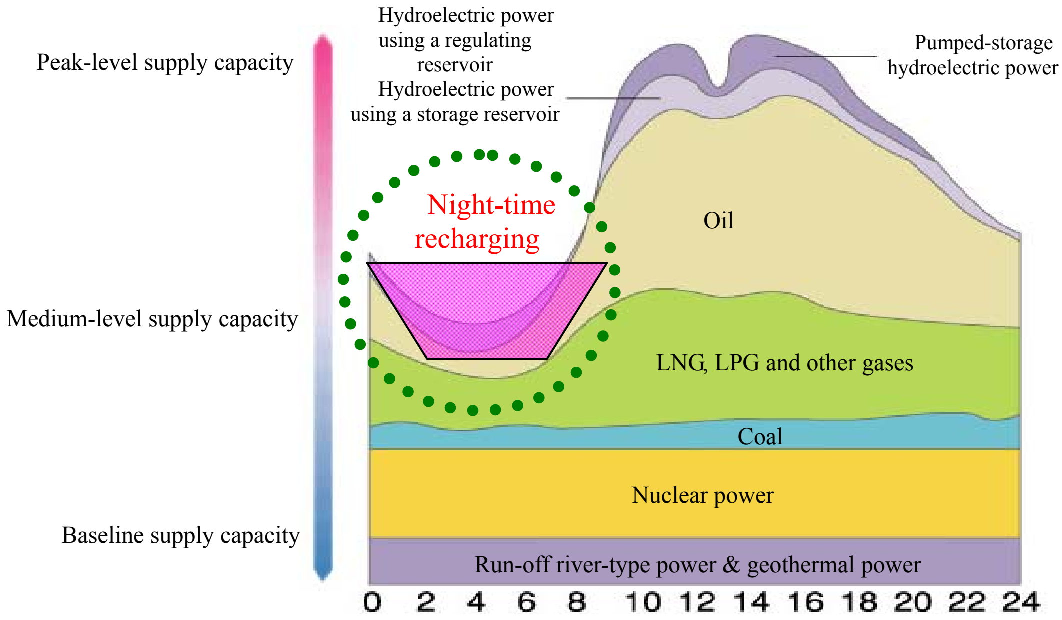
Source : Automakers' web sites and press releases

## 1-2 Prominent Features of and Challenges for Electric Vehicles

### 1-2-1 Benefits of Deployment of Electric Vehicles

One benefit of deploying electric vehicles is that it is expected to reduce $CO_2$ emissions compared with gasoline- or diesel vehicles. This is because electric vehicles can use power sources with fewer $CO_2$ emissions, such as renewable energy and nuclear power, as they run on electricity. Secondly, the deployment of electric vehicles will contribute to a stable energy supply by reducing dependence on fossil fuels (particularly oil) and on foreign energy sources. Thirdly, the use of night-time electricity for battery recharging is expected to even out the burden on electricity supply over the course of the day as shown in Fig. 1-1.

**Fig. 1-1 Daily Pattern of the Burden on Power Supply**




### 1-2-2 Prominent Features and Challenges

**(1) Fuel Economy and Driving Range**

As shown in Table 1-3, the fuel economy of an electric vehicle is 0.4MJ/km (110Wh/km), better than 2.1MJ/km(15.5km/L) for a gasoline vehicle. However, the driving range of electric vehicles is shorter than that of internal engine-powered vehicles, as even an electric vehicle equipped with the most advanced battery can run only just over 100 km on a single charge.

Table 1-4 shows the average distance driven for gasoline and diesel vehicles in Japan. The average distance driven per day for mini-vehicles is approximately 19.7 km, suggesting that an electric vehicle equipped with the most advanced battery could meet the town driving needs of a mini-vehicle owner with one or two plug-in recharges at home per week. However, over-discharging of the battery should be avoided from the viewpoint of the longevity of batteries currently available, and there are many other challenges to overcome, including the need to establish a network of roadside recharging facilities and to shorten the recharging time (development of fast recharging technology).

**Table 1-3 Comparison of Fuel Economy (10.15 mode ; Japan)**

| | | Mini-vehicle | Small vehicle |
|---|---|---|---|
| Electric vehicle | (Kwh/km) | 0.11 | |
| | (MJ/km) | 0.40 | |
| Gasoline vehicle | (km/l) | 20.6 | 15.5 |
| | (MJ/km) | 1.6 | 2.1 |
| Hybrid vehicle | (km/l) | | 30.6 |
| | (MJ/km) | | 1.1 |
| Diesel vehicle | (km/l) | | 19.7 |
| | (MJ/km) | | 1.8 |

**Table 1-4 Number of Passenger Cars Owned in Japan and the Distance Travelled**

| | Fuel | 1,000 vehicles | Km per vehicle per year | Km per vehicle per day |
|---|---|---|---|---|
| Passenger car | Gasoline | 39,768 | | |
| | Diesel | 2,549 | | |
| Total | | 42,317 | 10,144 | 27.8 |
| Mini-vehicle | Gasoline | 13,512 | 7,183 | 19.7 |

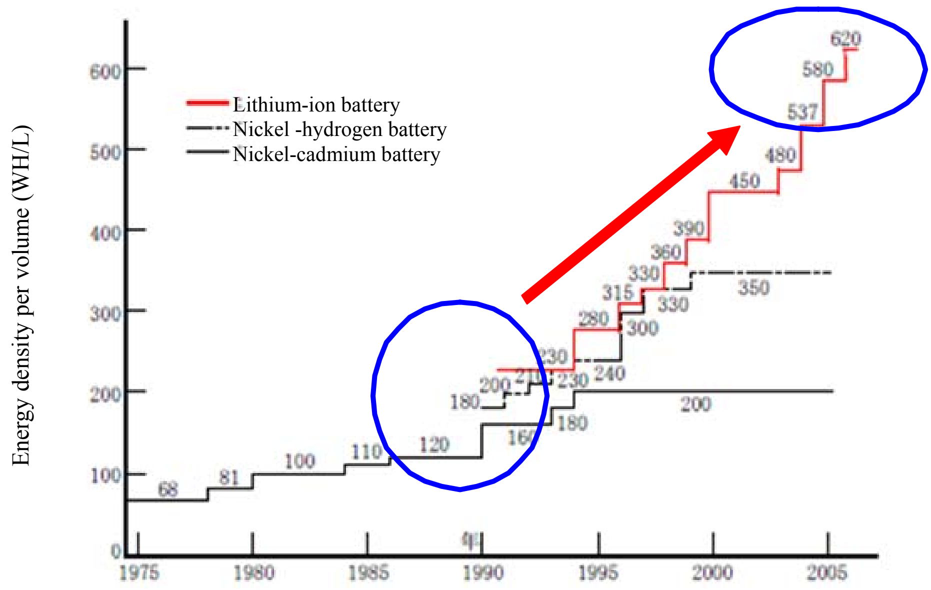
Source : Number of vehicles owned: Data compiled by the Automobile Inspection and Registration Information Association and the Annual Statistics of Automotive Transport (Ministry of Land, Infrastructure, Transport and Tourism)

Note : Fuel economy of an electric vehicle: AC electricity consumption (recharging from an AC power source)
Source : Electric vehicle: Data for the iMiEV and a report by the JHFC (fiscal 2007) were used as a reference.
Gasoline vehicle : The average of the figures for all passenger cars based on the list of fuel economy data prepared by the Minister of Land, Infrastructure, Transport and Tourism (March 2006)
Hybrid vehicle : The average of the figures for the Prius and the Civic based on the above list of fuel economy data
Diesel vehicle : A report by the JHFC

### (2) Development of Low-Cost, High-Performance Battery

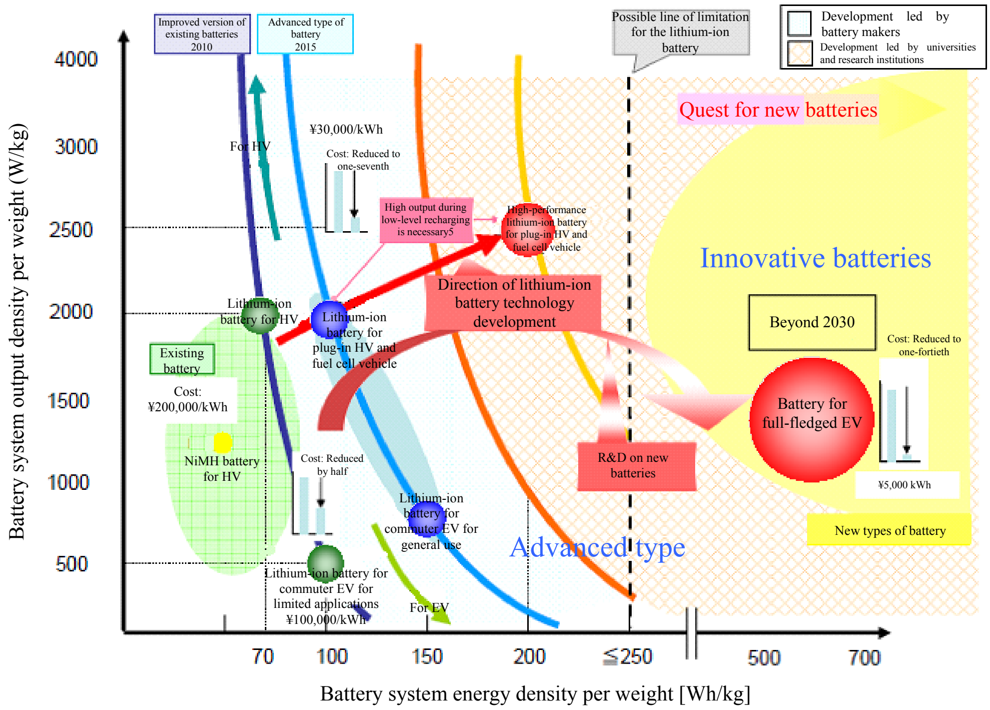
The greatest challenge to overcome in spreading the use of electric vehicles is their driving ranges. The key to extending the range will be in reducing battery cost and improving battery performance, which means increasing the battery output per weight (and per volume) and the battery energy density. Until now, the nickel metal hydride battery, which has a high energy density and which is suited to recharging quickly, has been used in hybrid vehicles. However, the lithium-ion battery is regarded as the most promising candidate as the mainstay battery for electric vehicles. As shown in Fig. 1-2, the energy density per volume of the lithium ion battery more than doubled from 230WH/L in 1990 to 580Wh/L in 2005.

**Fig. 1-2 Trend in the Battery Energy Density per Volume**




Source : Data compiled by Panasonic Energy Co., Ltd.

**Fig. 1-3 Trend in the Battery Energy Density per Weight**




Source : Study group on next-generation battery technology for new-generation vehicles

Fig. 1-3 shows target scenarios for improving battery performance in the future. There are two scenarios: one is improving the performance of the existing lithium-ion battery as a medium-term goal (advanced type development scenario) and the other is developing an entirely new type of battery as a long-term goal (innovative battery development scenario).

### A. Advanced Type Development Scenario

Energy density improvement (Wh/kg) : from the current 100 to 150 (1.5-fold increase)

Energy output improvement (W/kg) : from the current 400 to 1,200 (a three-fold increase)

Cost reduction (¥10,000/kWh) : from the current 20 to 3 (reduction to one-seventh)

### B. Innovative Battery Development Scenario

Energy density improvement (Wh/kg) : from the current 100 to 700 (seven-fold increase)

Energy output improvement (W/kg) : from the current 400 to 1,000 (2.5-fold increase)

Cost reduction (¥10,000/kWh) : from the current 20 to 0.5 (reduction to a one-fortieth)

The advanced type development scenario is highly feasible. A battery developed under this scenario would more than double the driving range, thereby helping to spread the use of electric vehicles mainly as short-range commuter vehicles for town-driving. However, under this scenario, engine-powered vehicles are expected to remain the mainstay for overall transportation needs.

Meanwhile, the feasibility of the innovative battery development scenario is as yet unknown. However, a technological breakthrough could trigger a paradigm shift, leading to the arrival of electric vehicles with a driving range similar to that of gasoline vehicles.

# 2. Electricity Supply-Demand Condition and Future Outlook

## 2-1 Global Electricity Supply-Demand Condition

### 2-1-1 Trend in Global Power Generation Volume

As shown in Fig. 2-1, the global volume of power generation has grown steadily in recent years, with the volume in 2005 more than tripling from 1971 to 18,235TWh/year. The power generation mix has changed over the period, with the share of nuclear-power generation growing from only 2% in 1971 to 16% in 2005. Meanwhile, the share of thermal power generation using crude oil and oil products like fuel oil declined from 21% in 1971 to 6% in 2005 as a result of the past oil crises, among other factors. Power generation using fossil fuels (mainly coal) accounts for 67% of the total.

**Fig. 2-1 Trend in Global Power Generation Volume**

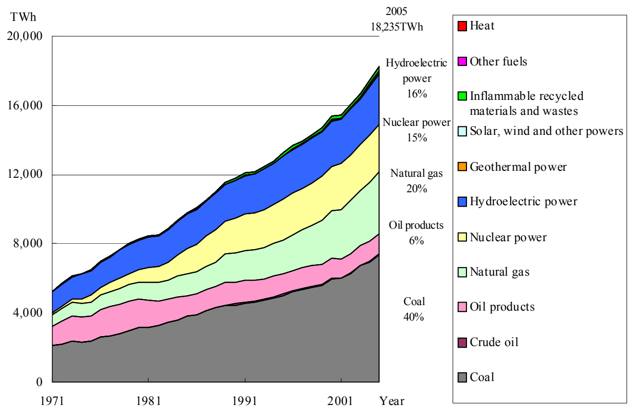
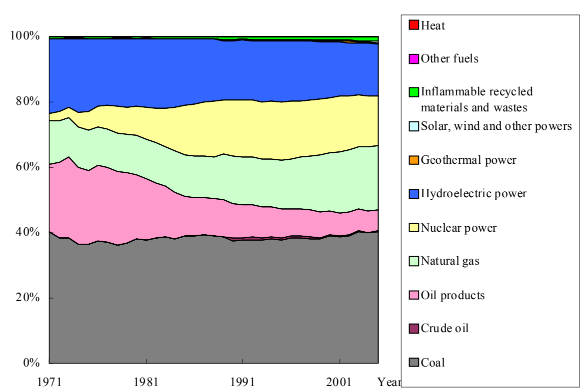



**Fig. 2-2 Trend in Global Power Generation Mix**



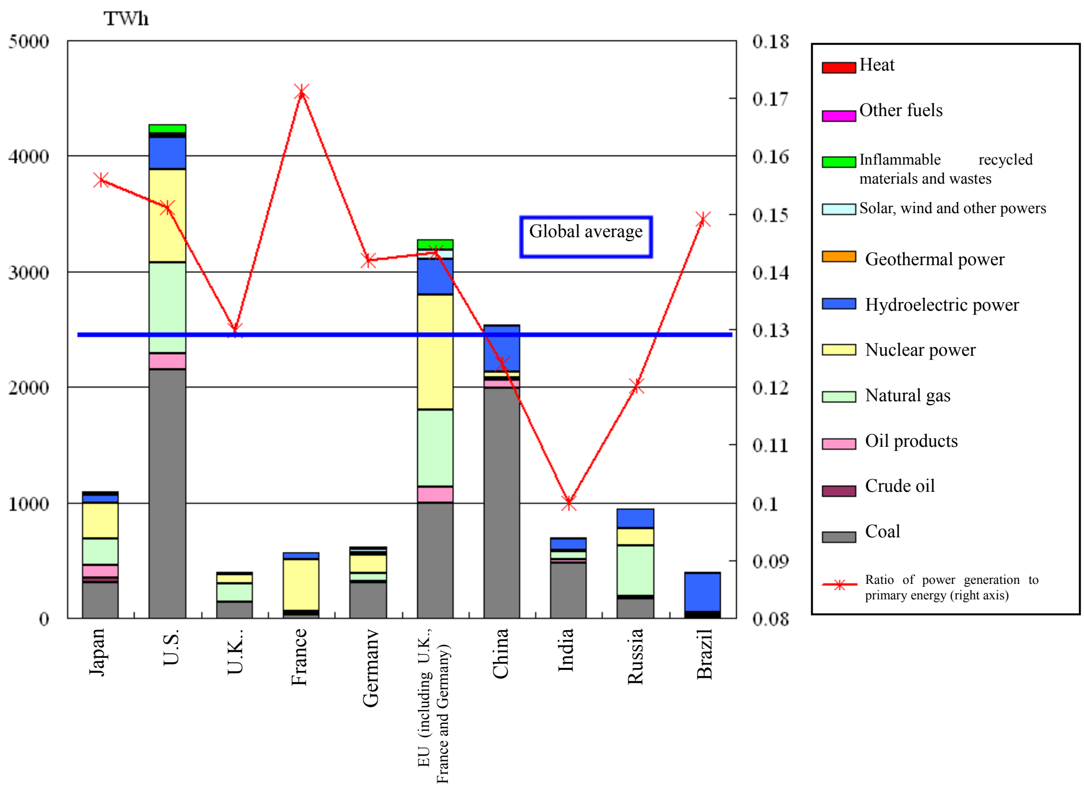

Note : 1TWh=1 billion kWh
Source : EA, Energy Balances of Non-OECD Countries 2005

### 2-1-2 Power-generation Volume and Power Source Mix in Major Countries

The power generation mix varies from country to country and from region to region. The power sources of Japan and the EU countries are well diversified. Among the EU countries, France relies mostly on nuclear-power generation. Meanwhile, Brazil depends significantly on hydroelectric power generation. Countries rich in natural resources use their own resource reserves to generate power, as in the case of China and Russia, which depend on coal and natural gas, respectively. As developed countries are well advanced in electricity, their ratio of the power-generation volume to the primary energy supply is relatively high. On the other hand, countries like China and, especially, India, face a serious power shortage, as their ratio of the power-generation volume to the primary energy supply is small. In the future, the ratio of the power-generation volume to the primary energy supply is expected to increase in developing and emerging countries, too, in line with the progress in electricity that comes with economic development.

As shown in Fig. 2-3, the United States and other developed countries still account for most of the volume in global power generation. However, China's and India's shares are growing sharply in line with their economic growth. The current power-generation volume in China matches the volume in the EU as a whole.

**Fig. 2-3 Power Generation Mix by Major Country and Region (2005)**



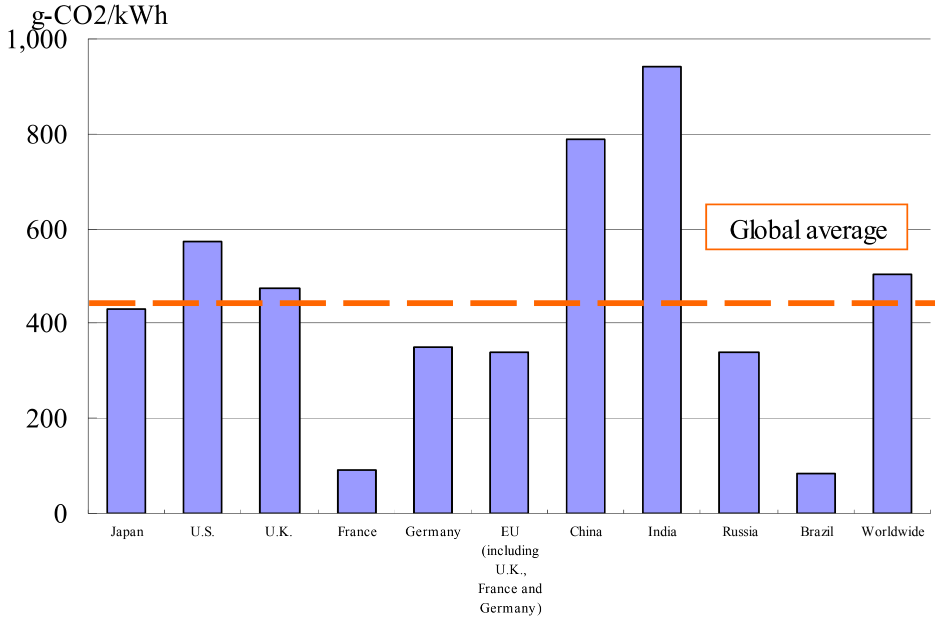

Note : The ratio of power generation to primary energy represents the total power generation volume divided by the total primary energy supply volume.
Source : IEA, Energy Balances of OECD Countries 2005, Energy Balances of Non-OECD Countries 2005

### 2-1-3 $CO_2$ Emission Intensity of Major Countries' Electricity Sector

In all developed countries except for the United States, the $CO_2$ emission volume per 1kWh of power generation is lower than the global average. The volume is also lower than the global average in Russia and Brazil, among emerging countries, as these two countries depend largely on natural gas and hydroelectric power. On the other hand, the volume is higher than the average in the United States, China and India, all of which depend heavily on coal. Moreover, the $CO_2$ emission volume in these countries is large because of their huge electricity consumption due to vast geographical and population sizes.

