Strategic Technology Roadmap
(Energy Sector)

~ Energy Technology Vision 2100 ~

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Ministry of Economy, Trade and Industry

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I. Introduction

The Ministry of Economy, Trade and Industry (METI) formulated the "Strategic Technology Roadmap" as a navigating tool for strategic planning and implementation of research and development investment, in March 2005 in cooperation with industry, academia, and public institutions. The "Strategic Technology Roadmap" consists of "Scenario for Introduction" showing policies to create demand for production and services, "Technology Overview" showing required technologies to satisfy the needs, and "Roadmap" showing technical targets on a time axis. It is formulated for 20 areas of information and communication technology, life science, environment and manufacturing.

Then, METI summarized the "Strategic Technology Roadmap" of the energy sector, consisting of the technology overview and the roadmap.

This "Strategic Technology Roadmap" of the energy sector was developed by backward examination (backcasting) of the technology portfolio to overcome constraints in resources and the environment, which will become a big concern in the future globally, on a long-term basis until 2100. The object is to prioritize long term based research and development, and to contribute to the discussion based on the long-term and global point of view such as post-Kyoto international framework (subtitle: "Energy Technology Vision 2100").

In order to formulate this map, a draft was developed by the "Ultra Long-Term Energy Technology Committee" in The Institute of Applied Energy. In the committee and working groups, academic, business, and governmental knowledge were gathered from universities, private enterprises (manufacturers of goods, components, materials, equipments, etc.), the Ministry of Economy, Trade and Industry (Agency of Natural Resources and Energy, the relevant Divisions, and Industrial Science and Technology Policy and Environment Bureau), NEDO, the National Institute of Advanced Industrial Science and Technology, etc. In addition, the Research and Development Subcommittee of the Industrial Science and Technology Policy Committee under the Industrial Structure Council (chairperson: Shigefumi Nishio, vice president of the University of Tokyo) deliberated the draft.
II. Basic concept and approach to formulate the strategic technology roadmap

1. Basic concept

(1) Basic recognition of the energy sector

1) Energy is the foundation for activities of the entire human race. Constraints on energy connect directly to the level of human utility (quantity of economic activity, quality of life).
2) Consideration of future energy supply-demand structure should take into account both resource and environmental constraints.
3) Based on the long-term scope, the key to achieve a truly sustainable energy supply-demand structure is technology (it is impossible to achieve it without the technology).
4) However, in order to establish the technology, a long lead time is required for research & development, introduction & promotion, the establishment of related infrastructure, and also there is actually great uncertainty because various kinds of options are selected in the actual society.

(2) Characteristics of the approach

In this examination, we set the prerequisite that the resource and the environmental constraints do not degrade utility but enrich the human race (improve utility), and basically developed the technology portfolio for the future in order to realize it through development and use of the technologies.

At that time, we executed backward examination (backcasting), considering the above period, to summarize required technological specifications, timeframe, etc.

We made out a challenging technology portfolio based on the following assumptions:

(a) Since we made out the future image based on the assumption that we will solve all problems by technologies without degrading utility, the effect of modal shift or changing of lifestyle were not expected.
(b) Although the assumption of the future resource and environmental constraints includes high uncertainties, based on the point of view that we will resolve risks on these constraints as smoothly as possible, we assumed rigorous constraints as "preparations".
(c) In the development of the future technology portfolio, we have set excessive conditions about energy structure to identify the most severe technological specifications. As a result, if all of them are achieved, the constraints are excessively achieved.
1) Generally, energy plays an important role in economic activities. Energy consumption becomes larger due to the enlargement of economical activities. On the contrary, constraints on energy use decrease economic growth.

2) Recently, while the global energy demand has been increasing rapidly due to the fast economic growth of developing countries such as China, there is an argument that the global energy market has already entered a new stage with a structural imbalance of supply and demand. They mean that the risk of the constraints on energy is becoming higher. On the other hand, from the global point of view, energy used in the transport sector largely depends on fossil fuel, so if we assume that the current supply-demand structure of energy will continue, it may be unavoidable that the resource constraints will become a big issue in the long run.

In addition, most anthropogenic greenhouse gas emission is energy-originated CO₂, and the supply-demand structure of energy is tied closely to the global warming problem. We can say the future supply-demand structure of energy also depends on how these environmental constraints will become obvious.

Consequently, when we think about the future supply-demand structure of energy, we have to bring the resource and the environmental constraints into view.

3) In order to resolve these global-scale problems such as the resource and the environmental constraints, and to achieve global sustainable development, all countries have to realize a truly sustainable supply-demand structure of energy on a long-term scope: for example, improving energy efficiency, cutting off "the linkage" between economic growth, energy consumption and CO₂ emission, and increasing use of non-fossil fuel energy.

In order to realize it, we have to establish technology that can alter the supply-demand structure of energy fundamentally (for example, in the transport sector, significant mileage improvement and development of non-fossil fueled vehicles), and prepare for future constraints.

4) When we think about preparation for the future, we have to fully consider that a long time (lead time) is required for research & development, market introduction & diffusion, and development of related infrastructure in order to establish the technology.

In addition to the uncertainty of whether the technology can be established or not, we have to keep in mind that the mere existence of specific technology cannot resolve problems because, in the real world, various kinds of options are selected according to social situations and aerial features at that time.
In order to prepare for the future constraints, it is essential not to build necessary measures haphazardly, but to go ahead with strategic consideration based on a long-term scope, bringing the whole image of energy supply-demand into view.

In this study, a backward examination (backcasting) methodology was used by setting the assumed resource and environmental constraints in the year 2100 as the starting point. We also identified the requirements that technology should satisfy (technology specifications) and made up the future image of technology with relevant requirements such as the establishment time of the technology (considering lead time in order to resolve the constraints) under the condition that the economy will continue to develop.
2. Approach based on backcasting

(1) Assumption of constraints based on future perspectives

Although assumption of the future resource and environmental constraints includes high uncertainties, based on the point of view that we will resolve risks on these constraints as smoothly as possible, we assumed the following rigorous constraints as "preparations". These constraints are considered as the conditions that make up the future technology portfolio of Japan.

1) Resource constraints

Assumption of resource constraints (global)

While the world economy continues to grow,

- Assumption of oil production peak: 2050
- Assumption of natural gas production peak: 2100

Condition of the future image of technologies in Japan

Since we depend on imports to supply most of our resources, we set the condition that the existing energy can be replaced with other energy by the assumed timings of production peak, through diversification of energy resources, the increase of usable resources and increased efficiency of energy usage.

2) Environmental constraints

Assumption of resource constraints (global)

While the world economy continues to grow*, if CO₂ emission can be maintained at the same level as the current condition, CO₂ emission intensity per GDP (annual CO₂ emission/GDP) should improve as follows, compared to the current status.

- 1/3 in 2050
- Less than 1/10 in 2100 (more improvement after 2100 is considered)

Condition of the future image of technologies in Japan

Based on the consideration that we have achieved the maximum level of efficiency improvement until today, we assume that we will continue to lead the world also in the future. Therefore, we set the condition as the same level of the intensity improvement rate with the one derived from the assumption of the environmental constraints above (global).

*Concerning economic growth, the following assumptions are considered:

World's GDP: about three-times in 2050, and about ten times in 2100 compared with today.
Japan’s GDP: about 1.5 times in 2050, and about twice in 2100 compared with today.
● Overview of future perspective

1) World’s population and economy

It is estimated that the world population is increasing, and the economy (GDP) continues growing.

![Forecast of world population and GDP](image)

**Forecast of world population**
Comparison of the IPCC-SRES scenarios developed by (IPCC: Intergovernmental Panel on Climate Change) and IIASA-WEC (IIASA: International Institute for Applied Systems Analysis). Although there are differences between scenarios, at the mid-level forecast, economic growth can be estimated as about three times in 2050, and about ten times in 2100.

- **IPCC-SRES A1**: Rapid economic growth continues and new or highly effective technologies are rapidly deployed. In this case, regional disparities are decreased.
- **IPCC-SRES B2**: Modest Case
- **IIASA-WEC A**: Rapid economic growth, **B**: Modest case, **C**: Case of ecology investment

2) World’s energy consumption

Due to the population increase and economic growth, it is estimated that energy consumption is also increasing.

![Forecast of energy consumption](image)

**Forecast of energy consumption**
Although there are differences between scenarios from IPCC-SRES and IIASA-WEC, it is estimated that energy consumption is increasing.

- **IPCC-SRES A1**: Rapid economic growth continues and new or highly effective technologies are rapidly deployed. In this case, regional disparities are decreased.
- **IPCC-SRES B2**: Modest Case
- **IIASA-WEC A**: Rapid economic growth, **B**: Modest case, **C**: Case of ecology investment
3) World’s fossil fuel production

On the other hand, reserves of fossil resources such as oil have limitations, and there exist arguments that world oil production will peak by the middle of this century.

### IEA forecast

<table>
<thead>
<tr>
<th></th>
<th>Reference scenario</th>
<th>Low resource case</th>
<th>High resource case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remaining ultimately recoverable resources base for conventional oil, as of 1/1/1996 (billion barrels)</td>
<td>2,626</td>
<td>1,700</td>
<td>3,200</td>
</tr>
<tr>
<td>Peak period of conventional oil production</td>
<td>2028 - 2032</td>
<td>2013 - 2017</td>
<td>2033 - 2037</td>
</tr>
<tr>
<td>Global demand at peak of conventional oil (mb/d)</td>
<td>121</td>
<td>96</td>
<td>142</td>
</tr>
<tr>
<td>Non-conventional oil production in 2030 (mb/d)</td>
<td>10</td>
<td>37</td>
<td>8</td>
</tr>
</tbody>
</table>

There are various arguments in the fossil resource reserves from pessimistic ones to optimistic ones. These estimates do not reflect all variations of factors, and the indicated values should be regarded with some degree of margin.

On the other hand, in order to prepare for the future risks, it is appropriate to assume in the examination that oil production will peak around around the middle of this century and natural gas production will peak at the end of this century at the earliest.

### Estimates by P. R. Odell (Professor, Erasmus University, the Netherlands)

The Complementarity of Conventional and Non-Conventional Oil Production: giving a Higher and Later Peak to Global Oil Supplies

The Complementarity of Conventional and Non-Conventional Gas Production: giving a Higher and Later Peak to Global Gas Supplies

**Example of estimates for oil and natural gas production**

4) CO₂ emission scenarios

If we should stabilize atmospheric carbon dioxide concentration levels in the future in order to deal with global environment problems, it is said that reduction of carbon dioxide emission is required. While the economy is growing and energy consumption is increasing, we have to improve carbon dioxide emission intensity (CO₂/GDP) to stabilize the carbon dioxide concentration level.

With regard to the environmental constraints, various scenarios are examined internationally based on the argument that we have to make an effort to control atmospheric CO₂ concentration below a prescribed level in order to prevent global warming. Most of the estimates suggest that a decrease CO₂ emissions is required within this century to achieve the goal.

For example, the WG I scenario shows that it is necessary to control global CO₂ emissions roughly to the current level, i.e. 7 - 8 Gt-C in 2000, both in 2050 and 2100 in order to achieve 550 ppm stabilization.

**Global carbon dioxide emission scenario**

Various estimations are available for stabilization scenarios at 550 ppm and 450 ppm. The figure shows WG I scenario developed by IPCC Working Group I and WRE scenario by Wigley, Richels and Edmonds.
● Energy efficiency improvement in Japan

When considering the current carbon dioxide emission intensity, we can say that Japan has realized the highest level of energy efficiency in the world through development and deployment of technologies (the intensity of Japan is 1/3 of the world’s average and 1/8 of developing countries). It is important to diffuse our excellent technologies globally and also to maintain our international competitiveness with further enhancement of our technologies as our advantage in the future, and at the same time, contribute to resolve global constraints in resources and the environment.

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**Transition of carbon dioxide emission intensity (CO2/GDP)**

**Example 1: Power generation efficiency**

**Example 2: Energy intensity per 1 ton of crude steel**

**Example 3: Energy intensity per weight of cement produced**

**Example 4: Refrigerator-freezer**

**Example 5: Air conditioner**

**Example 6: Automobile**

Example of efficiency improvement in Japan
(2) Assumption for future energy consumption

We executed case studies by setting an extreme condition on the energy supply and demand structure.

Case A: Maximum use of fossil resources such as coal combined with CO₂ capture and sequestration

While supplying energy by fossil resources such as coal or non-conventional fossil fuels of which reserves are comparably rich, generated CO₂ is captured and sequestered.

If we depend largely on the capture and sequestration of CO₂, a great amount of CO₂ has to be sequestered. However it is now supposed that the capacity for geological sequestration is limited in Japan, so realization of ocean sequestration is an essential condition.

Case B: Maximum use of nuclear energy

Energy for all sectors is supplied by nuclear power which emits no CO₂. Electricity and hydrogen are assumed to be the energy carrier for sectors including transport and industry.

If depending on nuclear power largely, based on resource limitations of uranium ore, acquisition of non-conventional nuclear fuel such as recovery of uranium from seawater, or establishment of a nuclear fuel cycle is an essential condition.

Case C: Maximum use of renewable energy combined with ultimate energy-saving

As well as maximizing the use of renewable energy, energy demand will be reduced as much as possible by energy-saving, highly efficient utilization, self-sustaining, improvement of conversion efficiency to control required energy supply, and to maintain or improve the quality of life at the same time.

It is essential that both renewable energy technologies and energy-saving technologies are fully established and deployed.

● Three cases as technological scenario

In examining a vision for the energy technologies of Japan under the assumptions on constraints for fossil resources and the environment, we considered this energy supply structure.

We can draw a triangle of primary energy structure as shown in Figure 1.

* In this primary energy triangle, the characteristics of a position vary according to the reliability of supply or cost of three energy supply sources at that time. Therefore, the position on the triangle does not represent a definite evaluation.

Figure 1. Triangle of primary energy supply structure
In this examination, we have set three extreme cases as a technological scenario for case studies on the assumption that we have to prepare to overcome the constraints even in a crisis situation.

Case A: Maximum use of fossil resources such as coal combined with CO₂ capture and sequestration
Case B: Maximum use of nuclear energy
Case C: Maximum use of renewable energy combined with ultimate energy-saving

These three cases assumed extreme societies of which the primary energy supply structures are in the vicinity of vertices of the triangle.

Measures common to the three cases: considerations of "energy-saving, highly efficient utilization, self-sustaining"

Measures such as "energy-saving, highly efficient utilization, self-sustaining" and "improvement of conversion efficiency" can reduce energy demand, while realizing "utility" at the same time. They are essential in case C, but also reduce energy demand in both case A and case B, so they are effective to all cases. However, beside this basic concept, we have assumed in the examination that we cannot largely depend on energy saving in the case of A and B in order to identify technologies required for preparation for the future.
Features of each case and image of energy supply and demand structure

Case A: Maximum use of fossil resources such as coal combined with CO₂ capture and sequestration

Significance
Even if CO₂ capture and sequestration is largely utilized, while it can reduce CO₂ emission generated from use of non-conventional fossil resources significantly, it is merely a transitional solution because we still have to continue to consume finite resources. However, this has an immediate effect, and can be regarded as an emergency measure.

Potential
Potential of CO₂ sequestration is supposed to be high worldwide. On the other hand, there may be a limitation for geological sequestration potential in Japan. However, if ocean sequestration is realized, the potential in Japan becomes larger.

Technical feasibility
From the technological point of view, geological sequestration is partially realized and expected to be put into practical use. Ocean sequestration has a task to verify its impact on the marine ecosystem.

Applicability
CO₂ can be captured efficiently from centralized large-scale CO₂ emission source such as power plants, hydrogen production facilities and industrial facilities. On the other hand, it is difficult to capture CO₂ from diversified CO₂ emission sources such as automobiles and households.

Others
Additional energy and costs are required for CO₂ capture and sequestration.

Image of final energy demand in case A (sample estimation)

Note: The future estimation is one of the examples based on various assumptions and conditions.
Case B: Maximum use of nuclear energy

Significance
If nuclear power is widely utilized, the fossil resources constraints and environmental constraints are largely mitigated.

Potential
Except for problems of siting and radwaste disposal, potential is high. However, when assuming the use of current light water reactor only, there may be resource limitations of uranium ore. In addition, considering that the worldwide situation related to nuclear nonproliferation, foresighted review may be required to determine its large scale deployment.

Technical feasibility
From a technical point of view, although development of the nuclear fuel cycle is continuously required, it can be realized without serious difficulty because the existing technologies currently being planned can be utilized.

Applicability
Beside nuclear power generation, hydrogen production by water electrolysis or by heat use can be considered.

Others
Since long lead-time is required to install a facility and the service period is also long, long-term planning is necessary.

Image of final energy demand in case B (sample estimation)
Case C: Maximum use of renewable energy combined with ultimate energy-saving

Significance
If technologies for renewable energy and energy-saving are established, they can provide common and basic technological public good. There is not a major difficulty for deployment, and it is effective in reducing fossil resources constraints and environmental constraints worldwide.

Potential
Although renewable energy has logically almost no limitation in potential (assuming the use of all renewable energy sources), its energy density is low and output is not stable in many cases, so constraints on siting and operational conditions may limit the potential. Consequently, significant improvement of energy-saving is essential.

Technical feasibility
Significant technology innovations such as a drastic improvement of conversion efficiency to increase the quantitative potential, development of new utilization technologies, etc. are required for both renewable energy and energy-saving technologies.

Applicability
In the industrial sector, drastic changes in the production process, and development and deployment of comparably large renewable energy sources are required. In the residential/commercial and the transport sector, application in a wide range of purposes is required. Especially, self-sustainable systems with the combination of extreme energy-saving and renewable energy using periphery low-density energy are important.

Others
While the turnover time of the stock is considered to be relatively short (around 10 years or less) for appliances for residential/commercial use, it is relatively long for production processes (about 20 - 30 years).

Image of final energy demand in case C (sample estimation)

Note: The future estimation is one of the examples based on various assumptions and conditions.
Examination for demand sectors

In order to bring the constraints into shape as technological specifications, we conducted examinations based on demand sectors.

Specifically, in order to facilitate the evaluation and the consideration of effective measures, we have introduced a proper CO₂ emission intensity for each demand sector such as industry, residential/commercial and transport, aiming at improvement of CO₂ emission intensity. Improvement of CO₂ emissions intensity for them is considered as a combination of the action for demand side (such as efficiency improvement of single unit and equipment) and efficiency improvement in the transformation sector.

Demand sectors and their typical CO₂ emission intensity

- **Industry**: \( \text{t-C/production volume} = \text{t-C/MJ} \times \text{MJ/production volume} \)
- **Commercial**: \( \text{t-C/floor space} = \text{t-C/MJ} \times \text{MJ/floor space} \)
- **Residential**: \( \text{t-C/household} = \text{t-C/MJ} \times \text{MJ/household} \)
- **Transport**: \( \text{t-C/distance} = \text{t-C/MJ} \times \text{MJ/distance} \)

Features of each sector

**Residential/Commercial sector**
- Demand is small in general.
- There is a technological alternative even if kerosene or city gas is directly used.
- Since the emissions level is small, CO₂ capture is difficult. If required, CO₂ would be captured and sequestered in the supply side.
- Stock turnover time of facilities and equipment are around 10 years. In the case of buildings, the time is around 20 - 30 years for detached houses and around 30 - 50 years for commercial buildings.

**Transport (automobile) sector**
- We should consider vehicles in combination with fuel-supply infrastructure.
- For vehicles, fuel with high energy density is required.
- Weight reduction of vehicles’ body and regenerative technology are cross-boundary actions, independently of fuel type.
- Since the specific emissions level is small, CO₂ capture is difficult. If we try to make CO₂ emissions zero in the transport sector, we have to supply energy to vehicles in the form of electricity or hydrogen which are supplied by nuclear power, renewables, or fossil fuels with CO₂ capture and sequestration.
- The lead time to develop new infrastructure is long, since we need a concomitance period of existing fuels and a new fuel before complete replacement. Turnover period for vehicles is around 10 - 20 years.
- In order to consider fuel for aircraft, examination on variation of air pressure and temperature and global infrastructure building is required.
- Others such as shifting to railway or shipping may have an effect.

**Industrial sector**
- Mainly, it consists of large scale intensive facilities. While it is energy intensive and generally cost effective to make improvements, which means the rationalization incentive is comparably high, the installation cost of equipment is so high that it is not easy to reconsider and reconstruct the whole production process.
- When fossil resources are used as feedstock or reducer, for example, in the iron & steel or the chemical industries, it is difficult to find alternatives. The process and scale in this sector enables CO₂ capture and sequestration if required when using fossil resources.
- Stock turnover time of equipment is around 10 - 30 years.

**Transformation (power generation and hydrogen production) sector**
- Mainly, it consists of large scale intensive facilities. A supply network is required.
- In order to improve energy conversion efficiency, it is necessary to improve efficiency of power generation and to reduce distribution loss.
- A method to accommodate load variation on the demand side is required (backup rate and storage).
- In order to improve CO₂ emission intensity, it is necessary to expand a share of non-fossil energy (nuclear power and renewable energy).
- The process and scale in this sector enable CO₂ capture and sequestration if required when using fossil resources.
- Stock turnover time of equipment is around 30 - 40 years (over 50 years in the case of nuclear power). In addition, a long lead time is required also for siting.
- For new energy supplies such as hydrogen, a long lead time may be required for the development of new infrastructure.
III. Energy technology roadmap

On the assumption that "utility (economic activities or quality of life)" acquired in the future increases in proportion to GDP\textsuperscript{vii}, we sort out the portfolio of technology specifications satisfying the constraints for each sector in the case studies for energy supply and demand structures\textsuperscript{viii}.

We also simulated deployment of the technology menu required to realize those technology specifications in chronological order, and summarized the energy technology roadmap.

### 1. Overview of technology specifications required per sector based on constraints (2100)

We picked out the most rigorous specifications from the case studies and the results\textsuperscript{ix} which are shown below.

#### Main technology specification requirements in 2100

<table>
<thead>
<tr>
<th>Sector</th>
<th>Requirement</th>
</tr>
</thead>
</table>
| Residential/Commercial | - While "utility" increases in proportion to GDP, 80% of required energy from transformation sector is reduced (per household, floor space).  
                  | - Share of electricity and/or hydrogen is 100%.                                                      |
| Transport       | - While "utility (≈ person-km, ton-km)" increases in proportion to GDP, fuel efficiency is improved equivalent to a 70% reduction of required energy. (for automobile, equivalent to an 80% reduction).  
                  | *considering improvement by shifting transport methods                                                 |
|                 | - Share of electricity and/or hydrogen is 100% (except aircraft).                                    |
|                 | - Fuel switch with appropriate timing to resolve resource constraints.                                  |
| Industry        | - While "utility (≈ production volume × production value)" increases in proportion to GDP, 70% of required energy is reduced (per utility).  
                  | - Primary fuel switch with appropriate timing to resolve resource constraints.                        |
| Transformation  | - Required energy for each demand sector is supplied sufficiently in each case.                       |

**Case A: Maximum use of fossil resources such as coal combined with CO$_2$ capture and sequestration**
- About twice the energy demand × 4-time of share of electricity and/or hydrogen ≈ about 8 PWh
- Effective use of fossil resources and carbon capture/sequestration

**Case B: Maximum use of nuclear power**
- About twice the energy demand × 4-time of share of electricity and/or hydrogen ≈ about 8 PWh
- Nuclear fuel cycle to resolve uranium resource constraints

**Case C: Maximum use of renewable energy combined with ultimate energy-saving**
- About twice the energy demand × energy-saving at demand sector about 0.3-time  
× 3-time of share of electricity and/or hydrogen ≈ about 2 PWh
Overview of technology specifications required for each sector in extreme cases

Case A: Maximum use of fossil resources such as coal combined with CO₂ capture and sequestration

In this case, we use fossil resources such as coal to satisfy "fossil energy demand" and execute CO₂ capture and sequestration to mitigate "CO₂ emissions". We examined this case on the assumption that we could not largely depend on energy-saving.