It can also be said that the $CO_2$ emission volume per unit of power generation in each region is significantly affected by the power gemeration mix there. As the electricity sector accounts for some 40% of the global volume of energy-derived $CO_2$ emissions, a study is under way on how to shift this sector to a low-carbon system amid growing concerns over global warming.

**Fig. 2-4 International Comparison of $CO_2$ Emissions per 1 kWh of Power Generation (2005)**




Note : $CO_2$ emissions per 1 kWh of power supplied at the power transmission end (including power used to generate heat for the co-generation system)
Source : IEA, Energy Balances of OECD Countries 2005, Energy Balances of Non-OECD Countries 2005

## 3. Current Status and Outlook of Renewable Energy

Research and development have been ongoing for a long time with regard to renewable energy as a means to provide a fundamental solution to the problem of natural resource depletion by lowering dependence on fossil fuels. Such energy has attracted increasing attention in recent years as a low-carbon-emission power-generation system. Renewables that are regarded as especially promising as a power-generation system and expected to be deployed on a large scale in the future are wind power, photovoltaic power and solar thermal power. These renewables are raising hopes due to their larger potential compared with the potential of other renewables, including bio-energy and micro-hydroelectric power-generation systems. It should be noted that the power-generation volumes for renewable energy systems cited in this report are based on the assumption of a power-generation capacity utilization ratio of 20% for wind power and 12% for photovoltaic power.

### 3-1 Wind Power

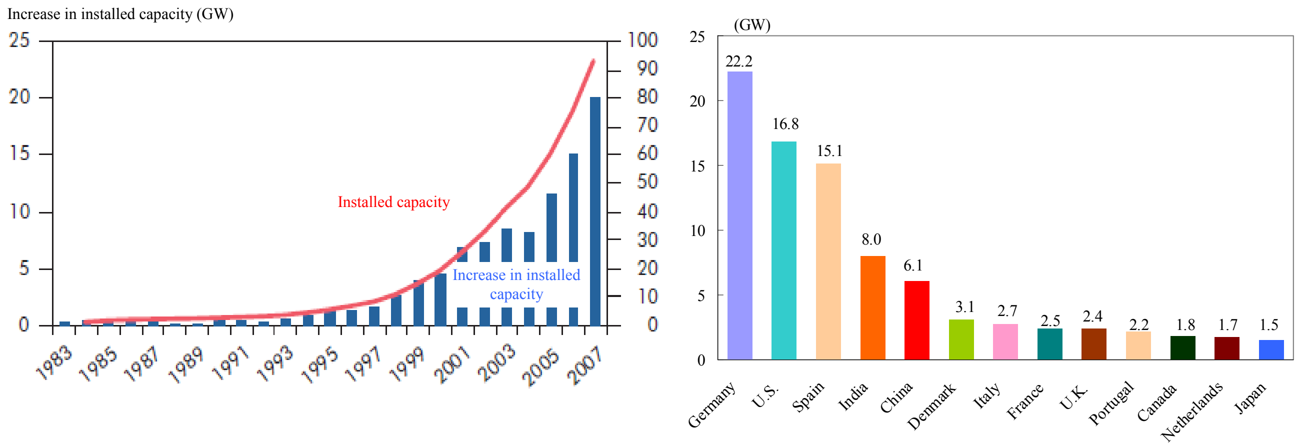
#### 3-1-1 Status of Deployment

Fig. 3-1 shows the trend in the global-installed capacity wind-power generation and the installed capacity by country. As indicated here, wind-power-generation facilities have increased sharply since the 1990s, particularly in Europe and the United States, boosting the global power-generation capacity by 20-30% annually. In 2007, the global generation capacity stood at

94GW. Germany, the United States and Spain together account for nearly 60% of the total, and the capacity in China and India is also growing.

**Fig. 3-1 Global Installed Capacity of Wind-power Generation**

**Trend in installed power-generation capacity** | **Installed capacity by country (2007)**

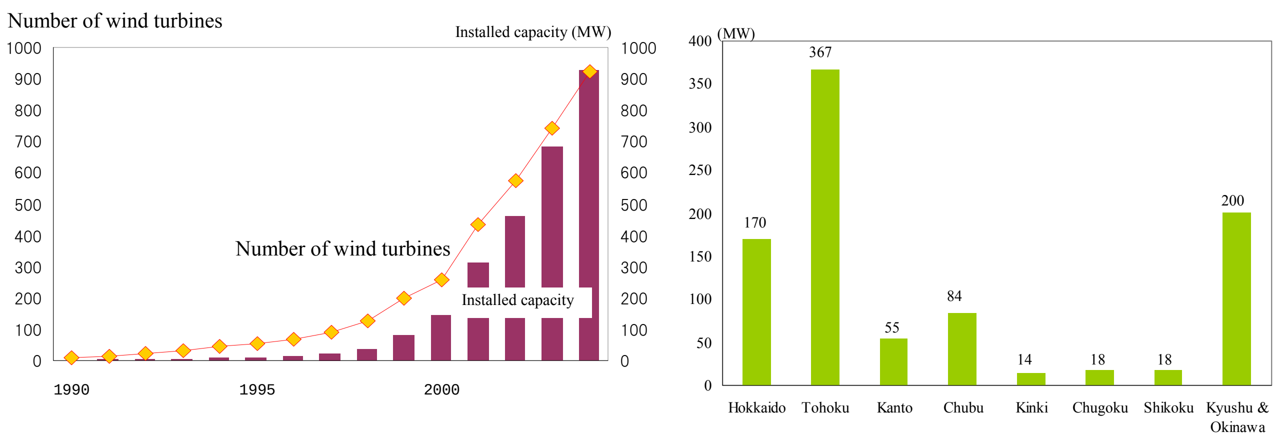



Source : Global Wind Energy Council, "Global Wind 2007 Report"

Fig. 3-2 shows the power-generation capacity in Japan and a breakdown of the capacity by region. Although the capacity is also growing in Japan, the ratio of wind power to the total power-generation volume in the country was only 0.22% in 2006. By region, there are large numbers of wind-power-generation facilities in Hokkaido, Tohoku and Kyushu, while the capacity is relatively small in Kanto and Kinki. The disparity is attributable mainly to geographical factors.

**Fig. 3-2 Installed Capacity of Wind-power Generation in Japan**

**Trend in installed power-generation capacity** | **Installed capacity by region (2005)**




Source : Compiled from materials prepared by NEDO

### 3-1-2 Supply Capacity

Based on the results of a nationwide survey on wind conditions, the New Energy and Industrial Technology Development Organization (NEDO) assumes the construction of wind farms with a capacity of 5,000 kW each on 1% of the areas where the average wind velocity is 5 m/s or more. This assumption constitutes the basis of NEDO's estimate of the potential installed capacity of wind power in Japan. According to this estimate, the potential wind-power supply capacity nationwide is 9.22 GW, with wind farms to be constructed mainly in Hokkaido, Tohoku and Kyushu. On the assumption of a capacity utilization ratio of 20%, the maximum possible wind-power-generation volume in Japan is estimated at around 16 GWh/year, which is equivalent to around 1.4% of the total power-generation volume in 2006. This estimate assumes the construction of onshore wind farms, but not offshore ones. The potential supply capacity will grow if offshore wind farms are included in the estimate. However, in reality, offshore wind farms are likely to be constructed only on a limited scale in Japan because of problems related to fishing rights, etc.

Worldwide, the potential wind-power supply capacity is much higher. For example, the World Energy Council (WEC) estimates that 29.14 million $km^2$ of areas are available for wind-power generation worldwide on the assumption that areas where the average wind velocity of 5.1 m/s to 8.8 m/s are suitable as wind farm sites. On the basis of this available area size and the same assumptions used in the NEDO estimate for Japan, the potential global wind-power supply capacity would come to approximately 74.6 billion kW as shown in Table 3-1. On the assumption of a capacity utilization ratio of 20%, the global wind-power-generation volume would come to approximately 130 trillion kWh/year, which is around seven times as large as the global total power-generation volume in 2005. This estimate takes into consideration wind conditions on land areas but not other factors, such as the distance from areas where there is electricity demand to wind farm candidate sites, and the total size of areas available for wind-power generation will be limited if such factors are taken into consideration. Meanwhile, if offshore wind farms are taken into consideration, the potential supply capacity would grow.

**Table 3-1 Areas Available for Wind-power Generation and Potential Supply Capacity Worldwide**

| | Areas available* (10,000 $km^2$) | Potential supply capacity** (billion kW) |
|---|---|---|
| North America | 788 | 20.2 |
| Central & South America | 331 | 8.5 |
| Western Europe | 197 | 5.0 |
| Ex-Soviet & East Europe | 678 | 17.4 |
| Middle East & North Africa | 257 | 6.6 |
| Rest of Africa | 221 | 5.7 |
| East Asia & Asia-Pacific | 419 | 10.7 |
| Rest of Asia | 24 | 0.6 |
| Total | 2,914 | 74.6 |

Source : World Energy Council, "New Renewable Energy Resources"

### 3-1-3 Constraints Related to Grid Stability

In Japan, electric power companies set the upper limit on the volume of wind-power-derived electricity that may be connected to a power grid from the viewpoint of the grid stability. Under this condition, the maximum possible wind-power supply volume is just over 1% of the total power supply. In May 2008, the Federation of Electric Power Companies of Japan announced that up to 5 GW of wind-power-derived electricity and up to 10 GW of photovoltaic power-derived electricity can be connected to grids across Japan without affecting the grid stability.

Meanwhile, Germany, Spain and Denmark have already boosted the ratio of wind-power-derived electricity to between 5% and 17%. However, it is important to remember that the situation in these countries is different from the situation in Japan in that they have huge cross-border grids and make international electricity trade. Generally speaking, in order to maintain grid stability when unstable wind-power-derived electricity is connected to the grid, it is necessary to strengthen power transmission and distribution networks, enhance grid management and increase both the power-storage capacity and the backup power output capacity. In other words, if the cost of such improvement measures can be financed, grid stability issues related to wind-power generation will be resolved.

For example, the U.K. Department of Trade and Industry (DTI) estimates[1] the cost of deploying wind power would be approximately 0.9 pound/MWh (approximately ¥0.2/kWh) at maximum if wind-power-derived electricity is to account for 20% of the total power supply. Hence, it is generally assumed that renewable energy-derived electricity, including wind-power-derived one, can be connected to a grid at a realistic cost if its ratio is around 20% or less, and, roughly speaking, this can be regarded as the potential deployment rate for renewable energy.

### 3-1-4 Power-generation Cost

As wind-power generation has already been introduced on a large scale, the power-generation cost is only slightly higher than or, in some cases, comparable to the cost of thermal and nuclear-power generation. According to the OECD's comparison of the costs of various power-generation systems in the United States and Europe[2] (on the assumption of discount rates of 5% and 10%), the cost of wind-power generation in the United States is $48/MWh with a discount rate of 10%, almost comparable to $43/MWh for gas-fired thermal power generation and $47 for nuclear-power generation. In contrast, the costs of photovoltaic-power generation and solar thermal power, at $209/MWh and $269/MWh, respectively, are several times as high as the cost of thermal and nuclear power generation. This situation applies in other countries as well.

According to the International Energy Agency (IEA), the estimated cost of wind power ranges from around $89 to $135/MWh in areas with weak wind conditions and from around $65 to $94/MWh in areas with average wind conditions. By 2015, the cost is estimated to drop to $53/MWh as shown in Fig. 3-3. Therefore, in areas with favorable wind conditions, the cost is likely to impose little constraint. However, the cost of offshore wind-power generation is several hundred dollars/kW

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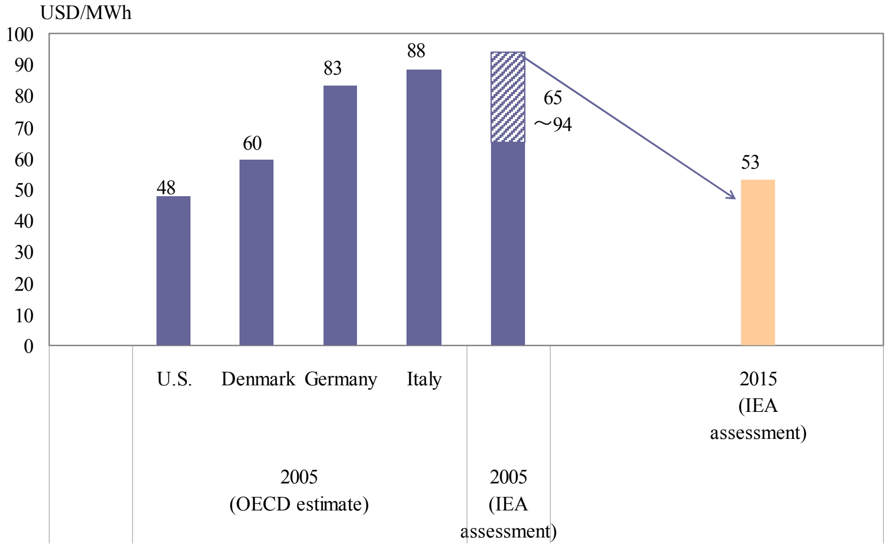
1 DTI "Quantifying the System Costs of Additional Renewables in 2020" (2002)
2 OECD "Projected Costs of Generating Electricity 2005 update"

higher than the cost of onshore wind power. Therefore, if wind power is to be deployed on a large scale in the future, it will be necessary to make efforts to reduce the cost of off-shore wind power.

**Fig. 3-3 Trend in the Cost of Onshore Wind-power Generation and the Future Outlook**

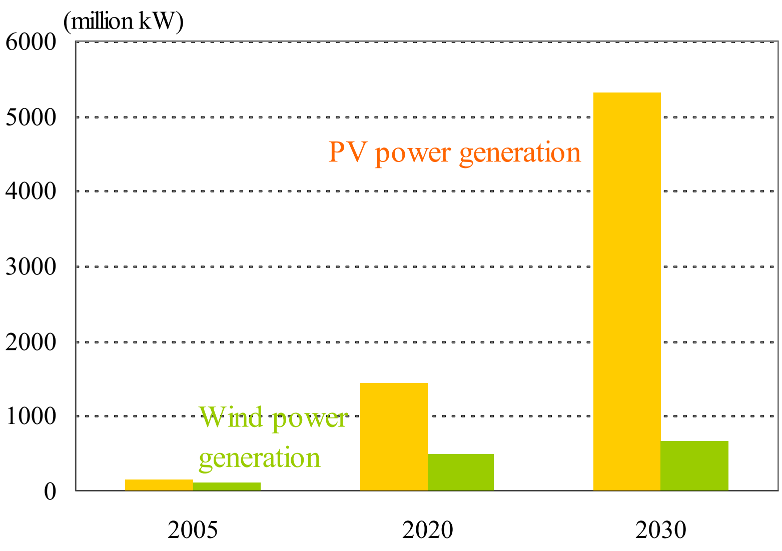



Source : IEA, "Energy Technology Perspectives 2008"

### 3-1-5 Outlook on Future Deployment

According to the "Outlook for Long-Term Energy Supply and Demand (2008)," compiled by Japan's Ministry of Economy, Trade and Industry, the photovoltaic-power generation capacity is estimated to increase 40-fold between 2005 and 2030 to 53.21 GW and the wind-power generation capacity is estimated to grow six-fold over the same period to 6.61 GW, as shown in Fig. 3-4.

**Fig. 3-4 Japan's Target for Installed Capacity of Solar and Wind Power Generation**



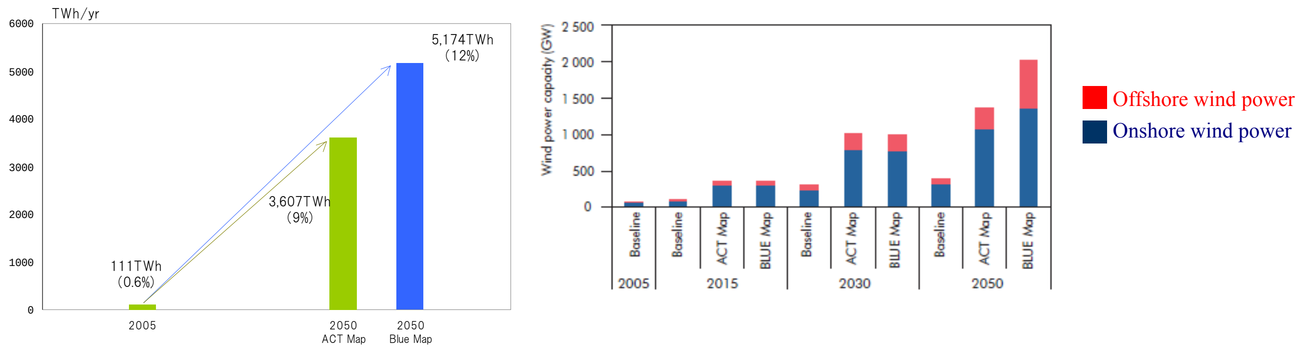

Source : Ministry of Economy, Trade and Industry, "Outlook for Long-Term Energy Supply and Demand"

The estimated wind-power generation capacity is equivalent to around 70% of the potential installed capacity mentioned in 3-1-2. Without building offshore wind farms, it would be difficult to raise the capacity far beyond the estimated figure. On the assumption of a capacity utilization ratio of 20%, the wind-power generation volume will be equivalent to around 1.3% of the total power-generation volume estimated for 2050.

In the meantime, the IEA estimates that by 2050, the global volume of wind-power generation will grow to 5,174 TWh/year at maximum (see Fig. 3-5), which will be equivalent to 12% of the global volume of overall power generation. While this is a very ambitious estimate, it can be said that as shown above, the figure is mostly feasible in light of the potential supply capacity and additional investment costs. Nevertheless, if the generation volume is to be actually raised to that level, countries around the world will need to implement policy measures to support the capacity installation of wind-power generation and make appropriate investments to ensure the grid stability.

According to an estimate by the Institute of Energy Economics, Japan (IEEJ) (reference case), the volume of power generation from renewable energy including wind power, photovoltaic power and solar thermal power, will grow to 2,479 TWh by 2050, and the above estimate is far higher than this figure.

**Fig. 3-5 Future Outlook on Global Installed Capacity of Wind-power Generation**




Source : IEA, "Energy Technology Perspectives 2008"

## 3-2 Photovoltaic and Solar Thermal Power Generation

### 3-2-1 Status of Deployment

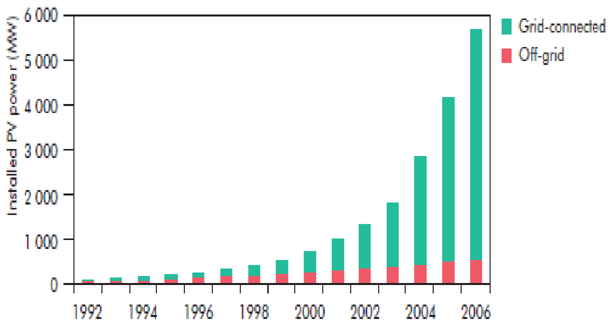
Active research on photovoltaic-power generation (solar cells) has been ongoing for several decades, and single-crystalline and polycrystalline silicon solar cells have been the mainstay types of cells until now. However, because of cost factors, there has also been a gradual shift to amorphous solar cells and compound-based solar cells, which accounted for approximately 9% of the total in 2007. As will be addressed later, the cost of photovoltaic-power generation is very high compared with the cost of other power sources, so the current research and development focuses on both improving efficiency and reducing the cost.

With regard to crystalline silicon solar cells, there is no fundamental constraining factor in terms of the supply of silicon itself. However, the rapid spread of photovoltaic-power generation has caused a supply-demand crunch for crystalline silicon for now, constraining the production of solar cells. Nevertheless, as the production capacity of crystalline silicon is being expanded substantially, this problem will be resolved in the medium and long term. In the meantime, with regard to compound-based solar cells, the limited availability of necessary rare metals may emerge as a constraining factor when such cells are deployed on a large scale in the future.

As shown in Fig. 3-6 and Fig. 3-7, the installed photovoltaic-power generation capacity of the IEA member countries is growing rapidly, with the installed capacity amounting to 5.7GW in 2006. Together, Japan, Germany and the United States account for 70% of the total capacity. In particular, the installed capacity in Germany has expanded rapidly in recent years as a result of the revision of the feed-in tariff system (under which electricity generated from photovoltaic systems are purchased at fixed prices). Most of the photovoltaic-power generation systems now in use have been installed on roofs of buildings and houses and are grid-connected, and this approach is expected to continue in the future.