Residential/Commercial, Transport
- Since the required demand is small and capturing CO₂ at the site is supposed to be difficult in these sectors, it is necessary to cover the demand with energy supplied by the transformation sector (share of electricity and/or hydrogen is 100%).
- In addition, fuel switching is required with appropriate timing to resolve resource constraints.

Industry
- While CO₂ capture and sequestration is simultaneously required in a large scale intensive facilities when fossil resources are used as feedstock, in the other facilities in which CO₂ capture is difficult, it is necessary to increase the share of electricity and/or hydrogen.
- In addition, switching of the feedstock is required with appropriate timing to resolve resource constraints.

Transformation
- We assume that most energy, except for feedstock, for a big facility in the industrial sector is supplied from the transformation sector as a form of electricity or hydrogen. At this time, it is necessary to supply electricity and/or hydrogen having about 8-times the current total power generated (= about twice the final energy demand × 4-time of share of electricity and/or hydrogen) by fossil resources. At the same time, CO₂ capture and sequestration is also required (in this case, a storage reservoir of 4-billion ton-CO₂/year (2100)) is required).

While GDP is about twice as big, the supply of electricity and/or hydrogen is about 8-times the current total generated power. This is because of the assumption that we will largely depend on electricity and/or hydrogen from the transformation sector in the future image of case A, while we are directly using fossil fuels (gasoline, kerosene, and others) currently on the demand side. We did not take effects of efficiency improvement by using electricity or hydrogen in the residential/commercial sector into consideration.

Image of technology specifications in 2100

- Case A assumes a situation where we cannot heavily rely on energy saving.
- The growing ratios of electricity and hydrogen in composition are considered.
- The capacity factor of power generation and hydrogen production facilities is assumed to be 80%.
- The amount of electric power generation and hydrogen production is estimated to grow approximately eightfold as electrification and shift to hydrogen, together with a 2.1-time increase in the total energy demand compared to the current level.
- 95% of CO₂ form the transformation sector and 80% of CO₂ form the industry sector is assumed to be captured and sequestrated.
- In the transport sector, aircraft are excluded.
Case B: Maximum use of nuclear power
In this case, we maximize the use of nuclear power to satisfy "primary energy demand" and mitigate increase of "fossil energy demand" and "CO₂ emissions". We examined this case largely on the assumption that we could not depend on energy-saving.

Residential/Commercial, Transport, Industry
- Excluding primary material in the industrial sector, it is necessary to cover the energy demand with electricity and/or hydrogen supplied from the transformation sector.
- In addition, switching of primary fuel is required with appropriate timing to resolve resource constraints.

Transformation
- We assume that most of the energy, except feedstock, in the industrial sector is supplied from the transformation sector as a form of electricity or hydrogen. At this time, it is required to supply electricity and/or hydrogen having about 8-times the current total power generated (= about twice the final energy demand × 4-time of share of electricity and/or hydrogen) by nuclear power.
- Considering the uranium resource constraints, establishment of atomic fuel cycle is also required immediately.

Image of technology specifications in 2100
- Case B assumes a situation where we cannot heavily rely on energy saving.
- The growing ratios of electricity and hydrogen in composition are considered.

[ Target in the Transformation Sector ]
(1) Production of Electric Power and Hydrogen
Eight times* the current total amount of power generation

[ Target in the Industrial Sector ]
(1) All demand is supplied with electric power and/or hydrogen with the exception of feedstocks and reductants

[ Target in the Transport and Res/Com Sectors ]
(1) 100% of energy demand is supplied with electric power and/or hydrogen

- The capacity factor of nuclear power facilities is assumed to be 90%.
- The amount of electric power generation and hydrogen production is estimated to grow approximately eightfold as electrification and shift to hydrogen, together with a 2.1-time increase in the total energy demand compared to the current level.
- In the transport sector, aircraft are excluded.
Case C: Maximum use of renewable energy combined with ultimate energy-saving

In this case, we use energy-saving to control the increase of "final energy demand" as much as possible and at the same time, use renewable energy to cover "primary energy demand" (as a result, "fossil energy demand" and "CO2 emission" are controlled). We examined this case on the assumption that we could not depend on nuclear power nor CO2 capture and sequestration.

Transformation
- We assume that all electricity and hydrogen required in the demand sectors is supplied by renewable energy. However, the potential of renewable energy may be limited, so significant progress of energy-saving is also required.
- At this time, it is necessary to supply electricity and/or hydrogen having about 2-times the current total power generated (= about twice the energy demand × about 0.3-time of energy-saving in demand sectors × 3-time of the share of electricity and/or hydrogen) by renewable energy.

Residential/Commercial
- While "utility" is increasing, 80% reduction (per household and floor space) of required energy from the transformation sector is required.

Transport
- While "utility (= person-km, ton-km)" is increasing, 70% reduction (improvement of fuel efficiency) of required energy from the energy transformation sector is required.
- In addition, fuel switching is required with appropriate timing to resolve resource constraints.

Industry
- While "utility (= production volume×value of products)" is increasing, 70% reduction (per unit utility) of required energy from the energy transformation sector is required.
- In addition, switching of primary fuel is required with appropriate timing to resolve resource constraints.

Image of technology specifications in 2100

- Estimates have been worked out on the assumption that some required energy will remain after energy-saving effects have been fully drawn out in every demand sector with a 2.1-time increase in the total energy demand on the current level secured and that they are to be filled with recoverable energy supplied from the transformation sector.
Considerations of technology specifications in 2050 and 2030

2050

Based on the portfolio of technology specifications in 2100, we identified the required technology specifications through backward examination (backcasting) under the assumption of the resource constraints in 2050 (the peak of oil production) and the environmental constraints (CO₂ emission /GDP=1/3) and GDP growth (1.5-time).

2030

Based on the technology specifications in 2100 and 2050, we executed backward examination (backcasting) and at the same time, considered the current technology level to identify the required technology specifications.
2. Energy technology roadmap

In order to realize the specifications portfolios in 2100, 2050 and 2030, we sorted out the menu for the key technologies (concrete specifications, if possible) according to time series, and showed it as the energy technology roadmap.

Note: The time axis is based on the assumption of the constraints. If the conditions of the constraints change according to situations or technology trends, the timeframe of the image described here should be shifted forward or backward accordingly.

3. Important points on energy technology roadmap

Residential/Commercial

In order to realize the technological specifications for the res/com sector, we should (1) carry out energy saving as much as possible including the equipment that will appear in the future, and (2) execute energy creation by using ubiquitous energies such as solar power. Through the advancement of (1) and (2) ultimately, “self-sustenance” which does not depend on the energy supplied from the transformation sector becomes possible. If the quantity of energy creation by renewable energy becomes large, we can distribute excessive energy through the energy grid network, or store energy to utilize it maximally according to the situation.

Energy-saving

The energy saving is carried out in the residential sector first and in the commercial sector next by spreading state of the art equipment. In addition, the improvement of thermal insulation efficiency in houses and buildings is effective as well as the improvement of air-conditioning equipment. The introduction of heat pump systems is effective for supplying hot water. Energy management contributes to some extent to in-house energy saving in the middle term. Energy saving is achieved sequentially as new equipment is introduced according to the improvement of the quality of life and the change of lifestyle.

Energy creation

Based on regional geographical features, various types of ubiquitous energy such as photovoltaic will be introduced. According to installation opportunity (such as space) or energy prices, new systems will begin to be installed in houses at first and then, installed in apartments and office buildings gradually.

Energy management

Following energy-savings, energy creation is deployed and the "self-sustenance," which does not depend on the energy supplied from a grid, starts in houses, where demand and supply are balanced. As energy creation progresses at the local community level, self sustainable systems in the commercial sector and then local community will become common. Energy storage technology plays an important role for self-sustainable systems using renewable energy.
Transport
The key factors of the technology specifications for the transport sector are "energy-saving" and "fuel switching". There are two energy-saving concepts: saving energy for machine units (vehicles, ships, aircraft), and saving energy with the collaboration of total transport systems.

Saving energy for machine units
Important tasks are: i) Improvement of efficiency of engines and drive systems and ii) weight reduction of body (vehicles bodies, hulls, and airframes)

Fuel switching
i) Synthetic fuels made of natural gas or coal (for reducing oil consumption); ii) biomass fuel that is carbon-neutral, and finally, iii) shifting to hydrogen and/or electricity that emits no CO₂, are required.

Since fuel switching to hydrogen and/or electricity needs a change of engines and drive systems, the fuel switching and improvement of them should progress together.

Comparing hydrogen and electricity, hydrogen has the advantage because of its excellent storage density and fueling speed. We assume hydrogen will be utilized for all except short-range automobile and railway. For applications for which use of hydrogen and electricity is difficult, we assume hydrocarbon fuel will still be used in 2100.

Automobile
In order to reduce 80% of energy demand in 2100, all automobiles will be replaced with highly efficient fuel cell hybrid cars (using hydrogen as fuel) or electric cars. As a result, the share of electricity and/or hydrogen becomes 100%, and CO₂ emissions from vehicles become zero.

In order to reduce 60% of energy demand in 2050, total share of fuel cell hybrid cars and electric cars has to be around 40% (in stock) and at the same time, most of the remaining cars should be internal combustion engine hybrid cars.

Mainstream automobile changes: from an existing internal combustion engine car → internal combustion engine hybrid car → fuel cell hybrid car. Electric cars are mainly used as compact cars for short-range transportation. The type of fuel for internal combustion engine changes from oil to synthetic liquid fuel by 2050. During this period of transition, a mixture of oil and synthetic fuel is utilized.

Ships, aircraft, and trains
Target reduction ratios of energy consumption by 2100 are; ships: 40%, aircraft: 50% and trains: 30%.

We save weight and improve motor efficiency for domestic vessels to save energy, and after 2050, the share of the hydrogen fuel becomes dominant. Energy for ocean vessels still depends on hydrocarbon fuel in 2100 because the international energy infrastructures are not ready to provide new energy. However, we promote energy-saving and use of biomass energy and try to minimize fossil fuel consumption.

Since it is relatively difficult to use hydrogen and electricity for aircraft, hydrocarbon fuel will still be used in 2100 for aircraft.

For trains, already using electricity, and which is highly efficient, efficiency is thoroughly improved under the assumption of 100% of share of electricity and/or hydrogen.

Traffic system
The most important action is to improve energy efficiency of existing systems such as traffic controls and unattended operations (improvement and weight saving). Also we will promote a shift to or combination of railway and seaway to decrease automobile traffic (fundamental modal shift). Development of equipment and facilities, and also big changes in the social system are required, however, we target only technological tasks here and do not include improvement of energy consumption (according to changes in the social system) into the estimation.
Industry

The industrial sector supports the economic foundation of Japan, which has only poor resources, and at the same time, provides technological seeds for each sector. We picked out innovative technologies relevant to the energy that can maintain and improve our international competitiveness while solving the resource constraints and environmental constraints, which the industries in Japan are facing.

Since there are various production processes in the industrial sector, and its energy utilization systems vary, we categorize the sector into five groups (four groups of raw material industries with large-energy-consumption: iron & steel, chemicals, cement, paper & pulp, and other) for examination. The other group includes non-manufacturing industries such as agriculture, forestry and fisheries, mining industry, and building industry, and other industries such as machinery and foods.

The characteristics of four groups of raw material industries whose products are generated from natural resources and their various energy conversions are simultaneously executed in production processes, we can call raw material industries in the material production (material conversion) sector.

We can show energy consumption structure in the material production (material conversion) sector. Provided energy is categorized in the following three areas:

1. Chemical energy stored in material
2. Exergy loss mainly in burning process
3. Waste heat in processes

High level of energy use in the production process "create skillfully"

(2) and (3) are consumed energy at processes and we have to reduce them to save energy. When we recover electricity or hydrogen from (2), we use the method called co-production*. With these two methods, we aim to reduce required energy for production processes in (2) and (3)*.

*Co-production:
For example, we can generate heat, electricity, and hydrogen efficiently from gasification processes even while using fossil fuels. Since we can recover exergy that is lost in the conventional production processes as electricity or hydrogen, this method seems to generate material and energy simultaneously when the same raw material is processed.
Regeneration of material/energy "use skillfully"
As can be seen in (1), a product (material) has chemical energy inside. After the life of a product terminates, we can regenerate this (1) as material or energy. In the processes of chemical and paper production, 60% or more of the energy is stored in the material. In these processes, large improvements effected by material/energy regeneration are expected.