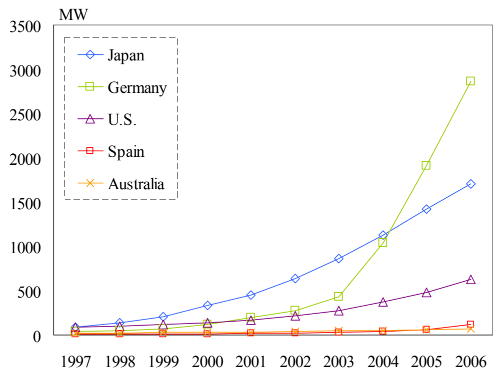
The solar thermal power-generation system generates electricity through a steam turbine using heat generated by solar light concentrated on heat-absorbing materials. Although solar thermal systems with a capacity of up to around 50MW have been in practical use in countries like the United States and Spain since the 1980s, solar thermal power generation is still in the trial stage and has yet to become widespread. In Japan, a test plant was built in Nio Town, Kagawa Prefecture, but the project was abandoned. Since then, no solar thermal project has been planned in Japan.

**Fig. 3-6 Trend in Installed Capacity of Solar Wind Power Generation**




Source : IEA, “Energy Technology Perspectives 2008”

**Fig. 3-7 Trend in Installed Capacity of PV Power Generation by Country**




Source : IEA, Photovoltaic Power System Programme

### 3-2-2 Potential Supply Capacity

Table 3-2 shows NEDO’s estimates of the potential installed capacity of photovoltaic-power generation in Japan. NEDO estimates the potential capacity at approximately 100 GW, the bulk of which will be installed in single-family homes and condominiums. On the assumption of a capacity-utilization ratio of 12%, the power-generation volume will come to 105TWh/year, equivalent to around 10% of the total power generation in Japan in 2006.

If the global solar power generation capacity is calculated on the same assumptions with this estimate, with capacity at houses calculated in proportion to the population ratio and capacity at industrial facilities calculated in proportion to the GDP ratio, it comes to approximately 3,800 GW, equivalent to around 20% of the global power-generation volume in 2005.

Solar thermal power generation is suited to regions where the sunlight intensity and sunshine rate are high and the annual rainfall volume is relatively small, given that it uses concentrated sunlight. For example, Africa, the Americas, the Middle East and Australia may be suitable regions. According to an estimate by the IEA, a solar thermal plant covering 100 square miles of area can meet all of the electricity needs of the United States, and there is no supply-side constraining factor. However, as solar thermal power generation is still at the early stage of deployment, its future is uncertain.

**Table 3-2 Potential Supply Capacity of PV Power Generation**

(Unit: GW)

| | Potential supply capacity in Japan (in the case of progress made in technology development according to NEDO's roadmap) | Potential supply capacity worldwide |
|---|---|---|
| Single-family homes | 45.4 | 2,274 |
| Condominiums | 16.5 | 826 |
| Public facilities | 10.4 | 521 |
| Industrial facilities, etc. | 29.6 | 215 |
| Total | 102 | 3,836 |

Source : NEDO

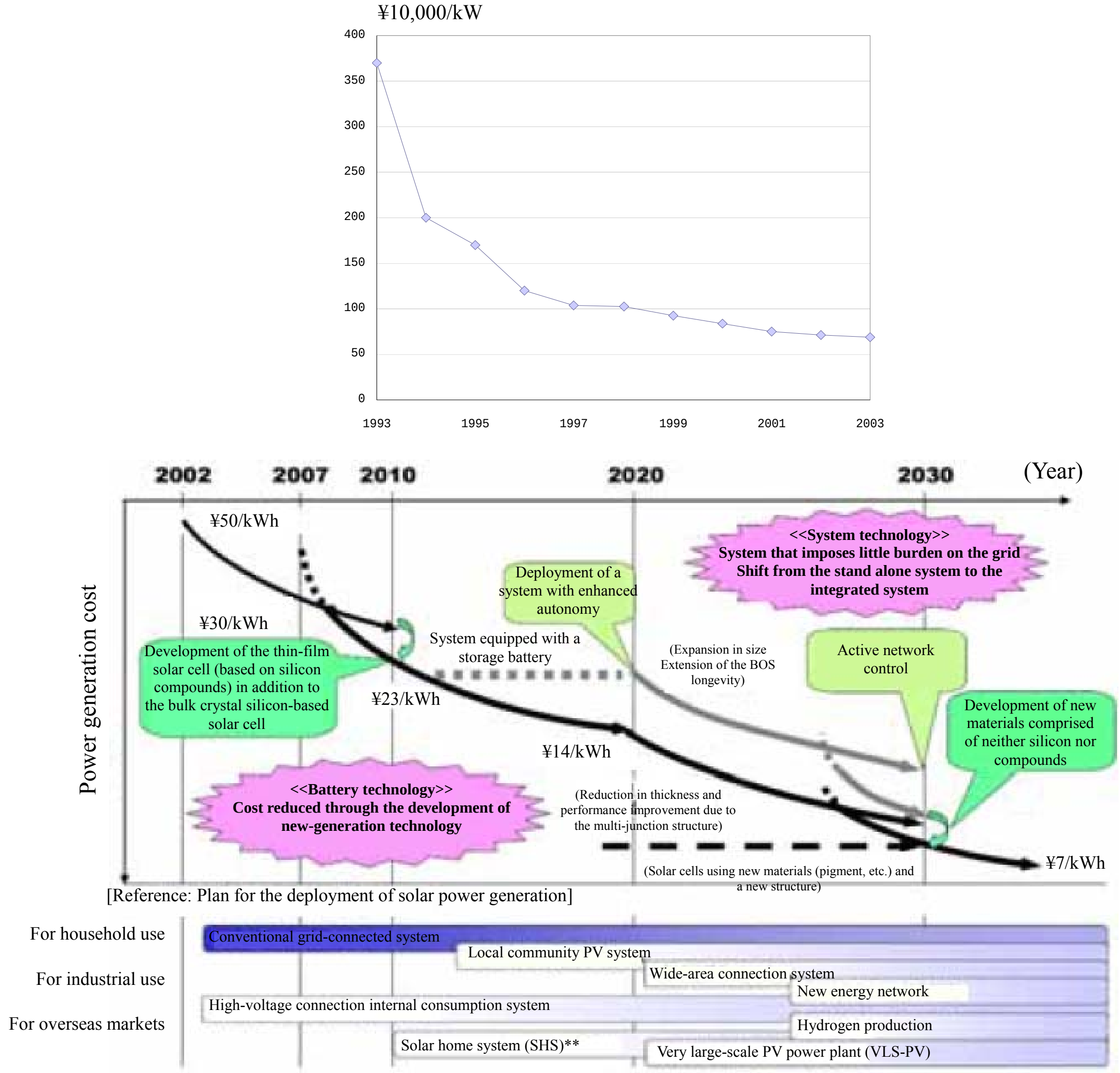
### 3-2-3 Power-generation Cost

As described above, the power-generation cost of photovoltaic and solar thermal power is very high compared with the cost of other power sources, so these systems are not competitive enough. For photovoltaic-power generation, the problem is that the manufacturing cost of solar cells has not been reduced sufficiently, and in the case of a solar thermal system, the high cost reflects the fact that it is still at the very early stage of deployment.

Nonetheless, the power-generation cost of photovoltaic power is decreasing rapidly as shown in Fig. 3-8. Under its photovoltaic power development program, NEDO aims to reduce the cost to ¥7/kWh by 2030.

According to the IEA, the cost of the photovoltaic-power generation system in 2006 was approximately $6.25/W, 60% of which was the manufacturing cost of solar cell modules. This cost has been dropping at a learning rate of 15–20%, and if the trend continues, the cost is expected to drop to $3.75-4.4/W by 2010 in line with a future large-scale deployment. If this trend of cost decline continues until 2050 to push the system cost down to $1.07/W, the power-generation cost would fall to $50–70/MWh.

**Fig. 3-8 Trend in the Price of Solar Power Generation Systems in Japan and the Cost Reduction Targets**

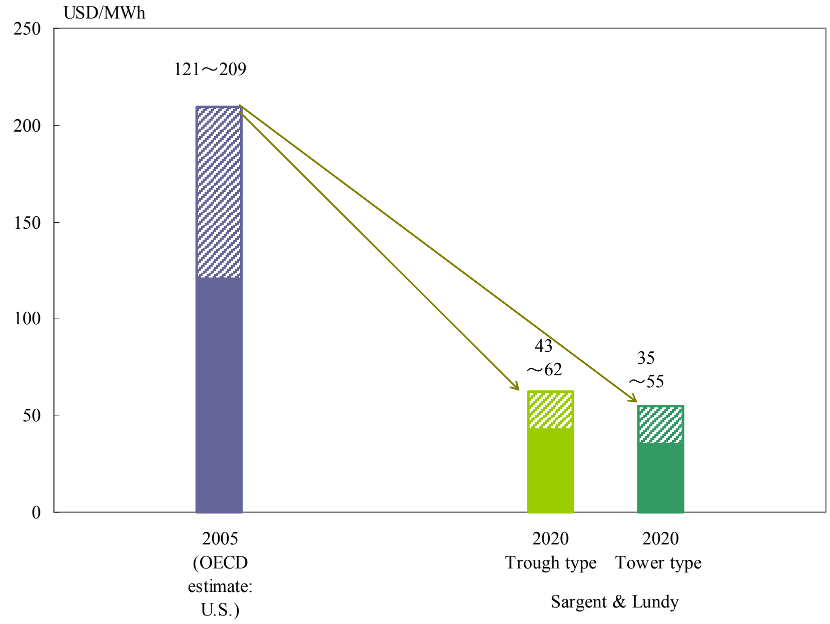



Source : NEDO

As shown above, the cost of photovoltaic-power generation is currently very high, and photovoltaic power will become competitive with other power sources only if the cost is reduced sharply in line with a large-scale deployment. Thus, cost reduction is the major challenge for photovoltaic power.

The future of solar thermal power generation is uncertain, since its deployment has so far been limited. However, its cost is expected to drop rapidly if mass production of solar thermal systems starts and technology development advances. While the parabolic trough is the mainstay solar thermal system, the tower is expected to achieve similar cost efficiency in the future. According to Sargent & Lundy LLC Consulting Group's estimate shown in Fig. 3-9, the future power-generation cost of the parabolic trough will range from around \$43 to \$62/MWh and the cost of the tower will range from around \$35 to 55/MWh.

**Fig. 3-9 Estimates of the Future Solar Power Generation Cost**

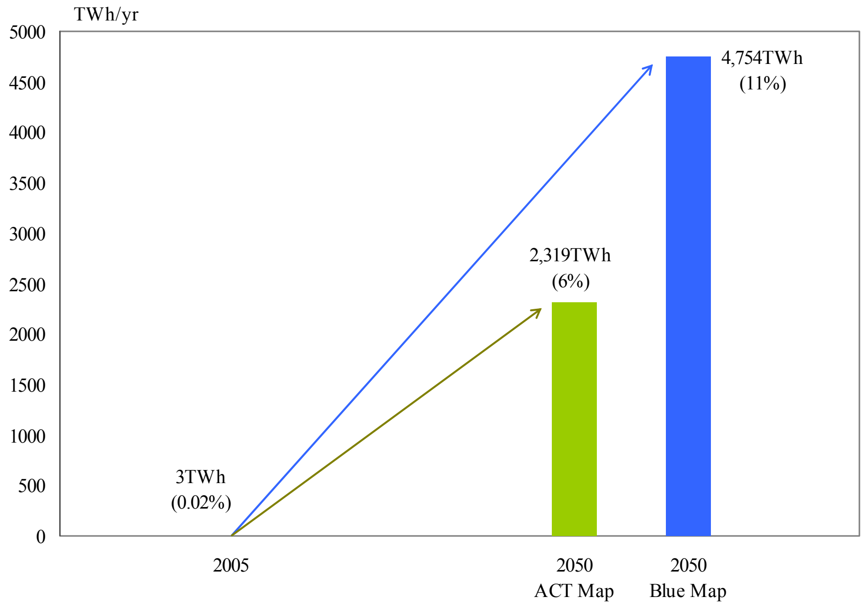



Source : Sargent & Lundy LLC Consulting Group, 2003

### 3-2-4 Outlook on Future Deployment

As mentioned in 3-1, Japan plans to expand the installed capacity of photovoltaic power generation to 53 GW by 2030, with installation at houses accounting for around 60% of the total. As this target is less than the potential supply volume as estimated by NEDO, this goal is likely to

**Fig. 3-10 Future Outlook on the Global Volume of PV and Solar Thermal Power Generation**




Source : IEA, “Energy Technology Perspectives 2008” be achieved if the government actively implements measures to encourage installation in homes.

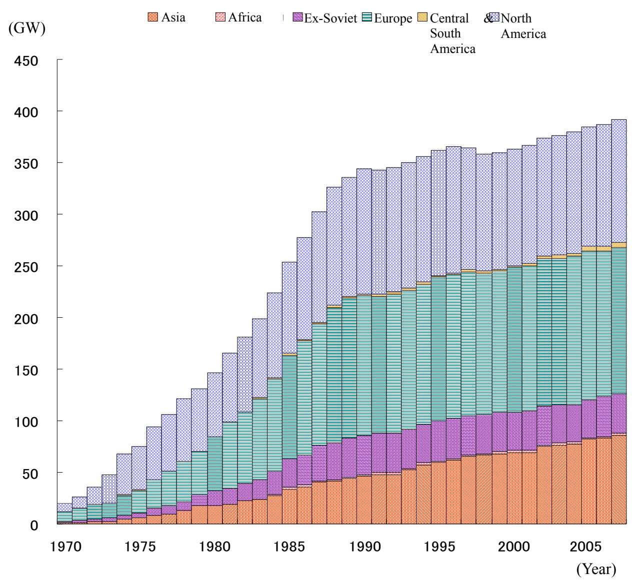
The potential global-installed capacity of 3.8 billion kW, which was mentioned in 3-2-2, would, roughly speaking, lead to a global power-generation volume of 4,000 TWh/year. Assuming electricity consumption of 5 kW per household, this would be sufficient to meet the needs of around 800 million households. According to the IEA's estimate of global installed capacity, as shown in Fig. 3-10, the installed capacity of solar systems, including photovoltaic and solar thermal systems, will grow by the year 2050 to a maximum of 4,754 TWh/year, which will be equivalent to 11% of the overall power generation. Such a huge increase in the installed capacity will be possible if governments around the world actively implement measures to support the deployment of solar systems and the cost drops sharply as a result of technology development and massive deployment.

# 4. Current Status and Outlook of Nuclear Power

## 4-1 Current Status of Nuclear-power Generation Worldwide

Nuclear-power generation is attracting strong attention as an effective means to combat global warming because it does not emit $CO_2$ in the power-generation process and also because the $CO_2$ emission amount over the entire life cycle of nuclear-power stations is extremely small compared with coal- and gas-fired thermal power stations. After World War II, various countries started developing nuclear-power generation, and in the 1970s, the installed capacity expanded rapidly, mainly in North America and Europe. Later, the growth slowed down, and the total volume of nuclear-power generation declined temporarily as a result of the closures of obsolete nuclear plants in the United States and Europe. In the 2000s, the installed capacity started growing again, led by installation in Asian countries, and many countries are planning to introduce nuclear-power

**Fig. 4-1 Trend in Global Installed Capacity of Nuclear Power Generation**




Source : Japan Atomic Industrial Forum, "World Nuclear Power Plants" generation on a large scale. As of January 2008, there were a total of 435 nuclear reactors in operation in 31 countries around the world, with the combined capacity of 392 GW. According to an estimate by the IEA, electricity derived from nuclear power accounted for 6% of the consumption of primary energy and 15% of the overall power generation. Fig. 4-1 shows the trend in the installed capacity of nuclear-power generation.

## 4-2 Key to Deployment of Nuclear-power Generation

While various countries are planning to expand nuclear-power generation or introduce it for the first time, the future deployment of nuclear power will be affected by many factors, including the power-generation cost, the potential supply capacity and social acceptance. An overview of these factors is below.

### (1) Power-generation Cost

In Japan, the Subcommittee to Study Costs and Other Issues of the Electricity Industry Committee under the Advisory Committee for Natural Resources and Energy conducted a cost assessment of nuclear-power generation in 2004. According to the assessment, on the assumption of a discount rate of 3% and a capacity utilization ratio of 80%, the cost of nuclear-power generation is ¥5.3/kWh, lower than the costs of all other power sources, including hydroelectric power (¥11.9/kWh), oil-fired thermal power (¥10.7/kWh), LNG-fired thermal power (¥6.2/kWh) and coal-fired thermal power (¥5.7/kWh).

In the meantime, in 2003, the Massachusetts Institute of Technology issued a report entitled "The Future of Nuclear Power," which argued that from the viewpoint of cost and non-proliferation, the U.S. government should focus its nuclear-power research and development on the once-through fuel cycle. According to the cost comparison made in this report, the cost of nuclear-power generation was estimated at $67/MWh, higher than the cost of coal- and gas-fired thermal power Generation. According to a cost assessment conducted by the University of Chicago and the Congressional Budget Office (CBO), the cost of nuclear power was also estimated to be higher than the cost of other power sources.

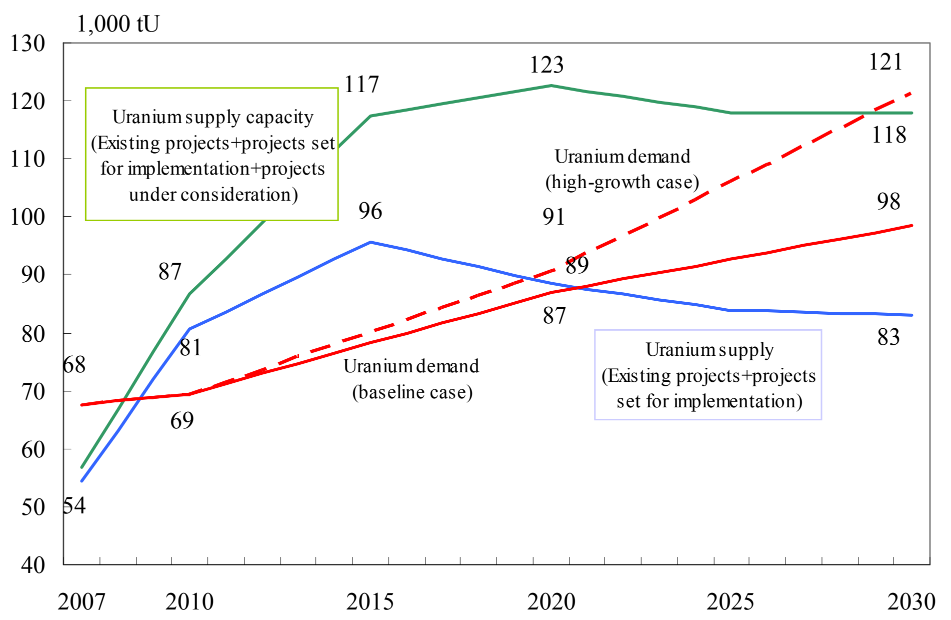
As shown above, the results of cost assessment vary from country to country and from organization to organization. The biggest point of difference between these various cost assessments is the discount rate. Generally speaking, nuclear-power generation is notable for its large initial investment cost and small operating cost, which means that a high discount rate is unfavorable for nuclear-power generation. Investors' expected return on stock and bond investments is generally higher in the United States than in Japan. U.S. electric power companies raise most of their necessary funds from the stock market, whereas Japanese electric power companies depend mostly on loans from banks, mainly low-interest loans provided by Development Bank of Japan and other lenders. This results in the difference between the discount rates assumed in cost assessments made in Japan and the United States. In order to encourage electric power companies to decide to invest in power sources with high initial investment costs, such as nuclear power plants, innovative coal and gas-fired thermal power plants installed with

CCS ($CO_2$ capture and storage) equipment, it is essential to either clarify the advantage of nuclear power as a low-carbon power source through carbon pricing, ensure a business condition that would allow them to raise a large amount of funds with low risk or implement policy measures that would support them in other ways. If a cost advantage is ensured for nuclear power, nuclear power is likely to be deployed rapidly not only in China and India, which are already promoting large-scale nuclear-power development plans to meet their huge electricity needs, but also in South East Asia and the Middle East, where nuclear power has not yet been deployed.

**(2) Uranium Supply-Demand Condition**

In the 1970s, uranium production increased significantly and uranium prices surged amid expectations that nuclear-power generation would grow rapidly. However, nuclear-power generation later entered a period of stagnation worldwide and accordingly, uranium production declined and uranium prices remained slumped at less than $20/lb. As nuclear-power generation began to draw renewed attention in recent years, uranium prices started to rise in 2004, climbing above $130/lb in 2007 because of concerns over supply following a mining accident, among other factors. Although uranium prices fell back to around $60/lb later, they have been staying at relatively high levels compared with prices during the period of stagnation for nuclear-power generation.

**Fig. 4-2 Outlook on Uranium Supply-demand until 2030**




Source : Uranium supply : OECD/NEA, "Uranium 2007"
Uranium demand : Estimate by the authors

Therefore, investment in uranium resource development is rapidly becoming active, with the global investment amount growing from approximately $100 million around 2000 to nearly $10 billion in 2007. As a result, uranium production is expected to increase significantly. In 2006, the global volume of uranium production stood at 40,000 tons U, equivalent to only around 60% of the global needs, and the supply gap was filled with uranium released from stockpiles and extracted from dismantled nuclear warheads. However, according to “Uranium 2007,” a report prepared by the OECD Nuclear Energy Agency, the annual uranium production capacity is estimated to increase to 96,000 tons U in 2015 as long as additional production from development projects that have already been given the go-ahead is taken into consideration; and this figure will grow further to 117,000 tons U if additional production from projects in the planning stage is also included.