Moreover, the utilization of cross-boundaries becomes important in addition to the collaboration between industries, by utilizing waste for production plants across sectors and to use co-produced electricity and/or hydrogen across boundaries.

Energy reduction for production with few resources "create good things"
Improvement of functionality of products is not only essential to maintain and expand our nation’s international competitiveness, but also important tasks to provide seeds for technological innovation in each sector.

Iron & steel
The current processes by a blast furnace collect and utilize by-product gas and waste heat efficiently and their energy efficiency is extremely high. We assume that in first half of this century, improvement and updating of existing processes, introduction of new generation processes and primary energy reduction by use of waste (waste plastic, waste tire, biomass) will be realized. Also, until the supply of hydrogen using renewable energy becomes possible, by-product hydrogen becomes one of the supply sources of hydrogen. We imagine that in the latter half of this century, based on technological innovation and resources or environmental constraints, non-carbonization process of reducer and innovative iron-making processes to replace the blast furnace-converter technology will emerge. Moreover, in order to use coal as a reducer while satisfying environmental constraints, technology, which enables separation and capture of CO2 generated in iron-making processes with low temperature waste heat, is also effective.

Chemical
Since petroleum (naphtha) is used as raw material and fuel in chemical industries, it is necessary to develop a new process that does not consume oil by 2050. The current processes consist of the olefin basic pigment (such as ethylene, propylene, and BTX) production process by thermal decomposition of naphtha, and the process to produce thousands of chemicals by synthesizing basic pigments.

We think it is rational to establish a new process in which biomass, waste and coal are resolved to synthetic gas of CO and H2, to produce basic pigment olefin, and to utilize the existing production infrastructure after the synthesizing processes. Since 60% of used energy is stored as material in the chemical production, we have to reduce 40% of the energy consumed in the production processes with energy-saving technologies or co-production, and reduce required energy by gasification to regenerate 60% energy stored in materialvi.

Cement
Cement is produced from limestone as raw material, using coal etc. as major fuel. At present, waste and by-products (blast furnace slag, coal ash, sub-production gypsum, and scrap tire, etc.) are used as raw material and fuel. This system contributes to the stabilization of waste. In the future, using various waste such as slag from gas furnaces (which is supposed to be used in each sector or other industries) and non-reproductive paper from paper & pulp industry as pigment or fuel, "zero emission cement" processes without limestone and fuel is expected.
Paper & pulp
In the paper & pulp industry, 60% of products are regenerated, and they are recycled about three times generally. Black liquor from a pulp factory is utilized for a paper factory in the form of energy such as electricity and heat along with crude oil and coal. In the future, by utilizing biomass gasification combined cycle power generation facilities, we expect production processes that need no fossil fuels and can provide electricity outside.

We also expect that technology that can bring forward fast-growing timber as biotechnologies will be deployed across the industries.

Common technology in the industrial sector
Biomass and waste will become important materials and fuel mainly in the industries utilizing carbon (C) as a material. Therefore, management technology of materials will become important in the future.

Support documentation of energy technology roadmap for industrial sector is available separately.

Transformation
In order to satisfy the energy demand with reducing CO₂ intensity, the following three technology groups have to be prepared.

Effective use of fossil resources
In preparation for the oil production peak, we will execute a fuel switch to natural gas, and to coal, which has a comparably rich volume of resources. However, since coal is also a finite resource, it is important to improve effectiveness of use of fossil resources such as power generation (conversion) efficiency. Therefore, gasification power generation (fuel production) technologies and highly effective power generation technologies combined with fuel cells are required. Also, since fossil fuel generates CO₂ emission, CO₂ capture and sequestration (CCS) technologies are essential.

Nuclear power utilization technologies
Effective use of nuclear fuel resources is required. Therefore, it is fundamental to improve the efficiency of the current light-water reactor, and to establish a nuclear fuel cycle.

Renewable energy utilization technologies
It is important to improve effectiveness of power generation (conversion) by renewable energy such as solar power, geothermal, wind power and biomass. Since utilization ratio of facilities for solar or wind power is low, and these facilities need large installed capacity, technologies for easy installation are also required. Since natural energy is dependent on weather conditions, it is essential to establish large scale storage technologies and network system technologies including system control (energy management).
**Cross-boundary technologies**

Once a cross-boundary technology is established, it can work effectively in a wide range of applications. Therefore, it can be an important technology.

**Energy-saving technology**

If we can increase "utility" and at the same time, control the increase of "final energy demand", expansion of "primary energy demand", "fossil energy demand" and "CO₂ emissions" can be controlled as well. Therefore, this technology can be effective for all cases and sectors.

**Energy storage technology**

This cross-boundary technology is effective for improving the supply efficiency of large intensive power generation facilities and hydrogen production facilities (time, daily or seasonal adjustment, regional adjustment), to stabilize fluctuating electricity or hydrogen production from facilities using renewable energy sources, to utilize electricity and hydrogen efficiently in the residential/commercial sector, and to store fuel for an electric or a hydrogen vehicle.

**Power electronics technology**

This cross-boundary technology is effective for use of electricity transportation (power distribution) technologies, highly effective use of power and highly effective storage.

**Gasification technology**

This technology is effective for improvement of power generation efficiency and fuel (liquid fuel and hydrogen) production efficiency in the transformation sector, effective use of biomass and wastes, energy-saving in production processes of the industrial sector and energy creation.

**Energy management technology**

This technology is effective to control interaction between energy storage sites, to control variations of supply and demand, and to control maximum use between different energy types.

- **Others**

There are some technologies that we did not select for the roadmap development such as nuclear fusion, because they are not essential to resolve the constraints we assume at this time. However, if these technologies become available in the future, they can become options as alternative energy supply sources. If they can be introduced during the period on the roadmap, they contribute further to avoid resource constraints and environmental constraints.

We believe the results shown here can prepare for the risks of expanding energy demand in the future, which will be brought by expansion of "utility" when new products (robots and others) providing new "utility" become popular and transportation distances become longer. They also correspond to the technological specifications, which we set based on the assumption that the "utility" increases in proportion to GDP. If we can achieve these technology specifications, and the factors to reduce energy demand in each demand sector are realized, the increase of demand can be controlled. Then we can avoid further resource constraints and environmental constraints.
Examples of key factors to reduce energy demand

- Population decrease

Residential/Commercial
- Change of lifestyle according to the growing concern of energy-saving
- Saturation of energy demand in the kitchen in proportion to GDP
- Decrease of air conditioning energy by the increase of complex housing

Transport
- Progress of modal shift
- Progress of traffic system
- Decrease of need for transportation based on the increase of SOHO and change of urban structure

Industry
- Tertiary industrialization of the industrial structure
- Saturation of production needs in proportion to GDP
- Decrease of demand for production due to the paperless trend
- Decrease of demand for production due to longer operating life of production

● Image of society with the combination of three cases (highly possible image of society)

In Japan, the current capacity for geological CO₂ sequestration is considered to have limitations. We have to consider ocean sequestration to satisfy the required capacity, but there are tasks for ocean sequestration such as environmental assessment and social consensus. Case A cannot be a long-term solution when we consider the limits of fossil resources. Therefore, we think the combination of case C (utilizing renewable energy and ultimate energy-saving technologies) and case B (operating nuclear power reliably) is desirable for society on a long-term basis, by avoiding rapid climate change by CO₂ capture and sequestration as required on a mid-term basis.

However, evaluation and combination of these cases can vary according to situations in the future. It is important to prepare technologies through R&D for social and economic changes at various occasions in the future. As a result, we can acquire an optimal and robust energy system structure that can provide substitutability and compatibility as energy security, and can supply a stable amount of energy at any time flexibly within Japan.

Also, if we prepare for the three extreme cases we assumed, the advantages of each case can be provided, and then, their synergy effect enables the reduction of fossil resources consumption and CO₂ emissions, and use of fossil resources for longer periods. The final image is that we can realize zero-emission and 100% of self-sufficiency.\textsuperscript{xii}
Note: Realization image with achievement of technological specifications

If we achieve all technological specifications, the energy supply-demand structure of Japan will have a wide variety of options and we can select the optimal solution according to each situation. We show here a sample of estimation with minimum cost model based on some assumptions.

Sample estimation of final energy demand (Japan)

"Utility" will increase in proportion to GDP. Energy demand should be suppressed by energy-saving, energy creating, etc.

Note: The future estimation is one of examples based on various assumptions and conditions.

Composition of power generation and hydrogen is shifted to non-fossil energy.

Note: In 2050, while oil and gas will have certain shares in the direct use area, and supply sources of electricity and hydrogen will be shifted to non-fossil energy. We think the reason for this is that available reserves for oil and gas are set equivalent to conventional resources, and coal, which is a comparably rich resource, and renewable energy, which will become gradually reasonable, are selected in the minimum cost model.
IV. Issues in the future

1. Examination on a short term and medium term basis

This time we assumed the future constraints, executed backward examination (backcasting) and created "Energy technology vision 2100" which is an ideal image of technologies on a long term basis in this "Strategic Technology Roadmap (energy sector)".

We expect this study can be effective as infrastructure for research and development management with the addition of examination using forecasting on the basis of short term and medium term results.

2. Detailed study on key technologies

When we created the energy technology roadmap for each sector, we tried to show technologies as concretely as possible. Some technologies are not identified concretely although some alternatives exist at this point. Also, in some areas, we could not determine precisely what could be realized at the level to satisfy technology specifications in the future.

We overviewed the whole energy sector this time and considered the technological menu required for the demand sectors without focusing on the specific technology. In the case of additional examination, it is necessary to deepen discussion about the required technology menu satisfying the portfolio of technology specifications in the future.

V. Conclusion

This Strategic Technology Roadmap will be shown on the web site of the Ministry of Economy, Trade and Industry to provide information to consider strategy and details of research and development by both the private and public sectors.

Also, we will utilize this energy technology vision developed based on the backcasting methodology for future discussion on international framework on long-term and global problems. Moreover, we will try to improve it by utilizing forecasts, and utilizing them as the infrastructure for research and development management in Japan.
While the constraints and technologies have uncertainty, we compiled the future technology portfolio based on the current knowledge, and in the future, we will have to review it appropriately according to future estimations and up-to-date knowledge on technological development.

By looking to the challenging future image of technology, in addition to (i) solution of constraints of our nation, (ii) the world can have options and use excellent technologies widely that contribute to solve the global resource and environmental constraints, and (iii) we can improve technology that is one of our advantages to maintain and improve our international competitiveness over the future.

Resource constraints: What will the transition of fossil resources production and demand be like, and when will be the peak of its production? Environmental constraints: While quantitative correlations between CO₂ emission and climate change are highly uncertain, what level of emission restriction will be necessary in the future?

It is not realistic that the energy structure will become extremely imbalanced, and actually appropriate combination will be selected, but considering the uncertainty of technology, we settled on the most rigorous technology specification that can support the maximum "preparedness."

When considering the current carbon dioxide emission intensity, we can say that we have realized the highest level of energy efficiency in the world through development and deployment of technologies (the intensity of Japan is 1/3 of world’s average and 1/8 of developing countries as shown in Energy efficiency improvement in Japan)

It is not realistic that energy structure is extremely imbalanced. In the actual society, we have to select the optimal combination of three cases according to the international situations, social and economic situations including energy price trends, and technological progress. Here, we consider the uncertainty of technologies, and execute case studies based on the extreme condition to identify a technology portfolio to provide the maximum "preparedness".

If there is no change in the current linkage status in 2100, "when utility increases in proportion to GDP (= 10 times worldwide, around 2 times in Japan)", "final energy demand", "primary energy demand", "fossil energy demand" and "CO₂ emissions" increase.

The term "technology specifications" is used to represent requirements needed for a technology to resolve the assumed constraints.

It is not realistic that the energy structure will become extremely imbalanced, and actually an appropriate combination will be selected, but considering the uncertainty of technology, we settled on the most rigorous technological specifications that can support the maximum "preparedness". On the other hand, we think the technology menu for these technological specifications are not so different except for timing to acquire future options.