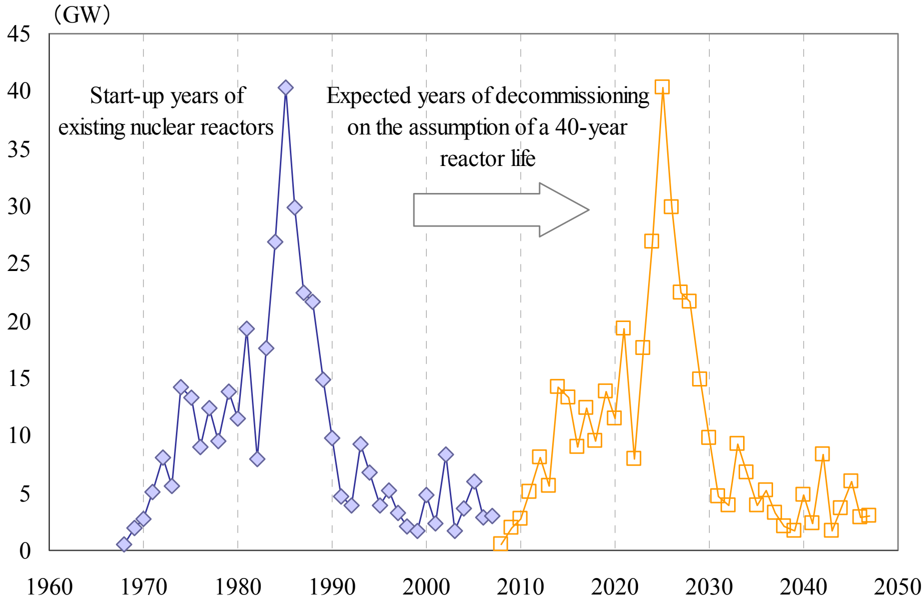
Meanwhile, as will be addressed later, the global installed capacity of nuclear-power generation is estimated to grow to approximately 571 GW by 2030 under our baseline scenario and to approximately 724 GW under the high-growth scenario. The annual volume of uranium demand is estimated to grow to 98,000 tons U by 2030 under the baseline scenario and to 121,000 tons under the high-growth scenario on the assumption of the average capacity utilization ratio of around 80%, the average reloading fuel burn-up (average heat value per one ton of uranium input) of 42GWd/t, a uranium concentration ratio (concentration of enriched uranium U235 added to nuclear fuel) of 3.7%, a tail concentration (concentration of remnant U235 generated in the enriching process) of 0.3% and a heat efficiency of 34%. Fig. 4-2 indicates trends in the estimated uranium demand and the uranium supply capacity projected in “Uranium 2007.”

As shown in Fig. 4-2, surplus supply capacity of 36,000 tons U and 32,000 tons U will arise under the baseline scenario and under the high-growth scenario, respectively, if the uranium supply-demand condition eases in the medium- to long-term as a result of the ongoing moves to expand production rapidly and if development projects now at the planning stage start to proceed smoothly by 2020. Therefore, the uranium supply-demand balance is not likely to emerge as a major constraining factor for future development of nuclear-power generation. However, there is a risk of the uranium supply-demand condition tightening in the future if development projects now at the planning stage fail to proceed smoothly due to a fallback in uranium prices or other factors.

### (3) Situation Surrounding Plant Construction and Equipment Supply

As mentioned in 4-1, many nuclear power plants were constructed in the 1970s and 1980s, mainly in the United States and Europe. The number of new plant start-ups peaked in 1985, and since the 1990s, nuclear-power generation has faced a period of stagnation. Fig. 4-3 shows the trends in the number of new plant start-ups and the expected number of decommissioned plants based on the assumption of a plant longevity of 40 years from the start-up of operation. As shown in this figure, for a long period of time from around 2015, plants with a combined capacity of around 5GW to 10GW or more are expected to be decommissioned annually. If the installed capacity of nuclear-power generation is to be expanded, it will be necessary to build new plants at a sufficient pace to more than offset the decline expected by the decommissioning.

**Fig. 4-3 Start-up Years of Existing Nuclear Reactors**




Source : Japan Atomic Industrial Forum, "World Nuclear Power Plants"

In the meantime, as orders for new nuclear reactors for commercial power generation have been sluggish since the 1990s, there has been consolidation among nuclear power plant manufacturers, resulting in a situation in which a small number of plant manufacturers capable of offering plant concepts and design know-how with high levels of cost efficiency and reliability dominate the market. As of 2009, the only global plant manufacturers that have international competitiveness are three Japanese companies (Mitsubishi Heavy Industries, Ltd., Toshiba Corporation and Hitachi Ltd.),Westinghouse Electric Corporation of the United States, which is owned by Toshiba, General Electric Company of the United States, which has formed a partnership with Hitachi, Areva of France, ROSATOM of Russia and AECL of Canada. These companies downsized their nuclear-power business during the slump in nuclear plant construction. Their plant construction capacity is expected to grow gradually as they increase their workforces again. However, it will likely be difficult for them to sharply expand the construction capacity at an early date given the need to secure adequate personnel.

In addition to expertise in plant design and construction, nuclear-power generation requires many special and sophisticated equipment and components, and only a limited number of companies can supply such equipment and components. In the most prominent instance, Japan Steel Works, Ltd. is said to be the world's only company that is capable of producing high-quality, large forgings for nuclear reactor pressure vessels, and some people predict that the limited supply capacity of such forgings will constrain the global capacity of nuclear plant construction. In light of the above, the number of new nuclear power plants that can be constructed is expected to be limited at least over the next 10 years or so, and the plant construction capacity is likely to virtually set the upper limit on the installed capacity of nuclear power. However, from a long-term perspective stretching as far ahead as 2050, the power-generation capacity may expand at a faster pace than in the 1970s if nuclear power deployed to the maximum possible extent and plant and equipment manufacturers increase their manufacturing capacity sufficiently to meet the needs. In particular, China aims to secure technology transfers from other countries so that it can foster a domestic industry capable of building nuclear power plants on its own. In order to ensure that nuclear-power generation is deployed in many more countries around the world, it will be necessary to enable countries that do not have a plant construction capacity to design and build plants on their own.

## 4-3 Outlook on Future Deployment

### 4-3-1 Plans for Deployment by Region

We can provide a rough estimate of nuclear power deployment over a period extending to around 2030 based on policy measures and estimates announced by individual countries. The figures cited below are based on an assumption of a global average capacity utilization ratio that is around 80% for nuclear power plants.

(a) Americas

In the United States, although no new nuclear reactor has been started up since the Watts Bar Nuclear Plant Unit 1 started operation in 1996, the government has established a legislative framework for supporting the construction of nuclear power plants, with more than 30 new plants planned. However, as not all of them are likely to be actually constructed, the installed capacity of nuclear-power generation will be expanded only on a limited scale. Meanwhile, Canada, which is well experienced in nuclear-power generation and has its own plant technology, has a plan to increase its power-generation capacity gradually.

Mexico, Brazil and Argentina also have nuclear reactors in operation, and they are expected to build more plants.

(b) Europe and Former Soviet Union

While the installed nuclear-power capacity is expected to increase in France, the United Kingdom and Finland, Germany, Spain, Sweden and Belgium have adopted the policy of phasing out nuclear power. However, there are moves to review this policy amid growing awareness about global warming. In Europe as a whole, the installed nuclear-power capacity is expected to continue decreasing slightly until 2030.

Russia, with its own light-water nuclear technology, is far advanced in nuclear-power generation, and it not only plans to build a large number of new nuclear plants on its territory but also aims to sell nuclear reactors to other countries. Among the former Soviet republics, Ukraine is building a new nuclear reactor. Kazakhstan, which is rich in uranium reserves and actively developing its nuclear-power industry, is also expected to build new nuclear plants.

(c) Middle East and Africa

In the Middle East, many countries, including the UAE, Jordan and Saudi Arabia, are starting to consider deploying nuclear power. However, as no detailed plans have been drawn up, we assume that none of the nuclear plants now under consideration will start operation until 2030 and that the two Bushehr reactors under construction in Iran will be the only reactors to have started operation by then in this region. In Africa, South Africa, which has the region's only nuclear reactor in operation, is expected to increase its installed nuclear capacity sharply in the future. Among other countries, Egypt is considering building a new reactor but has not announced a detailed plan.

(d) Asia

China has drawn up a large-scale nuclear-power development plan in response to the rapidly growing electricity demand, and it is already constructing nuclear power plants. The plan, which calls for the construction of plants with a combined capacity of 40GW by 2020, has a fair chance of being realized. Although an even more ambitious target has been set, we estimated China's future installed capacity mostly based on the development plan.

India has until recently focused on the development of nuclear-power generation using its own technology, intended to establish a thorium cycle. India has received a very limited degree of support from other countries because it conducted nuclear tests and refuses to accede to the Nuclear Non-proliferation Treaty (NPT). However, by taking advantage of the signing of a nuclear cooperation treaty with the United States, India is planning to promote the development of nuclear-power generation on a large scale using imported light-water reactors. The success of this plan will depend on political negotiations on the domestic and diplomatic fronts. We estimated the country's future installed capacity on the assumption that nuclear power will be introduced according to this plan.

In Southeast Asia, although Thailand, the Philippines, Malaysia, Indonesia and Vietnam plan to deploy or introduce nuclear power, the implementation of their plans are likely to be delayed and the pace of deployment is expected to vary from country to country.

We assume that the installed capacity in Japan and South Korea will increase mostly according to their plans. As for Taiwan, we assume that the country's plan to phase out nuclear reactors in operation will be delayed.

### 4-3-2 Outlook on Development of Nuclear-power Generation Worldwide

The development of nuclear-power generation around the world is expected to proceed steadily, led by Asia, with the installed capacity projected to grow from 387 GW at the end of 2006 to 504 GW in 2020 and to 571 GW in 2030. The volume of electricity generated by nuclear power is projected to increase from 2,800 TWh/year in 2005 to 4,200 TWh/year in 2030. However, as the volume of electricity generated by natural gas- and coal-fired thermal power is set to increase more steeply, the ratio of electricity generated from nuclear power is expected to decline from around 15% in 2005 to around 12% in 2030. This means that under the existing policy framework, the greenhouse gas emission reduction effect to be gained from an increase in nuclear-power generation will be limited, making it necessary to implement more aggressive measures. Table 4-1 shows the expected trend in the global installed capacity over the period to 2030.

**Table 4-1 Future Outlook on the Global Installed Capacity of Nuclear-power Generation**

| | 2006 | 2010 | 2020 | 2030 |
|---|---|---|---|---|
| Installed capacity (GW) | 387.0 | 403.0 | 504.4 | 571.0 |

By 2030, the global installed capacity of nuclear power is estimated to increase by 185 GW. Of that amount, Asia will account for 124 GW, equivalent to a capacity of around 100 reactors. This number includes reactors to be built in countries that already have nuclear plants, such as China, India, South Korea, Japan and Taiwan, as well as countries planning to deploy nuclear power for the first time, including Thailand and Vietnam. The number of countries operating commercial nuclear power plants in 2030, including the latter countries, is expected to increase to more than 40 from 31 in 2006. As the use of nuclear-power generation spreads worldwide, it will become more important than ever to tackle such issues as assurance of nuclear plant safety, stability of uranium fuel supply and nuclear non-proliferation.

Among other organizations, the IEA forecasts in “World Energy Outlook 2007 - China and India Insights” that the global installed capacity of nuclear power will grow to 415 GW by 2030. In “Energy, Electricity and Nuclear Power Estimates for the Period up to 2030,” the IAEA assumes that the global installed capacity will grow to 691 GW by 2030 in the “high case” and 447 GW under the “low case.” According to “The Global Nuclear Fuel Market Supply and Demand 2007–2030,” compiled by the World Nuclear Association (WNA), the global installed capacity will grow to 529 GW by 2030 in the reference case, to 730 GW in the high case and to 285 GW in the low case. As the prospects for nuclear-power generation beyond 2030 are mostly uncertain, it is difficult to predict specifically what the status of development will be like. In terms of technological advance, in addition to existing reactors and their advanced versions known as evolutionary third-generation light-water and heavy-water reactors, new types of reactors may be deployed, starting in the 2020s in the case of small- and medium-scale reactors starting and in the 2040s in the case of fourth-generations reactors such as the fast-breeder reactor (FBR). However, other nuclear power-generation technologies (e.g., thorium cycle and nuclear fusion) have little chance of being commercialized by 2050.

According to the IEA’s “Energy Technology Perspectives 2008,” the global installed capacity of nuclear power will grow to 570 GW by 2050 under the Baseline scenario, to 1,250 GW under the BLUE Map scenario and to 2,000 GW under the BLUE Map hiNUC scenario. The BLUE Map scenario assumes that 30 GW of new capacity will be added annually from 2009 onward. However, in light of the time needed for plant construction and the construction capacity of plant manufacturers, this assumption appears to be somewhat unrealistic. Nonetheless, if the global installed capacity of nuclear power is expanded significantly and the supply capacity is strengthened, a sharp increase like this may be feasible after 2030.

Based mainly on forecasts (for the period leading up to 2030) made by the Institute of Energy Economics, Japan, we have come up with the following three scenarios while taking into consideration forecasts by other organizations and various variable factors.

1) Baseline Case

In accordance with a forecast by the Institute of Energy Economics, Japan, the global installed capacity will grow to 571 GW by 2030 and 15 GW of new capacity will be added annually thereafter, boosting the global installed capacity to 871 GW by 2050. This scenario reflects a situation in which the power-generation cost factor mostly works to support the spread of nuclear-power generation while the plant and equipment supply factor sets the limits on capacity installation.

In this case, governments will support the deployment of nuclear-power generation out of consideration for global environmental issues, and an upsurge in fossil fuel prices and the introduction of carbon pricing will prompt the construction of nuclear plants on a large-scale around the world. In major electricity-consuming countries like China and India, the installed capacity of nuclear power will show a particularly sharp increase, and the construction of new plants will proceed steadily in advanced nuclear power countries such as Japan, the United States and Russia. The policy of phasing out nuclear power, adopted by some European countries, will be reversed, or plant closures will be delayed substantially. Moreover, as a result of active financial and technical support provided by developed countries, Southeast Asian countries that are preparing to implement nuclear-power development plans, such as Vietnam and Thailand, will begin operations of reactors around 2020 or later, and Middle East countries will also introduce nuclear-power generation, leading to an increase in the global installed capacity. Because of the increase in the installed capacity, uranium prices will stay at a relatively high level of $60/lbU308 or more, prompting active uranium resource development.

2) High-Growth Case

In the IAEA's "high case," the global installed capacity will grow to around 700 GW by 2030. If this scenario is to transpire, the power-generation cost factor should support the spread of nuclear power and the plant and equipment supply factor should impose no constraint, thereby maximizing the deployment of nuclear power. The installed capacity will increase to 725 GW by 2030 and 25GW of new capacity will be added annually thereafter, increasing the capacity to 1,225 GW by 2050.

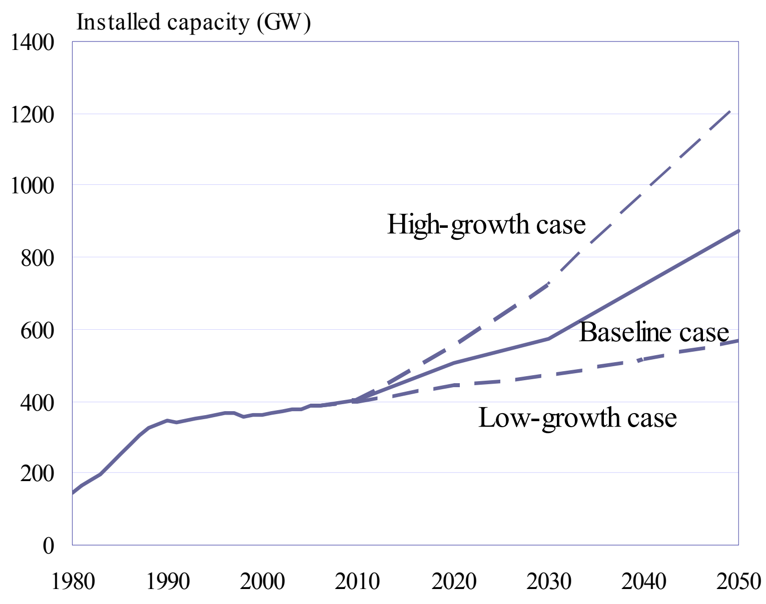
This case assumes that countries around the world, including both developed and developing countries, will introduce nuclear-power generation on a large scale because the advantage of nuclear-power generation in terms of policy support and cost assumed in the baseline case will be maintained. At the same time, it will also be necessary for construction of nuclear power plants to increase significantly, especially after 2030, not only in advanced nuclear power countries but also in emerging countries like China and India, leading to an unprecedented pace of growth in nuclear plant construction worldwide.

3) Low-Growth Case

In light of public awareness about global environmental issues and the current situation surrounding nuclear power, it is not realistic to expect installed capacity to decline as assumed in the WNA's Lower Scenario. A moderate increase assumed in the IAEA's low case and forecast by the IEA is the most realistic growth scenario. The prerequisite for the realization of the low-growth scenario is that the power-generation cost factor works to the detriment of the deployment of nuclear power. This scenario will transpire only when the negative cost factor combines with other constraining factors, particularly when political and social factors adversely affect the deployment of nuclear power. This scenario assumes that the global installed capacity will increase to 469 GW by 2030 and 5 GW of new capacity will be added annually thereafter, increasing the capacity to 569 GW by 2050.

Nuclear-power generation will fail to become cost-competitive and remain stuck in the period of stagnation that has lasted since the 1990s due to a drop in fossil fuel prices and the absence of carbon pricing or the introduction of carbon pricing with the low level of prices. As a result, spot uranium prices will decline to around $20–30/lbU3O8, dampening uranium resource development.

**Fig 4-4 Outlook on the Global Installed Capacity of Nuclear-power Generation until 2050**

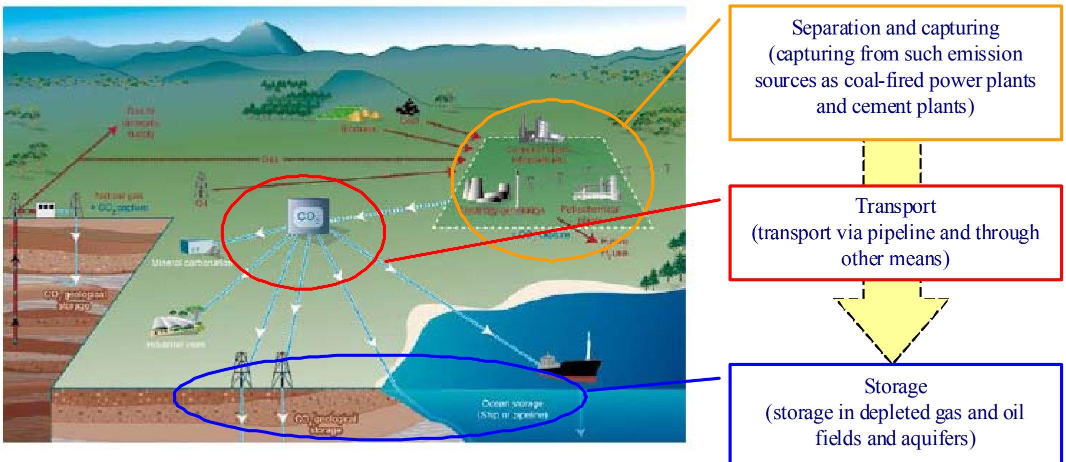


# 5. CCS

## 5-1 Mechanism of CCS

CCS, which stands for Carbon dioxide Capture and Storage, refers to a technology that curbs the release of $CO_2$ into the atmosphere by separating and capturing $CO_2$ from large $CO_2$ emission sources, such as thermal power plants, steelworks and cement plants, and storing it in underground reservoirs or sequestering it in deep-ocean waters for a long period of time in a stable way. CCS is regarded as an important option in the fight against global warming. Development of technology to separate and capture $CO_2$ efficiently and at a low cost will be the key to promoting the commercialization of CCS. The storage technology used in CCS has been adapted from the one developed for crude oil and natural gas development.

**Fig. 5-1 Concept Image of CCS**




Source: IPCC, IPCC Special Report Carbon Dioxide Capture and Storage

1) Separation and Capturing

Major $CO_2$ separation techniques include the chemical absorption method, the physical absorption method and the pressure swing absorption method; and major collection techniques include the oxy-fuel combustion method, the pre-combustion method, and the post-combustion method, which are applied in their respective capturing processes.

2) Transportation

Possible means of transportation of captured $CO_2$ include a pipeline transportation, which has been used in the United States, and transportation by $CO_2$ tanker. Until now, there have been no operations of any large $CO_2$ tankers.

3) Storage

Possible means of storage include ocean sequestering, which takes advantage of the ocean's ability to absorb and dissolve $CO_2$, and underground storage, which utilizes the storage capacity of such underground reservoirs as depleted gas fields and aquifers.

CCS may enable the reduction of $CO_2$ emissions at a relatively low cost, and it may also bring about commercial gains by contributing to enhanced oil recovery (EOR) in some cases. On the other hand, there are various criticisms and concerns, such as that CCS will impose an additional cost, that it will promote the use of fossil fuels, that input of additional energy will become necessary and that stored $CO_2$ may leak into the atmosphere.

## 5-2 Major Activities by Individual Countries

### 5-2-1 Major CCS Projects

Currently, several commercial CCS projects are under consideration. These projects are motivated by the following four factors.

(i) Proximity to Storage Reservoirs

There is a rich database of possible storage reservoirs, including depleted fields and aquifers, that are located near the $CO_2$ emission source (e.g., Sleipner, In Salah, Weyburn and Gorgon projects).

(ii) Low Separation and Capturing Cost (no need for significant additional investment)

The separation and capturing cost is low because an existing gasification plant that separates $CO_2$ during the gasification process is used, eliminating the need for additional significant investment (e.g., Sleipner, In Salah and Weyburn projects).

(iii) Expected Contribution to Enhanced Recovery of Oil and Gas

The injection of $CO_2$ is expected to contribute to an increase in oil and gas production, which will generate additional profits (e.g., Weyburn project).

(iv) $CO_2$ Reduction Incentive Arising from Carbon Tax, Emission Credit Trading, etc.

The imposition of a carbon tax or the introduction of $CO_2$ emission credit trading provides an economic incentive for reducing $CO_2$ emissions (e.g., Sleipner project).

Of the CCS projects, the Snovit project was abandoned, as it was judged to be incapable of achieving the original profit target and unfeasible in terms of cost. With regard to other projects under consideration, attention should be paid to external factors such as energy prices and the possible introduction of a carbon tax, as well as the results of feasibility studies. There are also commercial projects for the storage of $CO_2$ emitted from coal-fired thermal power plants, including the Zerogen-Stanwer project (starting in 2012 in Australia), the Saskpower project (starting in 2012 in Canada), the FutureGen project (starting in 2012 in the United States), the RWE project (starting in 2014 in Germany) and the RWE Tilbury project (starting in 2016 in the United Kingdom).

**Table 5-1 Major CCS Projects**

| Starting year | Project Name | Country | CO2 emission source | Storage reservoir type | Injected volume (10,000 t-CO2/year) | Participating companies |
|---|---|---|---|---|---|---|
| 1996 | Sleipner | Norway | Natural gas production | Ocean aquifer above a gas field | 100 | Statoil |
| 2000 | Weyburn | Canada | Coal gasification plant (transport via a 350 km pipeline) | Depleted oil field (EOR) | 100 | Petroleum Technology Research Center (Canada) |
| 2004 | In Salkh | Algeria | Natural gas production | Gas field | 120 | Sonatrack、BP、Statoil |
| 2007 | Snovit | Norway | LNG plant | Aquifer | 70 | Statoil |
| 2008 | Gorgon | Australia | Natural gas production | Aquifer | 500 | Chebron、Exxon Mobil、Shell |
| 2010 | Draugen | Norway | Natural gas-fired power plant, methanol plant | Depleted oil field (EOR) | 250 | Shell、Statoil |
| 2010 | Miller-Peterhead DF1 | U.K. | Hydrogen combustion turbine | Depleted oil field (EOR) | 180 | BP、ConocoPhilips Shell、Scottish and Southern Energy |
| 2011 | Carrson DF2 | U.S. | Oil pitch-based IGCC | Depleted oil field (EOR) | 400 | BP、Edison Mission Group |

Source : IPCC, IPCC Special Report Carbon Dioxide Capture and Storage and RITE, $CO_2$ Storage Technology (2006)

### 5-2-2 Details of Major Projects

1) Sleipner (Norway)

This project, which captures $CO_2$ emitted from natural gas production facilities, has stored one million tons of $CO_2$ annually since 1996. It has now grown into a major international CCS project, and the storage status is being monitored. Until now, no leakage of $CO_2$ has been observed. This project is expected to contribute to the accumulation of experiences and know-how useful for addressing the key issues for future commercialization of CCS, including storage safety and monitoring method.

**Fig. 5-2 Location of the Sleipner Project**


Source : IEA, Natural Gas Information 2006

2) Weyburn Project (Canada)

This project separates $CO_2$ from a synthesis gas plant in the U.S. state of North Dakota and transports it through a 350 km pipeline for injection into an oil field in the Canadian province of Saskatchewan for the purpose of enhanced oil recovery. Since 2001, 5,000 t-$CO_2$ of $CO_2$ per day has been injected. At this oil field, which was discovered in 1955, a total of 335 million barrels of crude oil have been recovered, and the injection of $CO_2$ is expected to lead to an additional production of at least 122 million barrels. About half of the injected $CO_2$ is recovered along with oil for reuse, with the other half sequestered underground. Stored $CO_2$ is being monitored through international cooperation.

**Fig. 5-3 Location of the Weyburn Project**


Source : IEA, Natural Gas Information 2006

### 5-2-3 Individual Countries' CCS Policies

1) United States

The Department of Energy has announced a carbon-sequestering technology roadmap for technology development in the period leading up to 2012. In 2003, the Carbon Sequestering Leadership Forum was established under the U.S. leadership for international exchanges of information. In the same year, President Bush announced a budget allocation of $1 billion for the construction of a zero-emission coal gasification power plant under the FutureGen project.

2) EU

With a view to achieving zero emission for thermal power plants using fossil fuels by 2020, the European Commission is conducting a study on the reduction of the $CO_2$ separation and capturing cost and the stability and reliability of $CO_2$ storage, and drawing up a map of potential $CO_2$ storage sites while seeking to improve the efficiency of thermal power plants. Moreover, new thermal power plants are expected to be required to be installed with CCS equipment.

3) Japan

Research and development are underway under the leadership of the Research Institute of Innovative Technology for the Earth (RITE). In 2005, the government drew up the Technology Strategy Map for $CO_2$ Fixation, which set forth a roadmap toward the establishment of underground storage technology by 2015. In 2006, the global environment subcommittee of the environmental committee under the Industrial Structure Council announced CCS 2020, Japan's first policy paper on CCS. CCS 2020 estimated the potential underground storage capacity at 5.2 billion tons, forecast that the potential volume of $CO_2$ storage in aquifers would increase after further exploration and recommended that efforts be made to further reduce the CCS cost in Japan, which ranges from ¥5,000/t-$CO_2$ to more than ¥10,000/t-$CO_2$.

4) International Framework

The 1996 guidelines set by the Intergovernmental Panel on Climate Change (IPCC), for which the Kyoto Protocol serves as the basis, does not recognize the use of CCS as a $CO_2$ reduction measure. At the First Session Conference of the Parties Serving as the Meeting of the Parties to the Kyoto Protocol, issues related to CCS were debated, and project boundaries, leakage and permanence were recognized as major issues. Currently, debate is ongoing as to whether or not CCS should be recognized as a Clean Development Mechanism (CDM), with a conclusion expected to be reached by the end of 2009. Canada has drawn up the $CO_2$ Capture & Storage Technology Roadmap (CCSTRM), while Australia has announced a CCS technology development roadmap for the next 30 years.

## 5-3 Current Status and Outlook of CCS in Japan

### 5-3-1 Potential Storage Capacity

In a report written by RITE, geological strata are classified according to their geological features into Category A (storage in anticline) and Category B (storage in geological structures with a stratigraphic trap). Table 5-2 indicates the potential storage capacity in Japan estimated for each category. This report shows not only the potential storage capacity in the whole of Japan but also the estimated nationwide distribution of the storage capacity. The estimate of the distribution is based on the following premises:

- Potential storage reservoirs should be located near areas where medium-size or large emission sources are concentrated.
- Potential storage reservoirs should be located where sedimentary rocks formed in the Tertiary and Quarternary periods are distributed.
- Geological strata comprised of layers of mudstone and siltstone on top of a thick layer of sand should be identified as candidates for storage reservoirs.
- The side boundary of the storage reservoir should meet either of the following conditions:

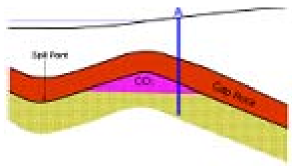
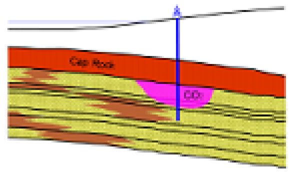
*Has a geological structure suited for tratigraphic trap;

*Constitutes a boundary at less than 800 meters underground and at less than 200 meters under water; and

*Constitutes a clear fault zone.

➢ The storage capacity should be calculated in volume terms based on the volume of the identified storage reservoirs and according to various parameters.

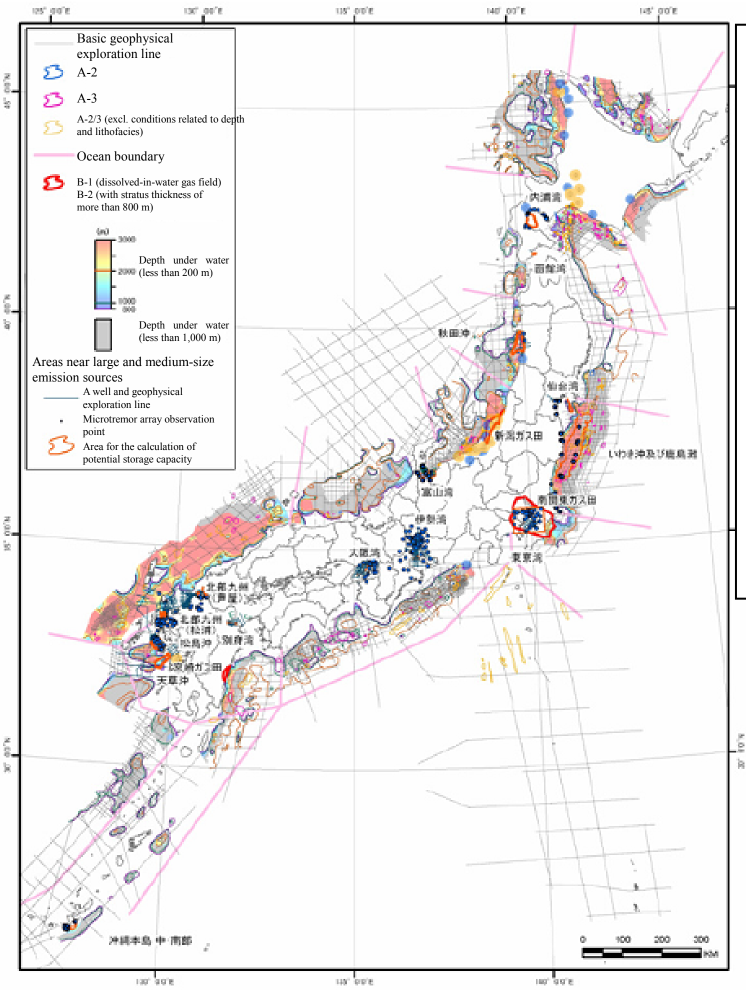
**Table 5-2 CCS Potential in Japan**

| Geological data | | Category A (Storage in an anticline structure) | Category B (Storage in a structure with a stratigraphic trap) |
|---|---|---|---|
| Oil and gas field | Rich data on wells and seismic exploration available | A1<br>3.5 billion t-$CO_2$ | B1<br>27.5 billion t-$CO_2$ |
| Basic test boring | Data on wells and seismic exploration available | A2<br>5.2 billion t-$CO_2$ | |
| Basic geophysical exploration | No data on wells, data on seismic exploration available | A3<br>21.4 billion t-$CO_2$ | B2<br>88.5 billion t-$CO_2$ |
| Concept image of storage | | Well<br> | Well<br> |
| Total | | 30.1 billion t-$CO_2$ | 116 billion t-$CO_2$ |
| Grand total | | 146.1 billion t-$CO_2$ | |

*Inland-area valleys and inland bays (e.g., Seto Inland Sea, Osaka Bay and Ise Bay) are not included.
*Geological strata eligible for CCS are those more than 800 meters underground and those less than 400 meters under water

Source : RITE, "Report on Results of Research and Development of Underground Storage Technology for Carbon Dioxide, 2007"

**Fig. 5-4 Distribution of Storage Reservoirs in Japan**




Major large storage reservoir candidate sites

Onshore
Yoshii-Higashikashiwazaki gas field: 0.8 billion t-$CO_2$
Nagaoka-Katagai coal-bed gas field: 0.21 billion t-$CO_2$

Offshore
Off Kashima-Soma: 6.97 billion t-$CO_2$

Onshore dissolved-in-water gas field
Southern Kanto gas field: 22.68 billion t-$CO_2$

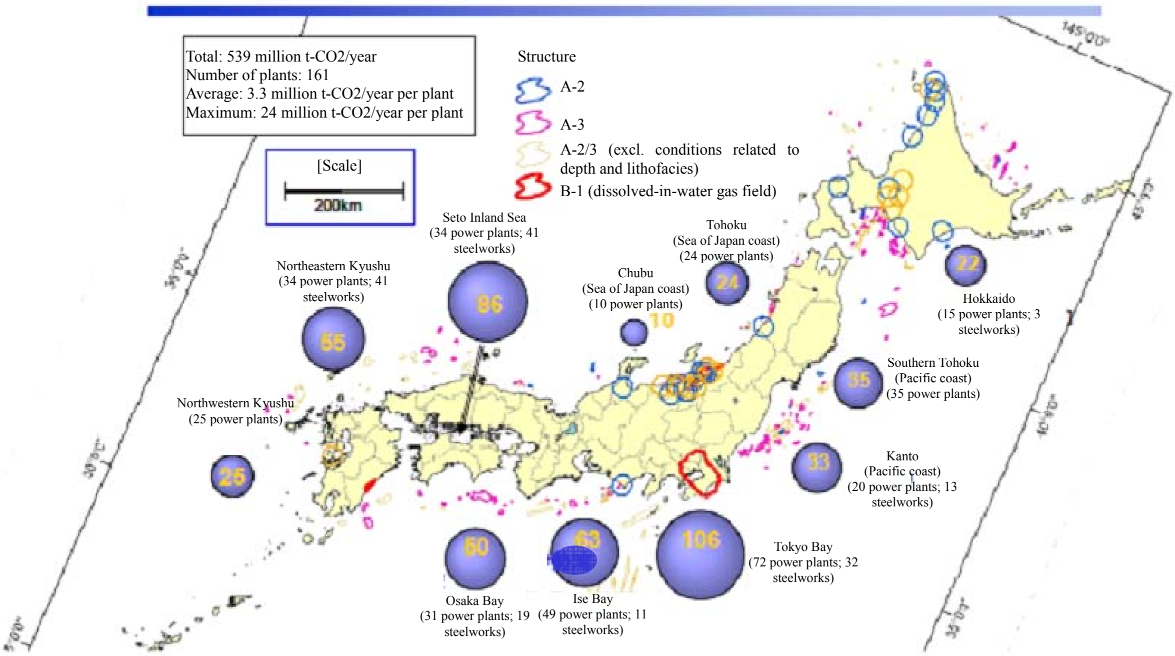
The total potential is estimated at 146.1 billion t-$CO_2$.
(Another organization estimates the total potential at 1.5 billion t-$CO_2$.)

Source : RITE, "Report on Results of Research and Development of Underground Storage Technology for Carbon, 2007"

We herein show the distribution of coal-fired thermal power plants, steelworks and cement plants as large $CO_2$ emission sources where CCS is expected to be introduced. As shown in Fig. 5-5, large $CO_2$ emission sources are distributed mainly in industrial zones in coastal regions. In the Kanto region, regarded as the largest emission source region, nearly 100 million tons of $CO_2$ are emitted annually.

In order to assess the total potential storage capacity in Japan, it is necessary to match each $CO_2$ emission source with a storage reservoir. For example, the Category A storage reservoirs closest to the Kanto region are located off Hamamatsu in Shizuoka Prefecture and off Miyagi, which means that 100 km to 200 km of transportation will be necessary to store $CO_2$ emitted in the Kanto region in a Category A storage reservoir.

**Fig. 5-5　Distribution of Large $CO_2$ Emission Sources and Storage Reservoirs**




Source : RITE, "Report on Results of Research and Development of Underground Storage Technology for Carbon, 2007"

### 5-3-2　Current CCS Cost

RITE is implementing model projects to assess the CCS cost in Hokkaido and Niigata.

**Table 5-3　Storage Costs (Hokkaido)**

| | From C steelworks to Tomakomai | From F steelworks to Tomakomai | From D steelworks to Tomakomai | From A thermal plant to the seas off Mukawa | From 3 emission sources to 2 injection sites | Unit |
|---|---|---|---|---|---|---|
| Storage volume | 100 | 100 | 100 | 100 | 234 | 10,000 t-CO2/year |
| Separation & capturing | 4,170 | 4,140 | 3,130 | 4,120 | 4,000 | ¥/t-CO2 |
| Pressurizing | 1,710 | 1,390 | 1,840 | 1,640 | 1,810 | |
| Transport | 2,760 | 820 | 590 | 220 | 1,410 | |
| Injection | 1,360 | 1,340 | 2,130 | 1,100 | 1,240 | |
| Total | 10,000 | 7,700 | 7,680 | 7,080 | 8,460 | |

Note : The price unit is ¥/t-$CO_2$
Source : RITE, "Report on Results of Research and Development of Underground Storage Technology for Carbon, 2007"

We herein show the concept of practical use of CCS by describing seven systems, including a steelworks and a thermal power plant. Table 5-3 shows the cost of each system in the model projects.

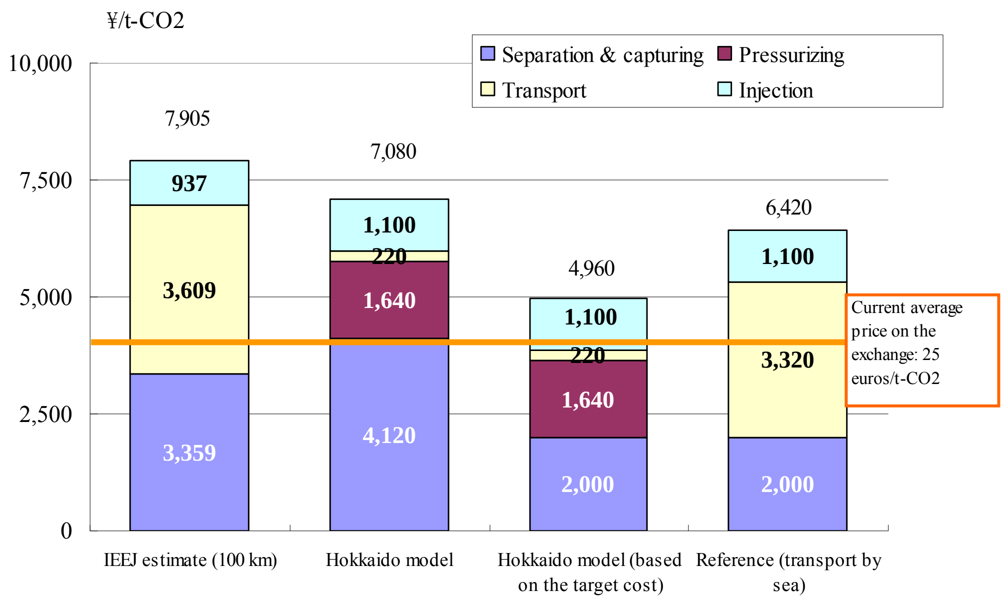
The model analysis results indicate that it is very important to select the combination of a $CO_2$ separation and capturing site and a $CO_2$ injection site so as to minimize the transportation distance, because transportation using a pipeline is costly in Japan. Meanwhile, as the separation and capturing cost accounts for a significant portion of the total cost, it will be necessary to maintain a high utilization ratio of $CO_2$ generation equipment and reduce the cost through technology development.

We compared the cost estimated on the assumption of 100 km of transportation and a storage volume of one million t-$CO_2$/year, the cost indicated by a model project and the estimated cost in a case where assumptions of the model project were altered. As a result, we found that the CCS cost in Japan is higher than the emission credit price on the European Climate Exchange (ECX).

The assumptions of the estimated costs used in the above cost comparison are as follows:

- Estimate by the Institute of Energy Economics, Japan (100km) : 100 km of pipeline transportation
- Hokkaido model : 8.4 km of pipeline transportation
- Hokkaido model (based on the target cost) : The separation and capturing cost is reduced to the government's target of ¥2,000/t-$CO_2$.
- Reference (transportation by sea) : The terms of transportation in the above target cost-based model is changed to 1,000 km of transportation by sea.