Work amount, which we can extract effectively from the total amount of energy is called "exergy", and extraction ratio is called "exergy rate". In order to utilize energy based on the view of exergy, we have to generate heat along with power generation and material production (exothermal reaction) as much as possible, and take necessary actions in the energy conversion and utilization processes to "utilize waste heat" and moreover, to "stop waste heat".

We call this system "sustainable carbon cycle chemical system (SC3)".

The ratio with which the domestic supply of energy is possible from the technical and infrastructure point of view, although it varies according to fuel prices.
Energy Technology Roadmap 2100
Residential/Commercial Sector

*Tentative Translation, Dec. 2006*
Concept of technological specifications in res/com sector

(1) Common constraints in all cases and sectors
- Resource constraints: Up to the production peaks (oil: 2050, natural gas: 2100), substitution of other energy resources should be realized.
- Environmental constraints: CO₂ emissions intensity (CO₂/GDP) to be reduced to less than 1/3 in 2050 and 1/10 in 2100.

(2) Technological specifications of each case
- The utility increases in proportion to GDP.
  - Case A (Maximum use of fossil resources such as coal combined with CO₂ capture and sequestration) and case B (Maximum use of nuclear energy):
    Switching the energy source supplied from the transformation sector to electricity and/or hydrogen entirely (the share of electricity and/or hydrogen in final energy demand becomes 100%).
  - Case C (Maximum use of renewable energy combined with ultimate energy-saving):
    Energy demand dependence rate on outside sources is reduced to 80% in 2100 by energy saving and energy creating.

(3) Technological specifications in 2030 and 2050 of case C
- The share of electricity and/or hydrogen (including energy supplies from transformation sector and energy creation in the residential and commercial sector itself) is 100% in 2100. The share of electricity and/or hydrogen in 2050 and 2030 are set considering the potential of energy creation, constraint of fossil resources, and so on.
- The reduction rate of energy demand in the residential and commercial sectors, and the breakdown of the reduction rate to energy saving and energy creating are studied by the "backcasting" method from the technological specification in 2100, considering the introduction of each energy source.

(4) The technological specifications and the time, etc. expected to meet the individual requirement at each time are arranged as the roadmap.

<table>
<thead>
<tr>
<th>Year</th>
<th>Share of electricity and/or hydrogen</th>
<th>Energy supplied from transformation sector*</th>
<th>Reduction by energy saving</th>
<th>Reduction by energy creating</th>
<th>CO₂ intensity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(residential/commercial)</td>
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<td>(residential/commercial)</td>
<td>(residential)</td>
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<tr>
<td></td>
<td></td>
<td>55% / 50%</td>
<td>45% / 35% reduction</td>
<td>30% / 30% reduction</td>
<td>3.5 t-CO₂/household (1 time)</td>
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<td></td>
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<td></td>
<td>60% / 55% reduction</td>
<td>35% / 45% reduction</td>
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<td>40% / 50% reduction</td>
<td>1.1 t-CO₂/household (1/3 times)</td>
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<td></td>
<td></td>
<td>70% / 70%</td>
<td>35% / 45% reduction</td>
<td>25% / 10% reduction</td>
<td>40 kg-CO₂/m² (1 time)</td>
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<td>40 kg-CO₂/m² (1/3 times)</td>
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<td>0 kg-CO₂/m²</td>
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<td>118 kg-CO₂/m² (1 time)</td>
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<td>180 kg-CO₂/m² (2/3 times)</td>
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<td></td>
<td>0 kg-CO₂/m²</td>
</tr>
</tbody>
</table>

*The percentage of the required energy reduction (per unit) from the transformation sector compared to the amount of total energy required increases in proportion to GDP.

Concept of technologies to achieve technological specifications in res/com sector

The case of "Maximum use of renewable energy combined with ultimate energy-saving" is technologically the most difficult when technological specifications are achieved with the aim of required energy reduction and CO₂ intensity in the residential/commercial sector. The R&D needs of the other cases are contained in this case. To achieve these technological specifications, the following is proposed:

(i) carry out energy saving as much as possible including the equipment that will appear in the future,
(ii) execute energy creation by using ubiquitous energies such as solar power.

Through the advancement of (i) and (ii) ultimately, "self-sustenance" which does not depend on the energy supplied from the transformation sector becomes possible. It becomes possible that surplus energy is accommodated through the energy network and moreover, this energy is utilized to the fullest, as the amount of energy creation from renewable energy increases.

(1) The energy saving is carried out in the residential sector first and in the commercial sector next by spreading state of the art equipment. In addition, the improvement of thermal insulation efficiency in houses and buildings is effective as well as the improvement of air-conditioning equipment. The introduction of heat pump systems is effective for supplying hot water.

(2) Based on regional geographical features, various types of ubiquitous energy such as photovoltaic will be introduced. According to installation opportunity (such as space) or energy price, new systems will begin to be installed in houses at first and then, installed in apartments and office buildings gradually.

(3) Electrification and/or switching to hydrogen will progress monotonically from the current level. The deployment will occur first according to the introduction of energy saving equipment and lifestyle changes such as the aging society, and then, to the increase of supplied energy of electricity and hydrogen as well as the decrease of fossil energy supplied from grids.

(4) Following energy-savings, energy creation is deployed and the "self-sustenance," which does not depend on the energy supplied from a grid, starts in houses, where demand and supply are balanced. As the energy creation progresses in a local community level, self sustainable systems in the commercial sector and then local community become common. Energy storage technology plays an important role for self-sustainable systems using renewable energy.
Energy saving

- Efficiency improvement of equipment
  - Lighting with less heat loss
  - Equipment with less heat loss
  - Improving thermal performance of housing and building → Active control of sun shading and thermal insulation
  - Efficient heating → Efficient heat transfer, preheating by unused energy
  - Improving electric power conversion efficiency → Electric power conversion with least loss
  - Food storage at room temperature

Use of ubiquitous energy
- Energy saving enables equipment using little energy
- Energy creation from ubiquitous energy

Photovoltaic generation
- Installation in all places such as PV paint
- Installation in windows
- Installation in curved surfaces
- Installation facilitation

Energy creation

- Efficiency improvement and increase of durability

Energy management

- BEMS+HEMS
- Self-sustainable housing and building
  - Demand management → Management of demand and energy creation → Energy accommodation in community
  - (Energy supply in community) → Supply and storage management in community → Self-sustainable community

Energy saving

- 2000: High efficiency lighting
- 2030: High efficiency LED
- 2050: Organic EL lighting
- 2100: Low heat loss & high efficiency lighting

Use of natural light
- Advanced use of solar light (high efficiency light focusing and transmission)
- Light storage, bio-chemical light emission

HVAC & hot water supply
- High thermal insulation, improvement of indoor air environment, improvement of wellness
- Active controllable construction material
- High efficiency heat pump, thermal storage air-conditioning, use of solar heat or unused exhausted heat
- Fuel cell cogeneration
- FC/GT hybrid system (commercial use)
- (Ultra-high efficiency FC using hydrogen)
- High efficiency hot water supply
- Vacuum insulation storage
- High efficiency heat pump

Kitchens
- High efficiency cooking
- New technology for cooking (food)
- Long time freshness of foods
- Long-term preservation at RT

Power and others
- Low power consumption PDP/LCD, high-capacity optical networking/storage
- LED/EL display
- Information appliances (Big screen display etc.)
- (High definition large screen, low power consumption)
- 45nm process SiC, GaN, AIN, etc.
- CNT transistor/diamond semiconductor, Single electron transistor

Common technology
- High efficiency devices (electric power conversion etc.)
- Thermoelectric conversion
- Piezoelectric/magnetostrictive/bio-photovoltaic conversion
- Cost reduction, high efficiency, installation facilitation
- Energy creation
- Thin film type
- Dyed-sensitized type, organic thin film type, etc.
- Super-high efficiency new type

Photovoltaic generation
- Cost reduction, high efficiency, installation facilitation
- Energy creation
- Thin film type
- Dyed-sensitized type, organic thin film type, etc.
- Super-high efficiency new type

Energy management

- Monitoring
- Cooperation with the grid
- Demand forecasting (Control including lifestyle and amenity)
- Energy accommodation
- Cooperation with energy storage system
- Cooperation with power and energy grid
- Energy storage and network
- Electric storage and network
- Local energy network (LEN)
- Hydrogen fuel cell
- Distributed energy storing

Outline

- 2000: Energy saving
- 2030: Energy saving
- 2050: Energy saving
- 2100: Energy saving

- Self-sustaining
- 0 t-CO₂/household
- 0 kg-CO₂/m²

- Energy supplied from transformation sector:
  - Residential
  - Commercial
  - CO₂ intensity
  - Residential
  - Commercial

- Energy demand:
  - Total energy demand
  - Residential
  - Commercial

- 2000:
  - 1 time
  - 45% reduction
  - 118 kg-CO₂/m² (1 time)

- 2030:
  - 1.5 times
  - 60% reduction
  - 77 kg-CO₂/m² (2/3 times)

- 2050:
  - 2.1 times
  - 80% reduction
  - 40 kg-CO₂/m² (1/3 times)

- 2100:
  - 0 t-CO₂/household
  - 0 kg-CO₂/m²

- The percentage of reduction of energy per unit should be supplied from the transformation sector, compared with total energy demand increases in proportion to GDP.
**Energy conservation**

- Energy saving is carried out in the residential sector first and in the commercial sector next by spreading state of the art equipment.
- In addition, the improvement of thermal insulation efficiency in houses and buildings is effective as well as the improvement of air-conditioning equipment. The introduction of heat pump systems is effective for supplying hot water.
- Energy management contributes to some extent to in-house energy saving in the middle term.
- Energy saving is achieved sequentially as new equipment is introduced according to the improvement of the quality of life and the change of lifestyle.

<table>
<thead>
<tr>
<th>Energy saving rate*</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Residential)</td>
<td>0%</td>
<td>30%</td>
<td>35%</td>
<td>40%</td>
</tr>
<tr>
<td>(Commercial)</td>
<td>0%</td>
<td>30%</td>
<td>45%</td>
<td>50%</td>
</tr>
</tbody>
</table>

*The percentage of reduction of energy per unit which should be supplied from the transformation sector, compared with total energy demand or utility increases in proportion to GDP.

**Lighting technologies**

- Promoting research and development of high luminous efficiency lighting device technologies, i.e. fluorescent lamps (FLs), white LED etc., with lowered heat loss, so that lighting energy consumption will be decreased by 30% in 2030 and 35% in 2050.
- Improving luminous efficiency of the mercury-free type FLs to replace conventional type high efficiency FLs after 2050.
- Developing high luminous efficiency white light source with high color rendering properties to replace incandescent lamps, and promoting use of natural light.
- Developing next generation lighting technologies including light storage to commercialize as local lighting around 2050.

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**Natural Light Use**

- **Natural lighting design architecture**
- **High efficiency light transmission technology**
- **High efficiency light focusing technology**
- **Next Generation Lighting**
  - High luminous efficiency white light source with high color rendering properties
  - Light storage and other technologies

**Non-technical factors**

- Measures of spreading state of the art equipment by "Energy Saving Labeling Program" etc.
Res/Com-8
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Air-conditioning energy saving

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate</td>
<td>40%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

- Improving the thermal performance of housing and buildings by air sealing and insulation to reduce air-conditioning energy, and keeping the indoor environment healthy and comfortable by well planned ventilation.
- Spreading high quality housing by convenient and highly accurate housing performance design and assessment technologies.
- Developing materials for thermal insulation, humidity conditioning, thermal storage, etc. and applying to building materials.