**Fig. 5-6 Comparison of CCS Storage Costs**



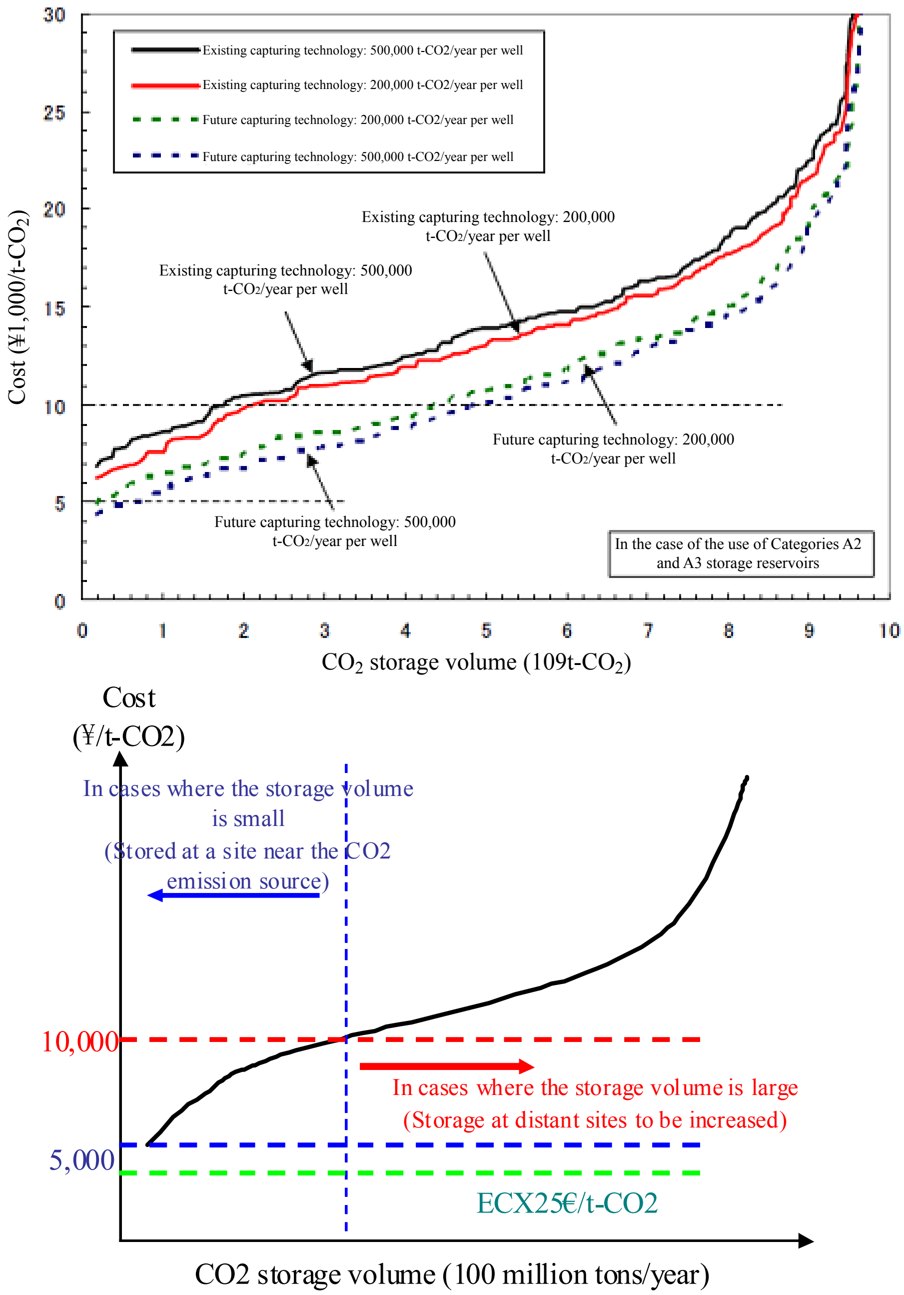

Note : Regarding the IEEJ estimate for a 100 kilometer pipeline transport and the reference case (transport by sea), the pressurizing cost is included in the transport cost

Source : RITE, "Report on Results of Research and Development of Underground Storage Technology for Carbon, 2007" and other materials

RITE estimated the CCS cost by taking into consideration the matching of emission sources and storage reservoirs across Japan. The process of the estimation is as follows:

We calculated the travel distance between each $CO_2$ emission source and storage reservoir by identifying the shortest route between them on the basis of such data as the location of the emission source, the annual emission volume and the location, depth and capacity of the storage reservoir on the assumption that the two sites will be linked through an underground pipeline built along roads. We also developed a model for minimizing the cost of transporting $CO_2$ from the emission source to the storage reservoir and injecting $CO_2$ and identified the cost and storage potential curves. Then, we calculated the transportation and injection costs for each pair of emission source and storage reservoir. The costs are calculated for each of the separation, capturing, pressurizing, transportation and injection processes and expressed as functions of the annual $CO_2$ processing volume. The volume of $CO_2$ emitted in each process is also expressed as a function of the annual $CO_2$ processing volume. Through these calculation processes, we eventually arrived at the CCS avoided cost. The results of the calculation are as shown in Fig. 5-7.

**Fig. 5-7　CCS Cost Curve (up : RITE estimate; down : concept graph)**




Source : RITE, "Report on Results of Research and Development of Underground Storage Technology for Carbon, 2007" and other materials

Consequently, the $CO_2$ reduction cost is expected to exceed ¥10,000/t-$CO_2$ if the storage volume surpasses around 90 million t-$CO_2$ /year. The cost is expected to be roughly halved through technology development. The emission credit price on the ECX in 2004 to 2008, cited as a reference, is about 25 euros/t-$CO_2$ or about ¥4,000/t-$CO_2$.

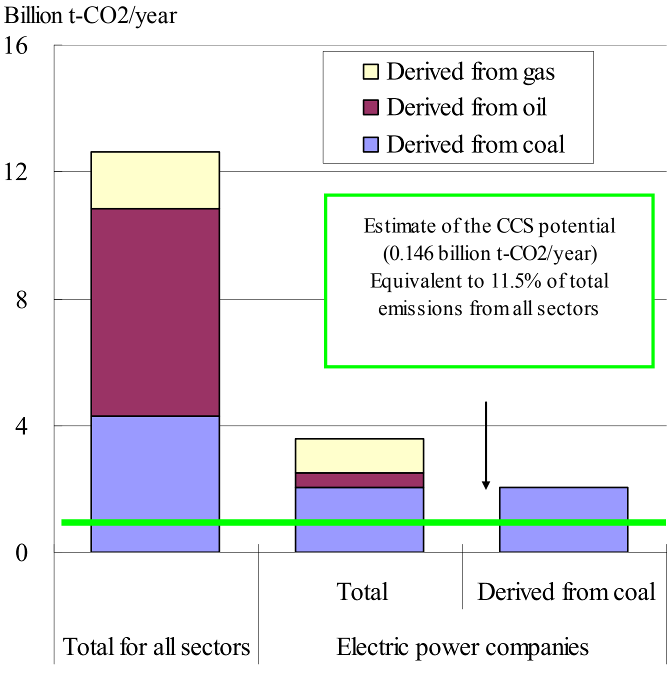
In light of the above, the separation and capturing cost accounts for most of the $CO_2$ storage cost, making it essential to reduce the separation and capturing cost and ensure an optimal matching of emission sources and storage reservoirs. In addition, the cost of $CO_2$ reduction made through CCS in Japan is apparently higher than the cost in Europe.

### 5-3-3 Future Outlook

We estimated a feasible potential CCS capacity based on the viable storage ratio for each category of geological strata that was assumed on the basis of RITE's category-wise storage potential. We assumed a storage period of 100 years, although there is no firm international consensus on the storage period.

Based on the above assumptions, the CCS potential is estimated at approximately 150 million t-$CO_2$/year (equivalent to around 10% of the total potential of 146.1 billion t-$CO_2$). This is equivalent to around 80% of $CO_2$ emitted by electric power companies in fiscal 2006 and around 11.5% of $CO_2$ emitted by all sectors.

**Fig. 5-8 $CO_2$ Emission Volume and the Estimate CCS Potential in Japan**




Calculation method
*To set an assumed ratio of viable storage to the potential storage capacity for each category as defined by RITE.

(A1: 80%, A2: 50%, A3: 30%, B1: 10%, B2: 0%)

*Storage period
The storage-monitoring period is assumed to be 100 years.

Source : Institute of Energy Economics Japan, Handbook of Energy and Economic Statistics

## 5-4 Status and Outlook of CCS Worldwide

### 5-4-1 Potential Storage Capacity

Several organizations, including the IPCC, have announced estimates of the global $CO_2$ storage potential. Geologically, the storage potential is estimated at approximately 10 trillion t-$CO_2$, enough to store 350 years' worth of global $CO_2$ emissions. Existing depleted gas fields, for which there are abundant test drilling data, are estimated to have a potential storage capacity for around 30 years' worth of emissions. To increase the potential for a greater capacity, it will be necessary to develop deep saline strata and aquifers as storage reservoirs. Such geological strata involve several unknowns, as there is not much drilling data on them.

**Table 5-4 Global CCS Storage Potential**

Gt-CO2

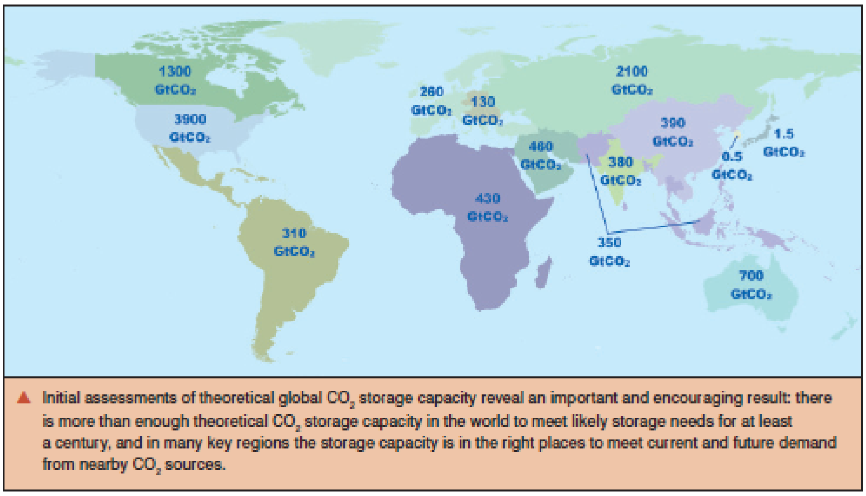
| Geographic strata | GTSP | | IPCC | |
|---|---|---|---|---|
| | Geographical capacity | Capacity in U.S. | Estimate High case | Estimate Low case |
| Deep saline strata | 9,500 | 3,630 | Uncertain, but possibly $10^4$ | 1,000 |
| Depleted gas field | 700 | 35 | 900 | 675 |
| Depleted oil field | 120 | 12 | | |
| Unrecoverable coal bed | 140 | 30 | 200 | 3-15 |
| Deep halite strata, basaltic strata | Unknown | 240 | - | - |
| Others | Unknown | Unknown | - | - |

Note : "Deep saline strata" refers to strata that are surrounded by sandstone and saline carbonate rocks (limestone and dolomite) formed in a sediment-filled valley and that contain sea water.
Source : GTSP, "Carbon Dioxide Capture and Geologic Storage,"and IPCC, "IPCC Special Report Carbon Dioxide Capture and Storage"

Unknowns related to Aquifers

- There are various storage methods, including physically trapping $CO_2$ under cap rocks, chemical dissolution and mineralization.
- There may be a gap between the initially estimated storage capacity and the actual capacity.

**Fig. 5-9 Distribution of Storage Potential (GTSP)**




Source : GTSP, "Carbon Dioxide Capture and Geologic Storage"

- Problems may arise from the reaction between dissolved $CO_2$ and the surrounding minerals.
- There is no consistent method for assessing capacity.
- Available geological data on deep saline strata and aquifers are limited compared with data on oil fields.

The IPCC assessed the distribution of storage reservoirs from the geological viewpoint, and decided to focus attention on sediment-filled valleys suited for the formation of geological strata that may contain oil, gas and coal reserves as potential storage sites. Among regions regarded as having large storage potential are the Middle East, the North Sea, the Ural region, the United States and Canada, where there are many sediment-filled valleys, suited for the formation of the anticline structure, and gas and oil fields.

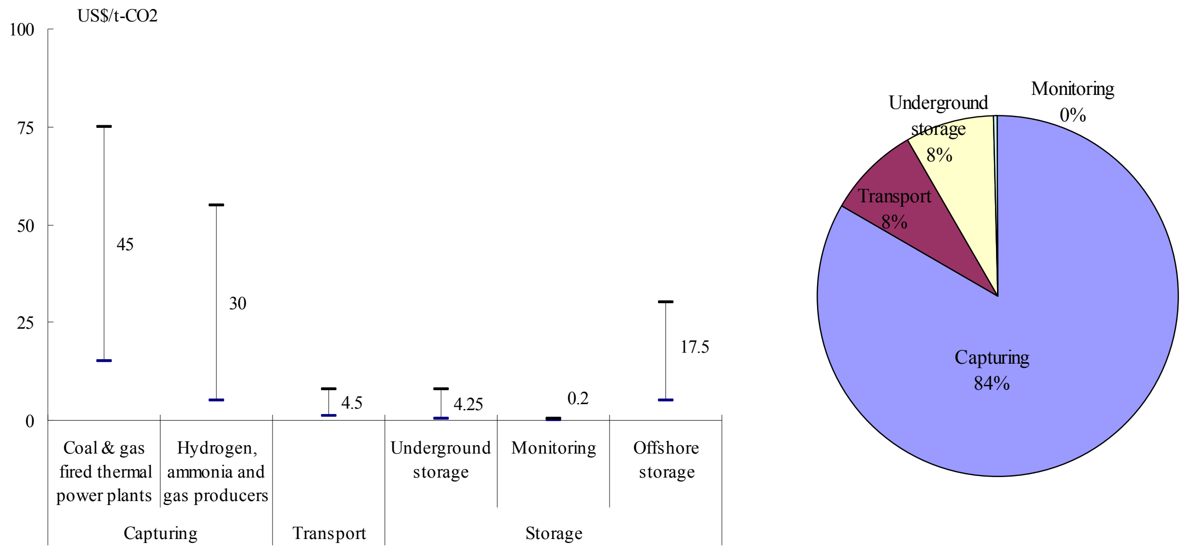
The Global Energy Technology Strategy Program (GTSP) estimated detailed, region-by-region storage potential. According to this estimate, regions rich in oil and gas, not to mention countries with a vast geographic area, have a large storage potential.

The estimated storage potential of major countries are as follows: 3,900Gt-$CO_2$ for the United States, 2,100Gt-$CO_2$ for Russia, 1,300Gt-$CO_2$ for Canada, 390Gt-$CO_2$ for China, 460Gt-$CO_2$ for the Middle East, 380Gt-$CO_2$ for India and 1.5Gt-$CO_2$ for Japan. Low-cost storage is expected in the United States in particular, as 95% of all large emission sources in the country are located within 50 miles of possible storage reservoirs.

### 5-4-2 Current CCS Cost

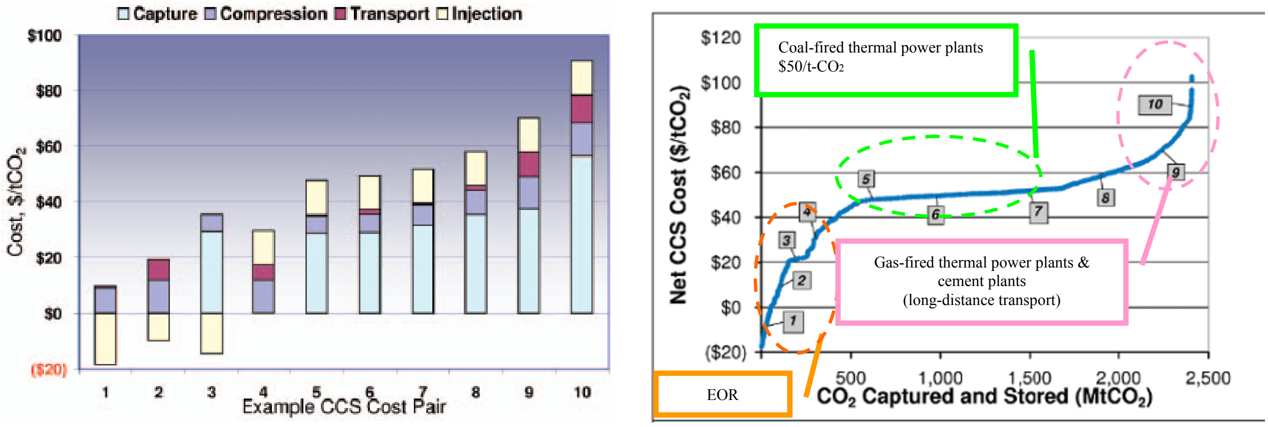
The CCS cost of coal-fired thermal power generation estimated by the IPCC ranges from \$17 to \$19/t-$CO_2$. The capturing cost accounts for most of the total cost. The transportation cost estimated by the IPCC is relatively low, compared with RITE's estimate. This is because the pipeline cost in Japan is high while the pipeline construction cost assumed in the IPCC's estimate is relatively low.

**Fig. 5-10 Cost Estimate by IPCC**
**(left : cost estimate; right : breakdown of the cost [median figures])**




Source : IPCC, "IPCC Special Report Carbon Dioxide Capture and Storage"

**Fig. 5-11 Cost Estimate by GTSP (left : cost by process; right : cost curve)**




Note : "5" and "6" represent the estimated costs for thermal power plants and "1" and "2" reflect the estimated revenue from oil and gas recovered through EOR.
Source : GTSP, "Carbon Dioxide Capture and Geologic Storage"

Regarding the CCS cost estimated by the GTSP, the assumed transportation cost is very different from the one used in RITE's estimate. The capturing cost is around \$30/t-$CO_2$ and the transportation and injection cost is \$15/t-$CO_2$. Whether EOR is possible or not is also the key to estimating the CCS cost.

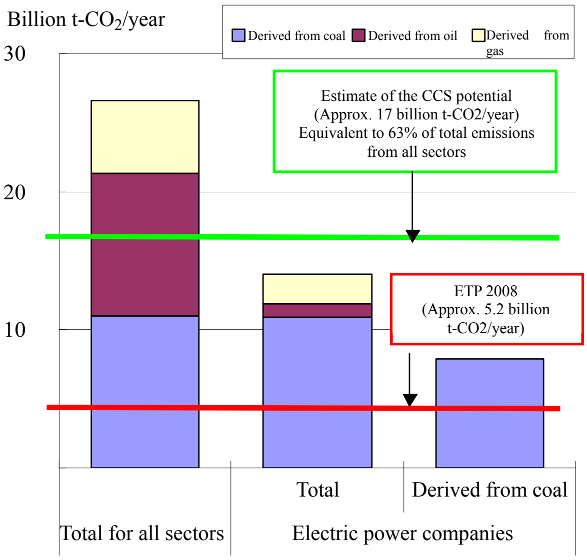
### 5-4-3 Outlook for the Future

We estimated the CCS storage potential based on a viable storage ratio calculated on the basis of the assumptions used by the IPCC and the GTSP.

The overall storage potential, mainly the potential of depleted oil fields, gas fields and coal mines, which are expected to have highly viable storage potential, is estimated at approximately 5 to 7 billion Gt-$CO_2$/year (equivalent to 19% to 26% of the global $CO_2$ emission volume in 2005, which stood at 26.5 billion t-$CO_2$). The use of deep saline strata and aquifers is expected to help expand the storage potential. If deep saline strata and aquifers are included in the estimate, the CCS potential is estimated at approximately 12 billion t-$CO_2$/year based on the above assumptions. However, it is important to remember that deep saline strata and aquifers involve some geological problems.

The ETP 2008 report estimates that the storage volume in 2050 will stand at around 5.2 billion t-$CO_2$/year (of which the power-generation sector will account for 3.5 billion t-$CO_2$) if an incentive of \$50/t-$CO_2$ is provided. Under the BLUE Map scenario of the ETP 2008 report, the overall storage volume in 2050 is estimated at 10.4 billion t-$CO_2$ and the storage volume in the power-generation sector at 5.6 billion t-$CO_2$. The ETP characterizes these estimates as "very challenging."

**Fig. 5-12 Global $CO_2$ Emission Volume and Estimated Global CCS Potential**




Calculation method

*To set an assumed viable storage ratio by using data compiled by the IPCC and the GTSP as a reference.