High performance construction material for housing and building

- Low thermal conductivity heat insulator (material) and insulation construction method
- Window glass with low coefficient of heat transmission and high airtight sash (material)
- Construction method of rooftop and wall greening
- Ventilation amount reduction in winter and summer with VOC reduction (adsorption and decomposition) (material)
- Building material of humidity control (material)
- Development and cost reduction of active solar control system such as external window shades
- High light reflex construction materials with self-cleaning functions by photocatalyst (material)
- Hydrophilic transpiring construction materials to promote cooling (material)
- Latent heat thermal storage construction materials improving efficiency of passive solar (material)

Housing quality assessment technology

- Housing quality design technology
- Housing quality assessment technology
- Nondestructive insulation testing technology
- Development and cost reduction of active solar control system such as external window shades
- High light reflex construction materials with self-cleaning functions by photocatalyst (material)
- Latent heat thermal storage construction materials improving efficiency of passive solar (material)

Non-technical factors

- Measures of spreading high quality housing and building with improvement of the "Housing Performance Indication Standard" etc.

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Technologies of high efficiency HVAC system

- The energy saving rate of 40% will be achieved by 2030 by spreading state of the art equipment by the "Energy Saving Labeling Program" and heat pump air-conditioners.
- The energy saving rate of 50% will be achieved by 2050 with the development of the technology for unused energy and heat sources, commercialization, and the spread (in addition to the energy saving) of equipment by 2050.
- The improvement of living space comfort according to individual lifestyles with the technology that satisfies both health/wellness and energy saving.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate</td>
<td>40%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

- Annual energy saving with improving efficiency of both COP rating and partial loading
- Heat pumps for cold district, Low GWP (Global Warming Potential) refrigerant/alternative technology
- Improving efficiency of dehumidification
- Air conditioning with separation of latent heat and sensible heat
- Highly efficient inverter for fans and pumps (commercial)
- Combined heat pumps both for refrigeration and air conditioning (commercial)
- Air conditioning with thermal storage (daily and seasonal)
- Utilize solar energy or exhaust heat for air conditioning
- Ground source heat pumps

Utilize unused energy/heat source

- Thermo control by clothing/textile
- Radiant cooling system
- Task ambient air conditioning system (commercial)
- Sound sleep AC, humidity control AC, central AC (residential)

Housing quality assessment technology

- Housing quality design technology
- Housing quality assessment technology
- Nondestructive insulation testing technology
- Development and cost reduction of active solar control system such as external window shades
- High light reflex construction materials with self-cleaning functions by photocatalyst (material)
- Latent heat thermal storage construction materials improving efficiency of passive solar (material)

Non-technical factors

- Measures of spreading state of the art equipment by the "Energy Saving Labeling Program" etc.
### Distributed power source technologies using fossil fuel

In order to utilize heat sources efficiently, improving efficiency of cogeneration using fossil fuels until 2050, and after 2050 deploying cogeneration to utilize hydrogen as an energy storage.

**Home use:** Gas engine cogeneration → Low/high temperature fuel cell → High efficiency fuel cells using hydrogen

**Business use:** Cogeneration including GE etc. → Cogeneration using high temperature fuel cells → (Hybrid system with GT etc.) → Ultra-high efficiency fuel cells using hydrogen

### Technologies of hot water supply

- Development of a high efficiency boiler with a high efficient heat pump.
- Development and spread of technologies for solar heat use and preheating of unused heat such as domestic waste heat.

---

#### Distributed power source using fossil fuel

<table>
<thead>
<tr>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home use cogeneration/High efficiency power generation</td>
<td>Improvement of power generation efficiency, further energy saving combination with high COP equipment, advancing functionality</td>
<td>Energy saving 49%</td>
<td></td>
</tr>
<tr>
<td>Small size high efficiency cogeneration</td>
<td>Power generation efficiency</td>
<td>40%</td>
<td>45-50%</td>
</tr>
<tr>
<td></td>
<td>Total efficiency</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>Gas engine cogeneration</td>
<td>Low/high temperature type fuel cell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(hydrogen-electrical power interconversion)</td>
<td>Lowering cost, extending facility life, efficiency improvement, downsizing and weight saving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business use cogeneration/High efficiency power generation</td>
<td>Power generation efficiency</td>
<td>35-45%</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Total efficiency</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>High efficiency power generation for business use</td>
<td>Cogeneration including gas engine etc.</td>
<td>High temperature type fuel cell</td>
<td></td>
</tr>
<tr>
<td>(hydrogen-electrical power interconversion)</td>
<td>Hybrid system with GT etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lowering cost, extending facility life, efficiency improvement, downsizing and weight saving</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sophisticated use of high temperature exhaust heat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Hot water supply

- Development of a high efficiency boiler with a high efficient heat pump.
- Development and spread of technologies for solar heat use and preheating of unused heat such as domestic waste heat.

<table>
<thead>
<tr>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water supply</td>
<td>Energy saving rate of hot water supply &gt;30%</td>
<td>45%</td>
<td>50%</td>
</tr>
<tr>
<td>Gas combustion type unit with recovery of latent heat</td>
<td>Thermal efficiency 80%</td>
<td>95%</td>
<td></td>
</tr>
<tr>
<td>High efficiency heat pumps</td>
<td>Instantaneous heating type (42ºC supply)</td>
<td>COP 5.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Storage tank type (65ºC supply)</td>
<td>COP 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compressor</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat exchanger</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Expansion work recovery</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Refrigerant</td>
<td>CO₂ refrigerant</td>
<td>Improvement of natural refrigerant</td>
</tr>
<tr>
<td></td>
<td>Vacuum insulation (storage tank and piping)</td>
<td>Vacuum heat insulator</td>
<td>Insulated pipe</td>
</tr>
<tr>
<td>Utilizing unused energy</td>
<td>Preheating by solar heat or unused heat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Non-technical factors**

- Measures of spreading state of the art equipment by "Energy Saving Labeling Program" etc.
**Kitchen**
- Reducing cooking energy 30% by 2030, 40% by 2050, with the development of highly efficient cooking equipment, new cooking technology, energy-saving heat-cooking vessels (shortening of cooking time) and others.
- Achieving energy-saving of 40% in residential, 50% in commercial, which are targets of energy-saving in the kitchen field with development of preserving completely cooked foods for a longer time at room temperature as well as energy-saving for cooking equipment after 2050.
- Reducing preserving energy for refrigerated/frozen foods with development of freeze-dried foods in 2050, and development of the technology for room temperature storage in 2100.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High efficiency cooking equipment</strong></td>
<td>Cooking energy reduction rate</td>
<td>40%</td>
<td>60%</td>
<td>80%</td>
</tr>
<tr>
<td><strong>High efficiency induction heaters</strong></td>
<td>Thermal efficiency</td>
<td>85%</td>
<td>90%</td>
<td>95%</td>
</tr>
<tr>
<td><strong>High efficiency natural gas/hydrogen cookers</strong></td>
<td>Cooking stove with high efficiency gas burners</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>New technology and equipment for cooking</strong></td>
<td>Combined heating cooker (combine with oven and steam-heating, etc.)</td>
<td>Energy-saving heat-cooking vessel (pasta, rice cooker, etc.)</td>
<td>New technology for cooking (ex. high pressure cooking)</td>
<td></td>
</tr>
<tr>
<td><strong>Long storage of food</strong></td>
<td>Cooking energy reduction rate</td>
<td>55%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td><strong>Production of freeze-dried food</strong></td>
<td>Freeze-drying technology</td>
<td>Freeze-drying technology of complete-cooked foods</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Long-term room temperature preservation</strong></td>
<td>Technology of complete - Technology for long time storage of complete-cooked foods at room temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Non-technical factors**
- Measures of spreading state of the art equipment by "Energy Saving Labeling Program" etc.

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**Power and other technologies**
- A variety of electric equipment is expected to be introduced in the future. High definition large screen FPD technology will represent this segment because of its trend to larger screen size and higher definition, resulting in the demand for high power consumption.
- Promoting research and development of power reduction technologies for large screen FPDs, so that their power consumption will be decreased by more than 40% in 2050.
- Promoting research of self light emission solid FPD, so that it will meet a luminous efficiency specification of 20 lm/W expectedly at 100" screen.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low power consumption PDP</strong></td>
<td>Low power consumption technology for high definition large screen PDP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High luminous efficiency PDP</strong></td>
<td>Low power consumption panel &amp; production process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High efficiency plasma discharge method</strong></td>
<td>High efficiency luminescence materials</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Low power consumption LCD</strong></td>
<td>Low power consumption technology for high definition large screen LCD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High luminous efficiency white light source</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High light transmission efficiency LCD panels</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LED, EL display</strong></td>
<td>High efficiency device technology (element, luminescent materials, thin film, etc.)</td>
<td>Panel production process</td>
<td>High definition, large screen, low power consumption</td>
<td></td>
</tr>
<tr>
<td><strong>Other display technologies</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Super thin bendable displays</strong></td>
<td>Organic TFT technology</td>
<td>Practical application of small screen display</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3D displays</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Non-technical factors**
- Possibility of great increase of electricity demand by the popularization of IT equipment, ubiquitous computing, robots, etc.
- Measures of spreading state of the art equipment by "Energy Saving Labeling Program" etc.

Jan/04/2006
Common technologies

- High efficiency power device is important to realize power saving for lighting, air-conditioning, supplying hot water, power-driven machinery, etc.
- The power device is necessary for not only the improvement of such appliances but also for energy management systems such as HEMS and BEMS.

<table>
<thead>
<tr>
<th>High efficiency device (power conversion etc.)</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output density</td>
<td>1 W/cm³</td>
<td>10 W/cm³</td>
<td>100 W/cm³</td>
<td>150 W/cm³</td>
</tr>
<tr>
<td>Power supply</td>
<td>Package type</td>
<td>Board type</td>
<td>Next generation CPU power supply</td>
<td>1MW converter</td>
</tr>
<tr>
<td>SiC devices</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitride devices</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNT transistor / Diamond semiconductors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single electron transistors (SET)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimizing line width of semiconductor circuits</td>
<td>190 nm</td>
<td>45 nm</td>
<td>22 nm process</td>
<td>Absolute minimum line width</td>
</tr>
</tbody>
</table>

Res/Com-14

Energy creating technologies

- Various renewable energy sources are introduced depending on individual characteristics of each community such as photovoltaic generation and biomass energy.
- The establishment of the technologies of installation, maintenance, and abandonment are important.
- Energy creating is disseminated to detached houses first, collective housing, and commercial buildings sequentially, according to conditions such as installation space, installation facilitation, and energy cost.

<table>
<thead>
<tr>
<th>Energy creating rate*</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>0%</td>
<td>15%</td>
<td>25%</td>
<td>40%</td>
</tr>
<tr>
<td>Commercial</td>
<td>0%</td>
<td>5%</td>
<td>10%</td>
<td>30%</td>
</tr>
</tbody>
</table>

*The percentage of creation of energy per unit which can reduce the energy supplied from the transformation sector, compared with total energy demand or utility increases in proportion to GDP.

Conversion technologies such as from unused energy to electric power

- The technical hurdles may be high.
- Energy creation will contribute to the "self-sustenance" of electric equipment along with energy saving, but the potential amount of individual energy source may be small.

<table>
<thead>
<tr>
<th>Thermoelectric conversion</th>
<th>Heat → Electricity</th>
<th>Micro power generation from unused exhaust heat, geothermal heat, solar heat, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piezoelectric conversion</td>
<td>Distortion → Electricity</td>
<td>Actuator, small sensor, and micro power generation</td>
</tr>
<tr>
<td>Magnetostrictive conversion</td>
<td>Distortion → Magnetic field</td>
<td>Actuator and micro robot</td>
</tr>
<tr>
<td>Bio-photo voltaic conversion</td>
<td>Light → Electron</td>
<td>Biosensor and biocomputer</td>
</tr>
</tbody>
</table>

Photovoltaic generation

- Development of several types of solar cells continues for the present, such as crystal silicon, thin film silicon, and dye-sensitized type, etc. The suitable solar cells will be selected from viewpoints of the generation efficiency, productivity, durability, etc.
- The solar module is diversified (lightweight, flexibility, the bifacial photovoltaics, and built-in inverter, etc.) and multifunctioned (sound insulation, thermal insulation, glare proof, etc.) to correspond to various usages and locations. Technological development is also necessary to increase additional value such as integration with construction materials and the material.
- Overall economic improvement is important, by means of more efficiency, cost reduction of the system and installation, adaptive flexibility, standardization of grid connection, increasing efficiency and reducing the cost of connecting equipment.

<table>
<thead>
<tr>
<th>Photovoltaic generation</th>
<th>Crystal Thin film type</th>
<th>Dye-sensitized type, organic thin film type, etc.</th>
<th>Super-high efficiency new type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost reduction and high efficiency</td>
<td>Module efficiency 22%</td>
<td>30% in 40 years</td>
<td>40% in 40 years</td>
</tr>
</tbody>
</table>

Installation facilitation

- Measures of deployment such as the bounty system.

Non-technical factors

- Measures of deployment such as the bounty system.

Res/Com-15
Energy management

- Energy management (HEMS/BEMS) that controls individual equipment integratively is introduced to satisfy needs of the residential and commercial for better quality. In addition, they will be integrated in communities and Town Energy Management System (TEMS) will be formed.
- The match of the energy demand is achieved with the energy supply from the photovoltaic generation and the biomass power generation, etc. from energy storage. Energy saving is promoted comprehensively by the cooperation with the electricity grid and energy system.

HEMS/BEMS

- HEMS will be introduced into all homes in Japan by 2030. The effect of energy saving by the demand forecasting and the energy management may be 10%.
- The effect of energy saving by the cooperation of the energy creation in this sector itself with the electric power and energy system may be 15%.
- BEMS will be introduced into more than half the number of the office buildings, mainly large-scale buildings, in Japan by 2030.

TEMS (Town-level Energy Management System)

- The local energy network (LEN) is formed to promote the introduction of distributed power sources such as photovoltaic generation etc.
- Energy management system in the community (TEMS) is begun as BEMS/HEMS spread.
- Energy management, including energy storage, is done along with renewable energy introduction.
- TEMS spreads and it will contribute to the control of voltage and the frequency control in power systems.

Non-technical factors

- Standardization of electric home appliances, business equipment, and IT systems.
- Development and diffusion of energy saving businesses such as ESCO and energy service providers (ESP).

Energy storage and network

- Energy storage such as electric storage begins to spread in where energy storage is needed, improvement of energy security, and measures of electricity fluctuation. The introduction will expand to measures for electricity fluctuation during day and night etc. along with the introduction of renewable energies (the amount of electric storage required for day and night is about 20 kWh/household).
- The surplus electricity which exceeds the storing capacity by the spread of renewable energy may be converted to hydrogen and the technology of hydrogen use will be put into practical use at the same time.
- Networks, including energy storage, are formed along with the spread of energy creation.
**Contribution of each energy technology in res/com sector**

In 2000, the share of the residential/commercial sector was a quarter of Japan’s final energy consumption and are approximately even in this sector. In the res/com sector, the technologies of each field listed in this roadmap may contribute to the realization of the technical specifications as follows:

The secondary energy consumption of the residential sector can be divided into one quarter air-conditioning (heating and cooling), one quarter hot water supplying, and the remaining lighting and power. The electricity consumption of the residential sector in Japan has increased substantially due to the growing use of more convenient appliances such as a warm toilet seats. The requirements for a better quality of life will continuously push up energy consumption under the BaU scenario which does not expect additional energy saving measures, however, it is somewhat different in the growing rate of each usage.

Energy consumption for commercial use has a wide variety depending on the business type such as offices, schools, restaurants, shops, hospitals, and hotels. The energy saving measures are different in the business types with large thermal demand such as hospitals and hotels and small thermal demand such as offices.

In this situation:

1. The BaU energy consumption for air-conditioning in the residential and commercial sector will likely increase as a result of a desire for better indoor air quality keeping comfortable a wider area for a longer time. However, improvement of the thermal performance of housing and buildings by the development of thermal insulating material, architectural designing, and building diagnostic technology reduce the air-conditioning energy assumed in 2050 by 50% as well as the improvement of efficiency of air-conditioning systems.

2. The energy consumption for hot water supply, which is assumed to be increasing gradually in the BaU scenario, is expected to be largely reduced by the popularization of energy saving equipment such as a high-efficiency heat pump water heaters, and utilization of cogeneration systems, etc.

3. Though the ratio of the energy consumption of the lighting to the whole is not so large, the large energy saving by its R&D can be expected.

4. For the kitchen, power, and other, the largest growth of consumption energy is supposed by the progress of conventional appliances such as big screen TVs, use of health appliances and IT equipment, and installation of electrical cooking appliances, as well as the arrival of new equipment, according to the lifestyle change such as the aging society and electrification. The efficiency improvement of electrical equipment such as TV, minimizing the standby energy loss, and so on are important technologies.

5. High efficiency switching devices, which are widely used for power sources and control of electric appliances, are the common basic technologies of various fields to maximize the effectiveness and minimize energy use.

6. For the energy creation from surrounding energy, the photovoltaic power generation is the technology which is most commonly applicable in the residential and commercial sector. The development of building materials and construction technologies are important as well as the R&D of the solar cell itself, in order for the photovoltaic system to spread widely with low cost to various space in buildings, facilities, and unused space without diminishing the original function. It is also necessary to attempt deploying other renewable energies such as biomass, wind power, etc. and unused energies such as the thermoelectric conversion according to the characteristics of detached houses and commercial buildings.

7. Energy management technology, such as an automatic lighting control and air-conditioning control, will be certainly efficient for energy saving besides the efficiency improvement of individual equipment. As the amount of introduction of renewable energy increases by the progress of energy creation, the optimum energy management by HEMS and BEMS with the electric storage system will be one of the key energy technologies at the stage of "self-sustainable" operations in household or building units. Furthermore, at the stage of the further spread of renewable energy, TEMS (Town-level Energy Management System) becomes an important technology for energy accommodation, energy storage, and quality control of supplied energy (for example, power voltage and frequency in the case of electricity).

The figure shown on the next page shows an example of tentative estimation of energy saving and creation from 2000 to 2050 for a three-person household.

---

**A tentative estimation of the breakdown of energy saving and creation by usage in the residential sector**

Assumed for three person detached household in Tokyo by Res/Com SWG

- Increasing energy in BaU
- Improving efficiency of thermal insulation
- Improving efficiency of HVAC & hot water supply
- Improving efficiency of electric appliances
- Energy creation

*Including kitchen instruments such as refrigerators, microwave ovens, ventilators, and so on, as well as ranges.*
Energy Technology Roadmap 2100
Transport Sector

*Tentative Translation, Dec. 2006*
Concept of technology specifications in transport sector

(1) Common constraints of all cases and sectors
- Resource constraints: Up to the production peaks (oil: 2050, natural gas: 2100), substitution of other energy resources should be realized.
- Environmental constraints: CO2 emissions intensity (CO2/GDP) to be reduced to less than 1/3 in 2050 and 1/10 in 2100.

(2) Technology specifications of each case
- It is assumed that the utility (person-km and ton-km) increases in proportion to GDP and the share of each transport mode such as automobiles, aircraft, ships, and trains do not change.
- Case A (Maximum use of fossil resources such as coal combined with CO2 capture and sequestration) and case B (Maximum use of nuclear energy)
  Most of oil demand will shift to synthetic fuel by 2050. The share of electricity and/or hydrogen will be 100% in 2100.
- Case C (Maximum use of renewable energy combined with ultimate energy-saving)
  In consideration of the balance of the environmental constraint and energy saving possibilities between the end use fields in 2100, it aims at the energy saving for each utility of 70% in the transport sector. In addition, the automobile sets the energy saving of 80% as a technological specification in consideration of the energy saving possibility according to each transport mode in 2100. The share of electricity and/or hydrogen of 100% is necessary to achieve the technology specifications.

(3) Technology specifications in 2050 of case C
- The energy saving technology specifications for the entire transport sector and for each transport mode are set with consideration of backcasting from technology specifications in 2100 as well as the balance of the common constraints and the energy saving possibility in the end use sectors. The share of electricity and/or hydrogen required for achieving the energy saving technology specifications on automobiles are set.

(4) Milestones in 2030 are set with back casting based on the requirements in 2050 and 2100
- For example, hydrogen/electric vehicles are required to be commercialized to compete in the market in 2030 if 40% of electricity and/or hydrogen use is to be achieved in 2050.

(5) A roadmap of technology specifications expected to meet requirements at each time

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility (person-km, ton-km)</td>
<td>1 time</td>
<td>1.5 times</td>
<td>2.1 times</td>
<td></td>
</tr>
<tr>
<td>Energy supplied from transformation sector* (overall)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automobiles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share of electricity and/or hydrogen</td>
<td>0%</td>
<td>30% reduction</td>
<td>60% reduction</td>
<td>80% reduction</td>
</tr>
<tr>
<td>CO2 intensity</td>
<td>180 g-CO2/km (1 time)</td>
<td>100 g-CO2/km (2/3 times)</td>
<td>50 g-CO2/km (1/3 times)</td>
<td>0 g-CO2/km</td>
</tr>
<tr>
<td>Aircraft, ships, and trains</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-20% reduction</td>
<td>20-35% reduction</td>
<td>30-50% reduction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The percentage of reduction of energy per unit should be supplied from the transformation sector, compared with utility increases in proportion to GDP.

Transport-2

Concept of technology group for technology specifications achievement in transport sector

The key factors of the technology specifications for the transport sector are "energy-saving" and "fuel switching". There are two energy-saving concepts: saving energy for machine units (vehicles, ships, aircraft), and saving energy with the collaboration of total transport systems.

In saving energy for machine units, important tasks are: i) improvement of efficiency of engines and drive systems and ii) weight reduction of body (vehicles bodies, hulls, and airframes).

For fuel switching, i) synthetic fuels made of natural gas or coal (for reducing oil consumption); ii) biomass fuel that is carbon-neutral, and finally, iii) shifting to hydrogen and/or electricity that emits no CO2 are required. Since fuel switching to hydrogen and/or electricity needs a change of engines and drive systems, the fuel switching and improvement of them should progress together. Comparing hydrogen and electricity, hydrogen has the advantage because of its excellent storage density and fueling speed. We assume hydrogen will be utilized for all except short-range automobile and railway. For applications for which use of hydrogen and electricity is difficult, we assume hydrocarbon fuel will still be used in 2100.

(1) Automobile
- In order to reduce 80% of energy demand in 2100, all automobiles will be replaced with highly efficient fuel cell hybrid cars (using hydrogens as fuel) or electric cars. As a result, the share of electricity and/or hydrogen becomes 100%, and CO2 emissions from vehicles become zero.
- In order to reduce 60% of energy demand in 2050, total share of fuel cell hybrid cars and electric cars has to be around 40% (in stock) and at the same time, most of the remaining cars should be internal combustion engine hybrid cars.
- Mainstream automotive changes: from an existing internal combustion engine car → internal combustion engine hybrid car → fuel cell hybrid car. Electric cars are mainly used as compact cars for short-range transportation. The type of fuel for internal combustion engine changes from oil to synthetic liquid fuel by 2050. During this period of transition, a mixture of oil and synthetic fuel is utilized.

(2) Ships, aircraft, and trains
- Target reduction ratios of energy consumption by 2100 are; ships: 40%; aircraft: 50% and trains: 30%.
- We save weight and improve motor efficiency for domestic vessels to save energy, and after 2050, the share of the hydrogen fuel becomes dominant.
- Energy for ocean vessels still depends on hydrocarbon fuel in 2100 because the international energy infrastructures are not ready to provide new energy. However, we promote energy-saving and use of biomass energy and try to minimize fossil fuel consumption.
- Since it is relatively difficult to use hydrogen and electricity for aircraft, hydrocarbon fuel will still be used in 2100 for aircraft.
- For trains, already using electricity, and which is highly efficient, efficiency is thoroughly improved under the assumption of 100% of share of electricity and/or hydrogen.

(3) Traffic system
- The most important action is to improve energy efficiency of existing systems such as traffic controls and unattended operations (improvement and weight saving).
- Also we will promote a shift to or combination of railway and seaway to decrease automobile traffic (fundamental modal shift). Development of equipment and facilities, and also big changes in the social system are required, however, we target only technological tasks here and do not include improvement of energy consumption (according to changes in the social system) into the estimation.
Efficiency improvement of automobiles
- The amount of utility (≈ vehicle number × running distance) supplied by automobiles increases in proportion to GDP.
- The efficiency improvement in power trains and energy saving by weight reduction is necessary to improve energy intensity.
- In order to decrease energy intensity and CO2 intensity drastically in the future, hydrogen fuel cell vehicles or electric vehicles that have high efficiency and don't emit CO2 should become mainstream.