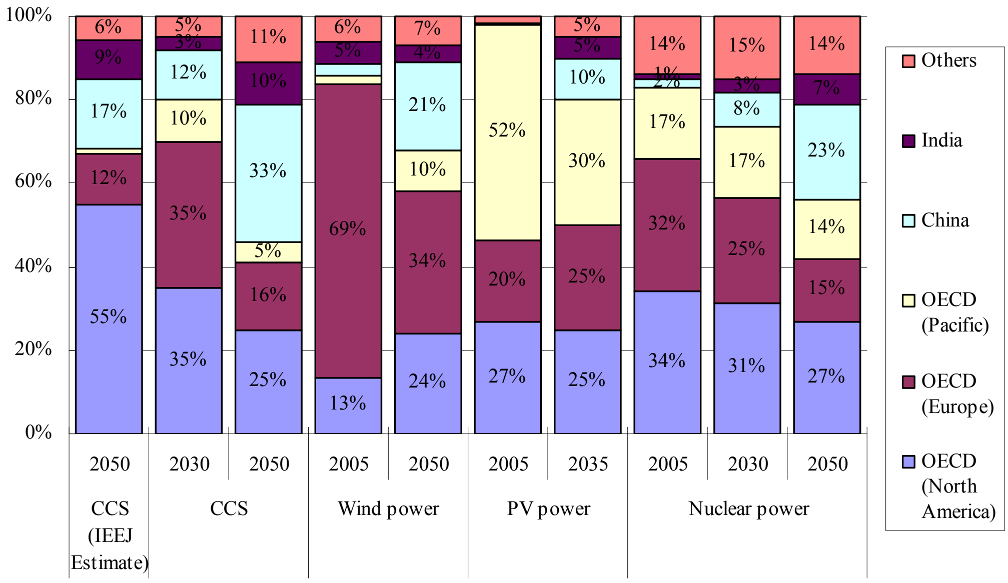
*(Depleted gas field: 80%; depleted oil field: 80%; coal bed: 50%; deep saline strata & aquifer: 10%)

*Storage period
The storage-monitoring period is assumed to be 100 years.

Note : 1Gt-$CO_2$=1 billion t-$CO_2$
Source : IEA, "World Energy Outlook 2007," "Energy Technology Perspectives 2008" and other materials

The global storage volume is estimated at around 3.6 billion t-$CO_2$ (equivalent to 32% of the total emission volume of the power-generation sector, which came to around 10.9 billion t-$CO_2$) based on the figures for 2005 and the above assumptions. Based on the estimated figures for 2050 and the above assumptions, the global storage volume is estimated at around 5.7 billion t-$CO_2$/year (equivalent to 24% of the power-generation sector, estimated at 23.7 billion t-$CO_2$).

**Fig. 5-13 Technology Deployment Share by Region**




Note : The regional geographic categories used in the calculation of the IEEJ estimate are the United States, Europe, Japan, China, India and others.
Source : IEA, "Energy Technology Perspectives 2008"

On a country-by-country basis, the United States will account for 55% of the global storage volume. According to an estimate of region-by-region deployment of new technologies in the ETP 2008 report, the U.S. share is estimated at 25% and the Chinese share at 33%. Although China's CCS potential as evaluated by the GTSP is not very high, the country is expected to have the largest $CO_2$ storage capacity according to the ETP 2008. More precise geological surveys and analysis should be conducted with regard to the $CO_2$ storage potential of China and Russia, whose vast geographic area requires thorough investigations.

## 5-5 Conclusion

$CO_2$ storage demonstration tests that are under way in many regions preparing for commercialization are expected to contribute to the accumulation of necessary management experiences and know-how. As uncertainties remain over the estimates of the global $CO_2$ storage potential, a further advance in geological surveys and analysis is necessary. Therefore, it is difficult to provide a clear, viable estimate of the potential at the moment. As for the CCS cost, the $CO_2$ separation and capturing cost is similar around the world, and continuous technology development is expected to reduce the cost. It is impossible to assess the transportation cost and the injection cost with a universal yardstick, as these costs are affected by local circumstances such as the depth of storage reservoirs, geological conditions and the distance between the emission source and the storage site. Depending on the circumstances, economic incentive may arise if CCS is used in combination with EOR. External factors that may affect the deployment of CCS include carbon price and the trend of carbon-free power sources, such as nuclear power and renewable energy.

There are presumably few technological obstacles to the deployment of CCS. However, if CCS is to be commercialized on a large scale, cost factors and public acceptability issues, such as whether underground storage of $CO_2$ is appropriate in the first place, could emerge as a challenge. Below, we will describe challenges and prospects for CCS in Japan and worldwide.

**Japan**

- High hopes are pinned on aquifers as storage reservoirs with a high potential. Detailed geological surveys and analysis will need to be conducted.
- The separation and capturing cost should be reduced continuously through technology development.
- As the transportation cost is high, the proximity of $CO_2$ emission sources to storage sites is important.

**Worldwide**

- Although the overall storage potential is vast if deep saline strata and aquifers are included, a close examination is necessary to assess their viability as practical-use actual storage reservoirs.
- If further efforts are made to reduce the capturing cost, it may become possible to store $CO_2$ through CCS at a $CO_2$ reduction cost as low as \$50/t-$CO_2$.

**Future Challenges**

- ◆ It is essential to reduce the energy input necessary for capturing $CO_2$ (equivalent to 20% to 40% of the power-generation volume) and the $CO_2$ capturing cost.
- ◆ How will CCS be characterized under the international framework for $CO_2$ reduction efforts? (Will it be recognized as a CDM and how long should $CO_2$ be stored?)
- ◆ What will a universal legal framework be like? (How long will such a framework require stored $CO_2$ to be monitored?)
- ◆ Will an international carbon market be established?

# 6. Supply Capacity, LCA Assessment and Cost Efficiency

## 6-1 Supply Capacity

### 6-1-1 Supply Potential of Nuclear Power and Renewable Energy

If electric vehicles are to be deployed on a large scale (on the premise of the selection of a low $CO_2$ emission power source), power sources for electric vehicles need to meet these conditions: (i) the supply potential of the source must be sufficient, (ii) the distribution of the source should not be uneven and (iii) stable and sustained supply should be possible. Sources that meet these conditions include renewable energy (see Chapter 3), nuclear power (see Chapter 4) and CCS-capable thermal power (see Chapter 5).

As for renewable energy, wind power and photovoltaic power meet these conditions. However, biomass power and geothermal power are unevenly distributed, and hydroelectric power, although it has a high potential, is expected to have little surplus supply capacity as an additional power source for automotive applications given its importance as a power source for existing needs. Regarding CCS-capable thermal power (particularly coal-fired thermal power), there are geographical constraints, as $CO_2$ storage sites are not evenly distributed and the storage capacity is limited, making it difficult to expect a large amount of power supply for automotive applications. Meanwhile, although the plant construction capacity constitutes a bottleneck for nuclear power, this problem can be resolved in the medium to long term.

In light of the above, renewable energy, including wind power and photovoltaic power, and nuclear power are expected to serve as additional power sources for automotive applications. Table 6-1 shows the maximum supply capacity (the potential capacity) that was mentioned in Chapters 3 and 4. This table also includes the estimated power-generation volumes based on a quantitative analysis model developed by the Institute of Energy Economics, Japan.

The combined maximum supply capacity (potential capacity) of nuclear power and renewable energy (wind and photovoltaic power) that may be attained around 2050 is estimated at 15.3 trillion kWh/year, including 6.1 trillion kWh/year (baseline case) for nuclear power, 5.2 trillion kWh/year for wind power and 4.0 trillion kWh/year for photovoltaic power. However, it should be noted that this estimate assumes that the power-generation cost of photovoltaic power will decline to ¥7/kWh from ¥30/kWh and that nuclear power-related problems like the construction capacity bottleneck will be resolved.

**Table 6-1 Supply Capacity of Nuclear Power and Renewable Energy**

| | Maximum possible supply capacity (2050) | | Estimate for 2050 (IEEJ reference estimate) | |
|---|---|---|---|---|
| | Installed capacity (billion kW) | Generation volume (billion kWh/year) | Installed capacity (billion kW) | Generation volume (billion kWh/year) |
| Nuclear | 0.87 | 6,100 | 0.54 | 3,809 |
| Wind | 2.95 | 5,174 | 1.77 | 2,479 |
| PV | 3.84 | 400 | | |
| Total | 7.66 | 11,674.0 | 2.31 | 6,288 |

Note : The figures for nuclear power are those in the baseline case. The capacity utilization is 80% for nuclear power, 20% for wind power and 12% for PV power.
Source : Nuclear power : Estimates cited in Chapter 4
Wind and PV power : Estimates cited in Chapter 3

Some 6.3 trillion kWh/year (see Table 6-1) out of the total supply capacity of 15.3 trillion kWh/year in nuclear, wind and photovoltaic power is set to be supplied for non-automotive applications, leaving approximately 9.0 trillion kWh/year for supply for automotive applications. The 9.0 trillion kWh/year is the maximum supply capacity of power for use in electric vehicles.

### 6-1-2 Power Supply Capacity for Electric Vehicles

Table 6-2 shows the volume of power necessary to meet the power needs of electric vehicles on the assumption that an average electric vehicle travels about 10,000 km annually with a fuel economy of 110 Wh/km.

Assuming that passenger vehicles owned around the world total 2 billion units and that all of them will be replaced with electric vehicles, the volume of necessary power would expand to 2.2 trillion kWh/year at maximum. Table 6-1 shows the necessary volumes of power corresponding to the maximum supply capacity and the number of electric vehicles in use. This indicates that nuclear power, wind power and photovoltaic power each has a sufficient supply potential to meet the power needs of electric vehicles alone.

However, it is important to remember that the estimated figures are based on the crude assumptions of a capacity utilization ratio of 80% for nuclear power, 20% for wind power, 12% for photovoltaic power, and a 100% usage of electricity from these power sources for electric vehicles.

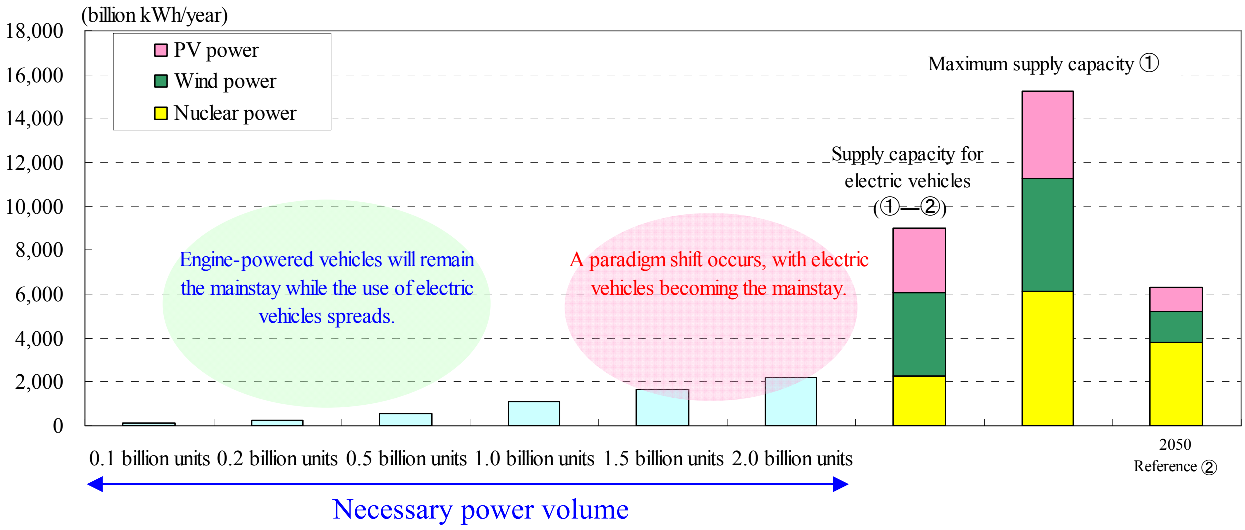
In practice, on the premise of a night-time recharging, only eight hours of power supply are used for electric vehicles in the case of nuclear power (as well as wind power), and in the case of photovoltaic power generation, electricity generated during the day is stored in a storage battery for recharging purposes. Therefore, in some cases, it will be possible to meet the power needs of electric vehicles with power from existing power sources, without using power from additional sources, by achieving efficient power supply management based on an optimal power source mix. This will reduce the necessary additional power supply capacity compared with the estimates calculated on the basis of the above assumptions. Moreover, as photovoltaic power and wind power are affected by weather conditions, power supply for electric vehicles is likely to come from a combination of these with nuclear or other power sources, rather than from these renewable energy sources alone.

**Table 6-2 Power Needs of Electric Vehicles**

| Passenger car | Million units | 100 | 200 | 500 | 1,000 |
|---|---|---|---|---|---|
| | Share (%) | 5% | 10% | 25% | 50% |
| Distance run | 1 billion km/year | 1,000 | 2,000 | 5,000 | 10,000 |
| Necessary power volume | 1 billion kWh/year | 110 | 220 | 550 | 1,100 |

Note: The assumptions are as follows :
Distance run per vehicle : approx. 10,000 km
Fuel economy : 110 Wh/km
Number of passenger cars owned worldwide : approx. 2 billion units
Global population : approx. 8 billion

**Fig. 6-1 Comparison of the Power Needs of Electric Vehicles and the Supply Capacity**




Note : The figures for nuclear power capacity are those in the baseline case, and the reference figure for 2050 (②) represent the power supply volume for non-automotive applications.

## 6-2 Life Cycle Assessment (LCA)

### 6-2-1 Definitions of Assessment of $CO_2$ Emissions (LCA Basis) and Power-generation Volume

The LCA assessment of power sources is classified into the assessment of upstream operations (drilling, production and transportation), the assessment of power plants (combustion and power generation) and the assessment of transmission and distribution networks (including transformer substations). The power-generation volume used in calculating the $CO_2$ emission volume per 1 kWh varies between the power generation end, the power transmission end, the demand end and the point of sales to users. (This is because of internal power consumption at power plants and transformer substations as well as power loss during transmission and distribution.) Although assessment is usually conducted at the power transmission end, this report also conducts assessment at the demand end, where electric vehicles are recharged. In Japan, the ratio of power lost during transmission and consumed at power plants for internal use to the power volume at the power generation end is around 9.9%.

Table 6-3 shows an international comparison of power-generation efficiency (by fuel type) and power loss during transmissions and at power plants.

**Table 6-3 International Comparison of Power Generation Efficiency (thermal power) and the Power Loss Ratio (2006)**

| | | Japan | U.S. | Europe | China | India | Worldwide |
|---|---|---|---|---|---|---|---|
| Ratio of power loss at plants and during transmission (%) | | 9.9 | 13.3 | 14.9 | 18.9 | 32.4 | 17.2 |
| Power generation efficiency (%) | Coal | 42.0 | 36.9 | 36.5 | 32.6 | 26.3 | 33.7 |
| | Oil | 46.1 | 35.4 | 38.7 | 34.2 | 30.8 | 35.8 |
| | Gas | 45.1 | 44.3 | 47.1 | 38.9 | 41.9 | 38.2 |
| | Thermal | 43.8 | 38.6 | 40.3 | 32.6 | 27.5 | 35.1 |

Source : Calculated based on IEA, Energy Balances (actual figures for 2006)
Power generation efficiency=heat efficiency

**Table 6-4 $CO_2$ Emission Volume by Power Source (LCA basis ; at the power transmission end)**

(g-CO2/kWh)

| | Oil | LNG | LNG combined | Coal | PV | Wind | Nuclear | Geothermal | Hydroelectric |
|---|---|---|---|---|---|---|---|---|---|
| Upstream sector | 45.1 | 108.9 | 94.4 | 78.1 | | | | | |
| Power generation sector | 738.5 | 522.9 | 423.2 | 903.2 | 10.1 | 8.3 | 18.5 | 9.7 | 1.9 |
| (combustion) | (738.3) | (488.3) | (405.8) | (873.8) | | | | | |
| Ash and waste disposal | | | | | | | | | |
| Total | 783.6 | 631.8 | 517.6 | 981.3 | | | | | |

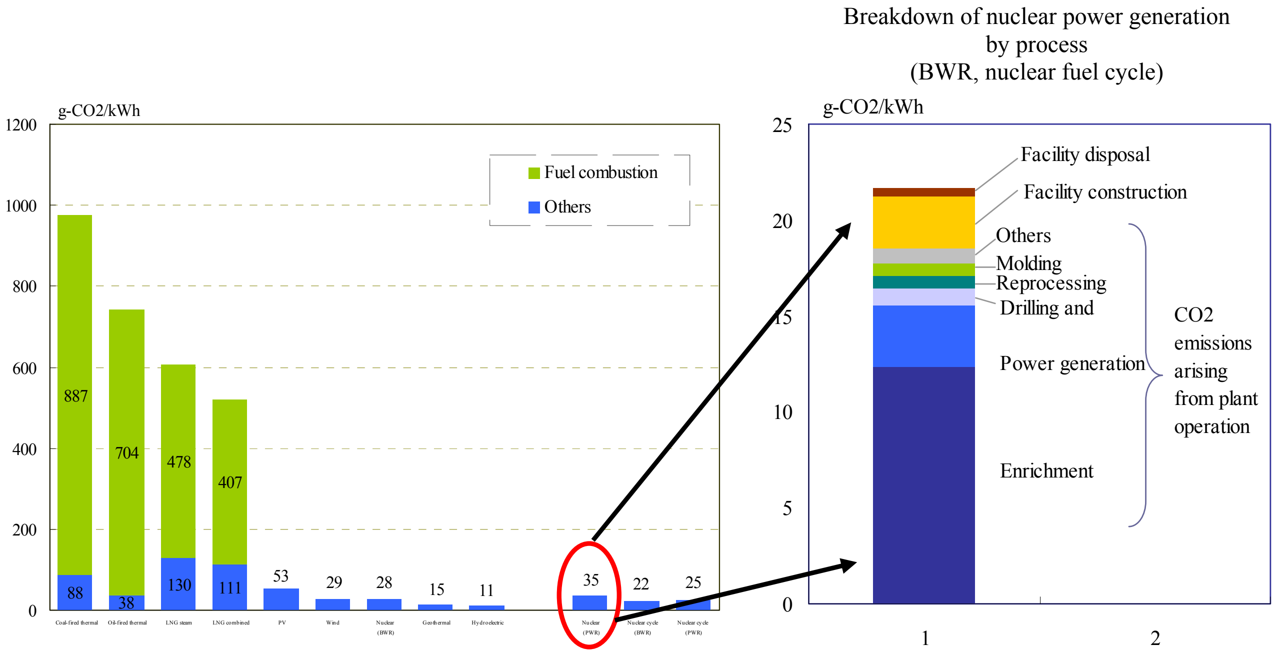
Note : $CO_2$ emissions resulting from input of energy for building construction and machinery production are excluded.
Source : Thermal power : Toyota Motor and Mizuho
Others : Estimated by the IEEJ based on data compiled by the Central Research Institute of Electric Power Industry

### 6-2-2 LCA Assessment by Power Source Type (in Japan's case)

Table 6-4 shows the $CO_2$ emission volume by type of power source (at the power transmission end in Japan) calculated on an LCA basis. The $CO_2$ emission volume per 1kWh (=3.6MJ) of power is 18.5g for nuclear power, 8.3g for wind power and 10.1g for photovoltaic power, all of which are less than around one-fiftieth of the emission volume for thermal power, which stands at between 517g to 981g.

Fig. 6-2 shows the LCA assessment of the $CO_2$ emission volume including emissions generated through input of energy for the construction and production of buildings and machinery. The emission volume per 1kWh of power at the power transmission end comes to 35g for nuclear power (pressurized water reactor), 29g for wind power and 53g for photovoltaic power.

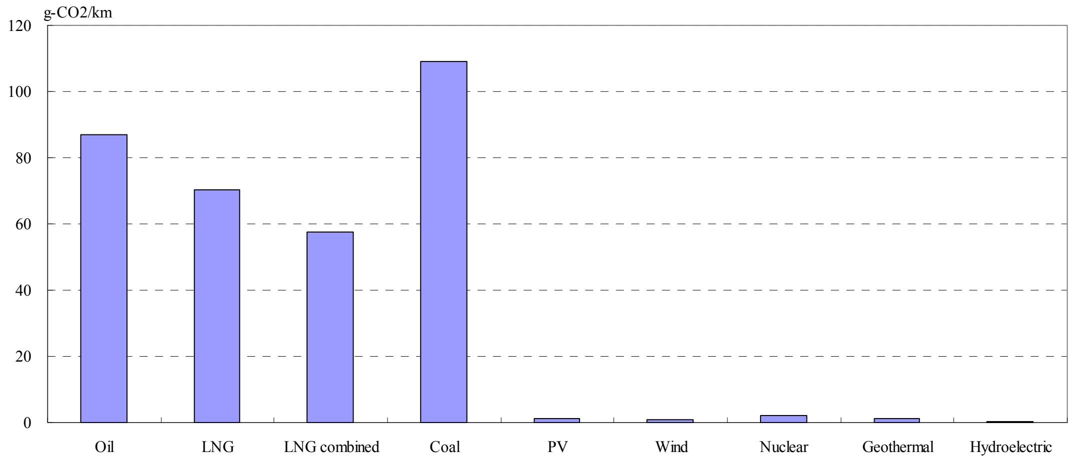
**Fig. 6-2 LCA Assessment of $CO_2$ Emissions by Power Source (at the power transmission end : emissions resulting from building construction and machinery production included)**




## 6-2-3 Comparison of $CO_2$ Emission Volume per 1 km of Distance Travelled by Power Source Type

Fig. 6-3 shows the $CO_2$ emission volume by power source type calculated on the basis of the $CO_2$ emission volume per 1 kWh of power for each type and an assumed fuel economy of 110 Wh/km. The power volume does not include power lost during transmission. The $CO_2$ emission volume comes to 2.1g for nuclear power, 1.0g for wind power and 1.1g for photovoltaic power, all of which are miniscule figures compared with 57.5g to 109g for thermal power.

**Fig. 6-3 $CO_2$ Emissions per 1 km of Distance Travelled by Power Source (at the transmission end)**




Note : Power loss during transmission is not included.

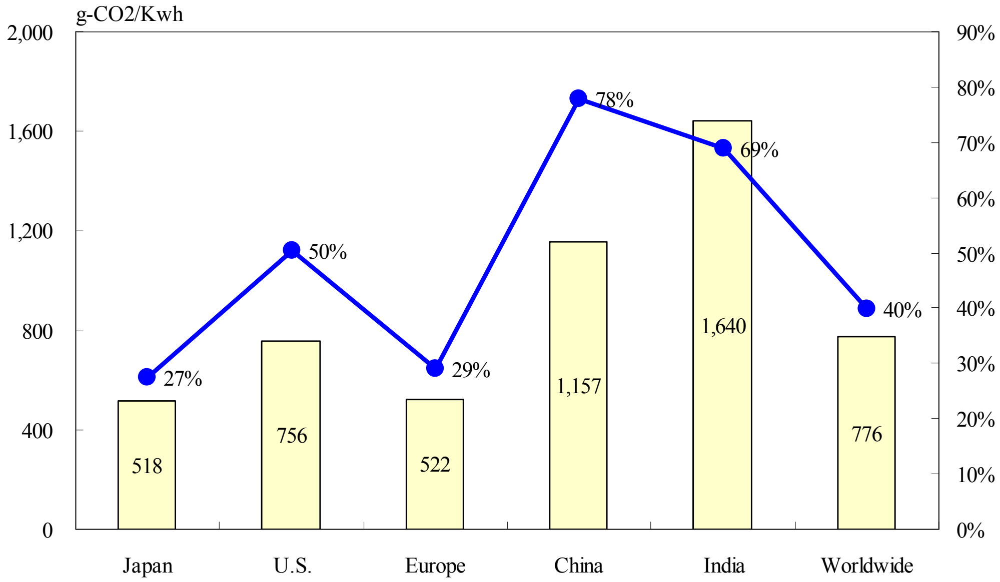
### 6-2-4 International Comparison of $CO_2$ Emission Volume Based on Power Source Mix (average)

Fig. 6-4 shows the $CO_2$ emission volume (at the demand end) on an LCA basis for individual countries calculated on the basis of country-by-country power-generation efficiency (by fuel type), the ratios of power loss at power plants and during transmission that are indicated in Table 6-3, and the assessment of $CO_2$ emissions by type of power source in Japan that are indicated in Table 6-4.

The $CO_2$ emission volume per 1kWh of power stands at 518g for Japan, 756g for the United States and 522g for Europe. The emission volume for China, at 1,157g, is more than double the amount for Japan, while the emission volume for India, at 1,640g, is more than triple that for Japan.

This is because coal-fired thermal power, which emits a large volume of $CO_2$, has a significant share in the power source mix of these countries: 78% in the case of China and 69% in the case of India. Moreover, as shown in Table 6-2 1, whereas the ratio of power lost at power plants and during transmission is around 10% in Japan, the ratio is 18.9% in China and 32.4% in India. In the future, the gap between developed and developing countries is expected to narrow as problems like power loss are resolved.

**Fig. 6-4 International Comparison of the $CO_2$ Emission Volume Calculated Based on the Power Source Mix (at the demand end)**




Note : $CO_2$ emission volume per 1 kWh of power at the demand end (excluding emissions arising from the use of heat)

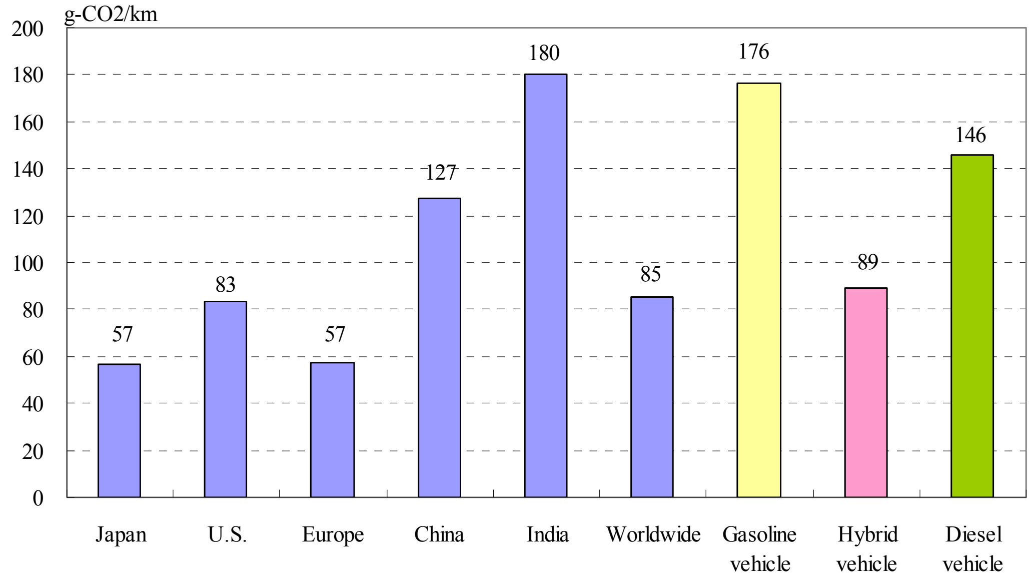
### 6-2-5 International Comparison of $CO_2$ Emission Volume per 1 km of Distance Travelled

Fig. 6-5 shows the $CO_2$ emission volume (at the demand end) per 1 km of distance travelled by an electric vehicle, calculated by multiplying the $CO_2$ emission volume (at the demand end) per 1 kWh of power indicated in Fig. 6-4 with the fuel economy indicated in Table 1-3.

In Japan and Europe, the $CO_2$ emission volume per 1 km of distance travelled comes to around 57g for electric vehicles, much lower than 176g for gasoline vehicles and 94g for hybrid vehicles. In China, the $CO_2$ emission volume per 1 km of distance travelled comes to around 127g for an electric vehicle, higher than 127g for hybrid vehicles, while in India, the emission volume stands at 180g for electric vehicles, higher than the emission volume for both gasoline-powered and hybrid vehicles.

It is important to remember that as shown above, the deployment of electric vehicles could increase $CO_2$ emissions in some cases, particularly in developing countries, on the premise of the existing power source mix. In the medium to long term, the deployment of electric vehicles is expected to reduce $CO_2$ emissions in developing countries, too, due to improvement in power efficiency and the power loss ratio as well as changes in the power mix (e.g., reduction in the share of coal-fired thermal power).

**Fig. 6-5 International Comparison of $CO_2$ Emissions per 1 km of Distance Travelled Calculated Based on the Power Source Mix (LCA basis ; at the demand end)**




## 6-3 Cost Efficiency

### 6-3-1 Comparison of Cost per 1 km of Distance Travelled by Power Source Type

As shown in Table 6-5, the current power-generation cost (at the power transmission end) comes to ¥5.3/kWh for nuclear power and ¥6.0 kWh for wind power, both of which are fairly competitive compared with ¥5.7 to ¥10.7 for thermal power. Fig. 6-6 shows the cost per 1km of distance travelled calculated by multiplying the current power-generation cost with the fuel economy indicated in Table 6-6.

**Table 6-5 Power Generation Cost by Power Source (¥/kWh ; at the power transmission end)**

| | |
|---|---|
| Hydroelectric & geothermal | 11.9 |
| Nuclear | 5.3 |
| PV | 30.0 |
| Wind | 6.0 |
| Biomass | 12.0 |
| Oil | 10.7 |
| Coal | 5.7 |
| Coal with CCS | 10.7 |
| Gas | 6.2 |

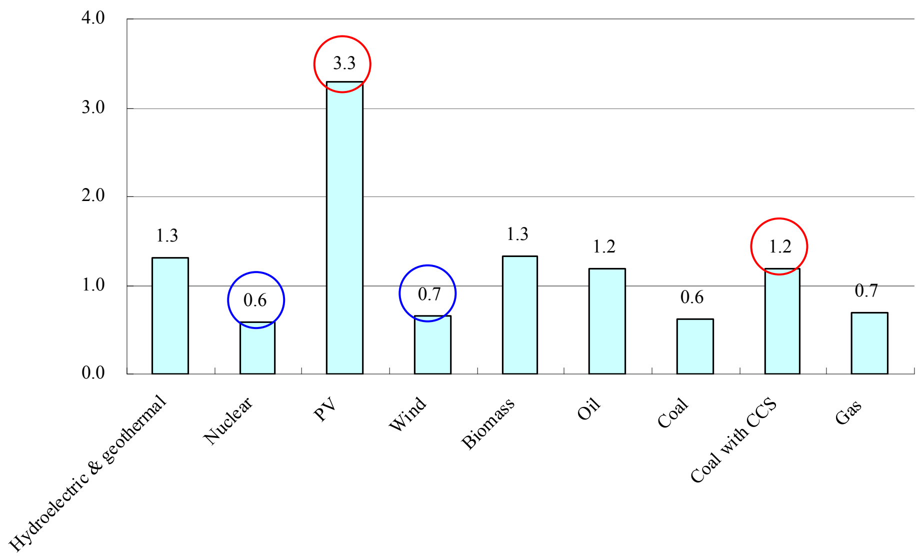
**Table 6-6 Fuel Economy**

| | (km/L) |
|---|---|
| Gasoline vehicle | 15.5 |
| Gasoline HEV | 30.6 |
| Diesel vehicle | 19.7 |
| | (kWh/km) |
| Electric vehicle | 0.11 |

Source : Compiled based on data compiled by the subcommittee on cost assessment, "Projected Costs of Generating Electricity" by the OECD/NEA, and materials prepared by the New and Renewable Energy Subcommittee

The energy cost per 1 km of distance travelled by an electric vehicle comes to ¥0.6/km for nuclear power and ¥0.7/km for wind power, both of which compare well with the cost for thermal power, which ranges from ¥0.6 to ¥1.2/km. Meanwhile, for photovoltaic power and CCS-capable coal-fired thermal power, the energy costs are far higher, at ¥3.3/km in the case of the former and ¥1.2/km in the case of the latter. If the cost of photovoltaic power generation is reduced from the current ¥30/kWh to ¥7/kWh (see Chapter 3), the cost per 1 km of distance travelled will drop to around ¥0.8/kWh, comparable to the cost for nuclear and wind power.

**Fig. 6-6 Cost per 1 km of Distance Travelled by Electric Vehicle by Power Source (at the power transmission end ; ¥/km)**



### 6-3-2 International Comparison of Current Energy Cost per 1 km of Distance Travelled Based on Electricity Rates

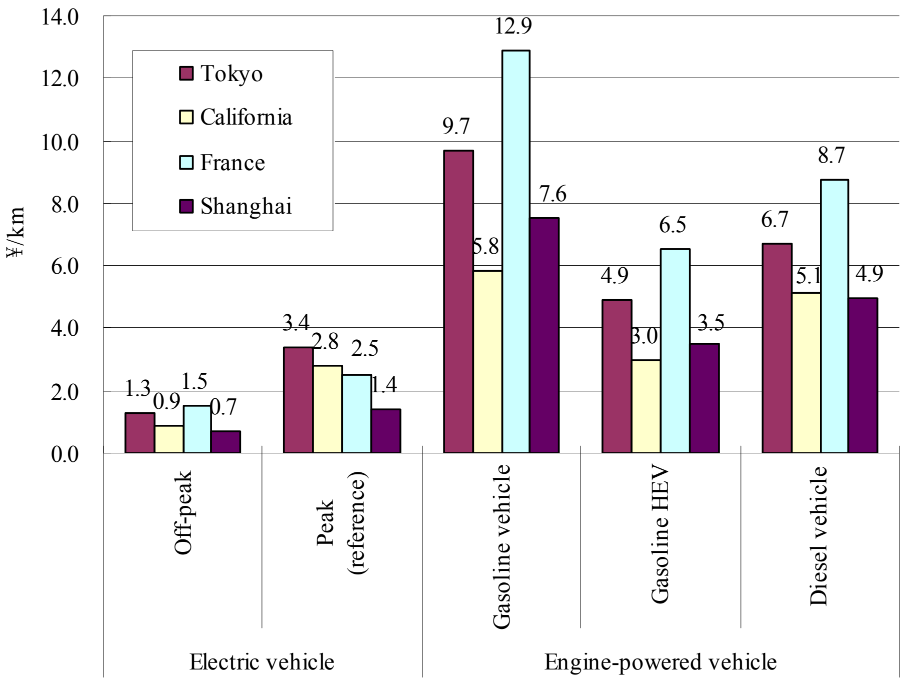
Table 6-7 shows country-by-country electricity rates (peak and off-peak rates) and gasoline and diesel prices. Fig. 6-7 shows the estimated energy cost by country calculated on the basis of the fuel economy indicated in Table 6-6.

**Table 6-7 Electricity Rates and Fuel Prices**

| | City | Electricity rate (¥/kWh) | | Fuel prices (¥/L) | |
|---|---|---|---|---|---|
| | | Peak | Off-peak | Gasoline | Diesel |
| Japan | Tokyo | 21.6 | 8.6 | 150 | 132 |
| U.S. | California | 17.6 | 5.6 | 91 | 101 |
| Europe | France | 16.0 | 9.8 | 200 | 172 |
| China | Shanghai | 9.1 | 4.5 | 117 | 97 |

Source : Electricity : Rates cited in Chapter 2
Fuel prices (incl. the consumption tax) : Calculated based on data compiled by the IEA, the Oil Information Center and the European Commission. Figures for fuel prices in China (Shanghai) are from 2007.

**Fig. 6-7 International Comparison of the Energy Cost per 1 km of Distance Travelled (at the demand end)**




The energy cost per 1km of distance travelled by an electric vehicle based on electricity rates (off-peak rates) in individual countries (in the case of night-time recharging) ranges from ¥0.9 to ¥1.5, far lower than the cost for gasoline-powered vehicles, which ranges from ¥5.87 to ¥12.9.

In Japan: cost for electric vehicles=¥1.3/km; cost for gasoline vehicles=¥9.7/km

In the United States: cost for electric vehicles=¥0.9/km; cost for gasoline vehicles=¥5.8/km

In France: cost for electric vehicles=¥1.5/km; cost for gasoline vehicles=¥12.9 km
In China: cost for electric vehicles=¥0.7/km; cost for gasoline vehicles=¥7.6/km

The energy cost for electric vehicles is already fairly competitive under the current electricity pricing system. In the future, the electricity pricing system, which does not assume large-scale deployment of electric vehicles, may be adapted so as to suit such a situation.

## 7. Conclusion and Future Challenges

### 7-1 Conclusion

**(1) Advantages of Electric Vehicles**

The advantages of electric vehicles are that they are effective in reducing $CO_2$ emissions, they contribute to a stable energy supply by reducing dependence on foreign supply sources for fossil fuels and they help to even out the burden on electricity supply over the course of the day as well as reduce electricity costs through the use of night-time recharging.

**(2) Prominent Feature of and Challenge for Electric Vehicles**

While electric vehicles have a superior fuel economy, their relatively short driving range of around 100 km is likely to limit their spread for now.

**(3) Key to Future Spread of Electric Vehicles**

(i) The key to the future spread of electric vehicles will be the development of low-cost, high performance batteries. The driving range of electric vehicles is likely to more than double in the future due to an improvement of the performance of the lithium-ion battery, leading to their spread as commuter vehicles for short-range driving.

(ii) Although it is possible that the development of an entirely new type of battery will turn electric vehicles into mainstay vehicles, it is not clear now how likely this scenario is.

**(4) Power Sources for Electric Vehicles (additional power sources)**

Power sources for electric vehicles, which should be selected with a low $CO_2$ emission as the prerequisite, must meet such conditions as (i) that the supply potential of the source is sufficient, (ii) that the distribution of the source is not uneven and (iii) stable and sustained supply is possible. Nuclear power and renewable energy such as wind and photovoltaic power are promising as power sources that meet these conditions.

**(5) Supply Potential**

(i) The combined supply potential (with the "supply potential" defined as the maximum possible supply capacity to be attained by around 2050) of nuclear, wind and photovoltaic power is estimated at approximately 15.3 trillion kWh/year.

(ii) With 6.3 trillion kWh/year of the total supply capacity set to be used for non-automotive applications, the maximum possible supply for automotive applications comes to 9 trillion kWh/year, a capacity mostly sufficient to meet the power needs of electric vehicles.

**(6) $CO_2$ Emission Volume per 1 km of Distance Travelled by Power Source Type**

The $CO_2$ emission volume per 1 km of distance travelled by an electric vehicle comes to 2.1g for nuclear power, 1.0g for wind power and 1.1g for photovoltaic power, compared with 57.5g to 109g for thermal power. Thus, electric vehicles using these power sources are almost $CO_2$-free.

**(7) $CO_2$ Emission Volume per 1 km of Distance Travelled Based on Current Power Source Mix (average)**

Compared with the $CO_2$ emission volume (at the demand end) per 1 km of distance travelled by a gasoline vehicle and a hybrid vehicle, 176g and 94g, respectively, the emission per the same distance travelled by an electric vehicle comes to the following:

(i) 57g in Japan and Europe, meaning that the $CO_2$ reduction effect will be significant, and;

(ii) 127g in China and 180g in India, indicating that the deployment of electric vehicles could increase $CO_2$ emissions in some cases. This is attributable to such factors as the large share of coal-fired thermal power in the power source mix and poor power-generation efficiency, as well as a high power loss ratio in developing countries and emerging countries. Although such problems are expected to be improved in the medium to long term, it is important to remember that the deployment of electric vehicles will not necessarily reduce $CO_2$ emissions under the current circumstances.

**(8) Energy Cost (at the demand end)**

(i) Based on the electricity rates (off-peak rates) and fuel prices in individual countries, the estimated energy cost per 1 km of distance travelled by an electric vehicle range from ¥0.9 to ¥1.5, far lower than the range of ¥5.7 to ¥12.9 for the same distance travelled by a gasoline vehicle.

(ii) Although the current electricity pricing system does not assume a large-scale deployment of electric vehicles, it may be adapted so as to suit such a situation in the future.

## 7-2 Conclusion and Future Challenges

The following is an assessment of how the supply stability, the $CO_2$ emission reduction effect and the cost efficiency will be like if electric vehicles and plug-in hybrid vehicles are to be deployed on the premise of the use of low-carbon power sources (renewable energy and nuclear power).

**(1) Energy Supply Stability**

(i) Additional power supply is secured through an increase in the capacity utilization ratio of existing facilities due to the use of night-time electricity and construction of new capacity. Although new capacity alone will be sufficient to meet the electricity needs of electric vehicles, the use of night-time electricity means that the actual volume of additional power to be made available through new capacity construction will be smaller than the nominal new capacity.

(ii) The use of renewable energy such as wind and photovoltaic power as well as nuclear power will help to reduce dependence on oil as fuel (dependence on foreign supply sources).

**(2) $CO_2$ Emission Reduction Effect**

(i) If low-$CO_2$-emission power sources (renewable energy and nuclear power) are used, the deployment of electric vehicles will contribute to the reduction of $CO_2$ emissions.

(ii) However, it may not contribute to the reduction of $CO_2$ emissions in cases where conventional power sources are used and the share of coal-fired thermal power in the power source mix is high.

**(3) Energy Cost**

(i) Under the current electricity pricing system (in the case of night-time electricity), the energy cost for electric vehicles will be lower than the cost for vehicles using oil-based fuels.

(ii) However, if a new power source (e.g., renewable energy) is to be used, further cost reduction efforts will be necessary so as to minimize the public burden because the current supply cost is high.

In light of the above, electric vehicles are likely to become popular as commuter vehicles for short-range driving. However, there are many challenges to overcome before the use of electric vehicles becomes widespread. In particular, research and development on an innovative high performance battery will be essential on the vehicle side, while on the power source side, further cost reduction will be necessary with regard to wind and photovoltaic power. In addition, quantitative research on how to optimize the power source mix (minimization of cost), including additional power sources for electric vehicles, will be needed.

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