Internal combustion engine (ICE) hybrid vehicles
- As for vehicles mainly used for intraregional driving such as pickup trucks and passenger cars, the shift to a hybrid system will progress, and non-hybrid vehicles will not be used by about 2050.
- The use of ICE hybrid vehicles for long-distance vehicles such as heavy-duty trucks will not advance because the advantage of hybridization is small (shift directly from conventional ICE vehicles to FC vehicles).
- Fuel efficiency improvement by weight reduction is expected for both conventional vehicles and hybrid vehicles.
- All ICE vehicles will disappear by 2100.
- When the HCCI engine is put to practical use, three kinds of engines will be integrated into two kinds (or even one).

The value of fuel efficiency is a ratio to that of current ICE vehicles (including the effect of weight reduction)

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional ICE vehicles</td>
<td>Vehicle weight reduction, engine efficiency improvement</td>
<td>1.5 times</td>
<td>2 times</td>
<td></td>
</tr>
<tr>
<td>ICE hybrid vehicles</td>
<td>Vehicle weight reduction, engine efficiency improvement, motor and power conversion efficiency improvement, system control improvement</td>
<td>(Shift to FC hybrid vehicles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy-duty trucks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional ICE vehicles</td>
<td>Vehicle weight reduction</td>
<td>(Shift to FC hybrid vehicles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel efficiency</td>
<td>1.5 times</td>
<td>2 times</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline engines</td>
<td>Efficiency improvement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel engines</td>
<td>Exhaust cleaning technology</td>
<td>Application expansion to passenger cars</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCCI engines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batteries for hybrid systems</td>
<td>Nickel-MH, Li-ion, Capacitor</td>
<td>(Apply to FC hybrid vehicles)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fuel efficiency 1.5 times 2 times

Non-technical factors
- Measures for the improvement of fuel efficiency by the "Top Runner Standards" of "Energy Saving Labeling Program" etc.
- Taxation discount and subsidies to gas-sipper (fuel efficient cars)

Fuels for internal combustion engine vehicles
- Fuels for ICE will shift from petroleum fuels to synthetic fuels by 2050. During the shift process, mixed petroleum fuels and synthetic fuels are assumed.
- Ethanol (or ETBE) and FAME have the possibility to be introduced in the early stage, but neither of them become a main component of the fuels due to their restricted supply.
- FT synthesis oil will be introduced as a blend component to diesel oil at first. In order to use FT synthesis oil for gasoline engines, processing technology development for high octane number fuel is necessary. The application will be later than that for the diesel engine. Also, synthetic gasoline by way of methanol produced from natural gas or coal may be used.
- The specifications of the fuel for HCCI engines are uncertain at the present time. There is the possibility that the fuels will be integrated into two kinds (or even one) in association with the integration of engines.
- Additionally, the use of DME, CNG, and LPG contributes to oil substitution and CO2 emissions reduction.

For gasoline engines
- Ethanol or ETBE
- Synthetic gasoline (by way of FT synthesis)
- Synthetic gasoline (by way of methanol)

For diesel engines
- Fatty acid methyl ester (FAME)
- Synthetic diesel oil (FT synthesis)

For HCCI engines
- New fuel for HCCI engines

Non-technical factors
- Taxation discounts on new fuel
- Revision of fuel standards and adjustment with exhaust emissions regulations
**Fuel cell hybrid vehicles**

- Fuel efficiency is a ratio of the mileage for each consumption of the unit hydrogen which is converted to that of gasoline (or diesel oil). The weight and volume of the hydrogen tanks are critical to secure a driving range of 500 km.
- The most important challenge is performance improvement of on-board hydrogen storage technology. The efficient improvement of fuel cells and vehicle weight reduction also contribute to the decrease of the weight and volume of the hydrogen tanks. High performance is requested for hydrogen storage technology to be applied to heavy-duty trucks.
- The hydrogen supply will start with the use of by-product hydrogen and on-site reforming of hydrocarbons, and then on-site water electrolysis becomes mainstream with an increase in fossil fuels prices. It is assumed that concentrated production with pipeline transportation may be done in regions where enough demand density is realized through the increasing consumption of hydrogen.

**The value of fuel efficiency is a ratio to that of current ICE vehicles (including effect of weight reduction)**

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passenger cars</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC efficiency improvement, weight reduction of hydrogen tanks and vehicles, motor and electric power conversion efficiency improvements</td>
<td>3 times</td>
<td>4 times</td>
<td>5 times</td>
</tr>
<tr>
<td>Hydrogen tank weight</td>
<td>170 kg</td>
<td>30 kg</td>
<td>20 kg</td>
</tr>
<tr>
<td>Hydrogen tank volume</td>
<td>300 L</td>
<td>50 L</td>
<td>30 L</td>
</tr>
<tr>
<td><strong>Heavy-duty trucks</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen tank weight</td>
<td>1.2 times</td>
<td>1.5 times</td>
<td>2 times</td>
</tr>
<tr>
<td>Hydrogen tank volume</td>
<td>4.2 t</td>
<td>500 kg</td>
<td>350 kg</td>
</tr>
<tr>
<td><strong>Common technologies</strong></td>
<td>Fuel cells</td>
<td></td>
<td>Motor</td>
</tr>
<tr>
<td>Efficiency</td>
<td>50%</td>
<td>55%</td>
<td>55%</td>
</tr>
<tr>
<td>Output density</td>
<td>1 kW/L</td>
<td>Several kW/L</td>
<td>Several kW/L</td>
</tr>
<tr>
<td>Motor (Induction motor)</td>
<td>Permanent magnet synchronous motor</td>
<td>In-wheel motor</td>
<td>Superconducting motor (large-sized vehicles)</td>
</tr>
<tr>
<td>Motor Efficiency</td>
<td>90%</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Electric power conversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>93%</td>
<td>99%</td>
<td>99%</td>
</tr>
<tr>
<td>Power density</td>
<td>1 W/cm³</td>
<td>10 W/cm³</td>
<td>100 W/cm³</td>
</tr>
<tr>
<td><strong>Vehicle weight reduction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Air-conditioning energy saving</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Solar cell roof**

- Cell efficiency: 30%

---

**Hydrogen storage technology**

- Storage density represents system storage density

<table>
<thead>
<tr>
<th>Storage density</th>
<th>3 wt%, 17g/L</th>
<th>9 wt%, 80g/L</th>
<th>12 wt%, 95 g/L</th>
<th>15 wt%, 118 g/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refueling time</td>
<td>5 minutes</td>
<td>2 minutes</td>
<td>5 minutes</td>
<td>5 minutes</td>
</tr>
</tbody>
</table>

**Storage materials**

- Inorganic systems: Mg, Li, N

**Compression/alloy systems**

- Low temperature/carbon: 40 g/L, 6 wt%
- Organic systems: 7 wt%

**Liquefied hydrogen**

- Liquefaction technology: Magnetic and gasified hybrid freezing
- Magnetic refrigeration

<table>
<thead>
<tr>
<th>% Carbon</th>
<th>30%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>1 day</td>
<td>1-10 days</td>
<td>10 days</td>
<td>10 days</td>
</tr>
</tbody>
</table>

**Thermal insulated tanks (on board)**

- Storage without release: BOG, Storage without release
- Innovative heat insulator and tank material

<table>
<thead>
<tr>
<th>Storage capacity</th>
<th>5 - 7 %/day</th>
<th>0.5%/day</th>
<th>&lt;0.1 %/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>14 days</td>
<td>30 days</td>
<td>30 days</td>
</tr>
</tbody>
</table>

**Hydrogen supply technology**

- Hydrogen stations
- Hydrogen production and supply technologies
- Centralized production and supply
- Forecourt production and supply

- Hydrogen supply networks developed by governmental investments, a strong initiative to introduce FCV into public vehicles, and FCV special zones
- Incentives to convert to FCV and a hydrogen society (favorable tax changes, higher priority on parking lots, and deregulation for driving into restricted places, etc.)
- Establishment of standards for FCV, fuel and hydrogen fueling equipments, and technological standards (both national and international)
- Promotion of maintenance industries and recycling systems for parts and materials of FCV.

Jan/04/2006
### Electric vehicle

- Fuel efficiency is a ratio of the mileage for each amount of the unit charged electric power which is converted gasoline (diesel oil) equivalent. The weight of electricity storage devices is critical to secure a driving range of 200 km.
- The energy density improvement and life extension of electricity storage devices are the most important challenges. Fuel efficiency improvement by body weight reduction also contributes to the weight decrease of the electricity storage devices. Small and light vehicles are easily converted to electric vehicles.
- The practical technologies with a moderate performance have been established for motors and electric power converters. After the prospect of electricity storage technology is established, the development of vehicles, new technologies for charging equipment, and extra power units, are started.
- For distance requirement of 200km or more, a satisfactory result may be achieved by the addition of a small extra power unit (several kW) only when necessary.
- There is a possibility that plug-in hybrid vehicles, which are both fueled and charged (refer to appendix 3), are put to practical use before pure 100% electric vehicles.

### The value of fuel efficiency is a ratio to that of current ICE vehicles (including the effect of weight reduction)

<table>
<thead>
<tr>
<th>Year</th>
<th>Weight reduction of battery and vehicle, motor and electric power conversion efficiency improvement</th>
<th>Supplementary power supply with solar cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>4 times 200 kg</td>
<td>5 times 160 kg</td>
</tr>
<tr>
<td>2030</td>
<td>6 times 600 kg</td>
<td>6 times 70 kg</td>
</tr>
<tr>
<td>2050</td>
<td>4 times 300 kg</td>
<td>4.5 times 220 kg</td>
</tr>
<tr>
<td>2100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Non-technical factors

- Charging facility network development by government investment, a strong initiative to introduce electric vehicles in the public sector, electric vehicle special zones
- Incentives to convert to electric vehicle (favorable tax changes, higher priority in parking lots, and deregulation for driving into restricted places, etc.)
- Establishment of standards for electric vehicles and charging systems, and technological standards (both national and international)
- Promotion of maintenance industries and a recycling system for parts and materials of FCV.

---

### Table

<table>
<thead>
<tr>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 kg</td>
<td>600 kg</td>
<td>600 kg</td>
<td>600 kg</td>
</tr>
<tr>
<td>200 kg</td>
<td>600 kg</td>
<td>600 kg</td>
<td>600 kg</td>
</tr>
<tr>
<td>200 kg</td>
<td>600 kg</td>
<td>600 kg</td>
<td>600 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>200 kg</th>
<th>600 kg</th>
<th>600 kg</th>
<th>600 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 kg</td>
<td>600 kg</td>
<td>600 kg</td>
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</tr>
<tr>
<td>200 kg</td>
<td>600 kg</td>
<td>600 kg</td>
<td>600 kg</td>
</tr>
<tr>
<td>200 kg</td>
<td>600 kg</td>
<td>600 kg</td>
<td>600 kg</td>
</tr>
</tbody>
</table>

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### Transport-10

### Transport-11
Vehicle weight reduction

- Vehicle weight reduction will progress with the use of light-weight (high-strength) materials and the shift to smaller passenger cars.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle weight</td>
<td>20% reduction</td>
<td>30% reduction</td>
<td>50% reduction</td>
<td></td>
</tr>
</tbody>
</table>

Light weight materials

- Various materials will be used in proper places as they are currently being used.

<table>
<thead>
<tr>
<th>Material</th>
<th>Strength 50 - 60 kgf/m²</th>
<th>150 kgf/m²</th>
<th>200 kgf/m²</th>
<th>250 kgf/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super-high-tensile steel</td>
<td>100 kgf/m²</td>
<td>300 kgf/m²</td>
<td>500 kgf/m²</td>
<td>700 kgf/m²</td>
</tr>
<tr>
<td>High tension aluminum</td>
<td>150 kgf/m²</td>
<td>200 kgf/m²</td>
<td>250 kgf/m²</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>150 kgf/m²</td>
<td>200 kgf/m²</td>
<td>250 kgf/m²</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>300 kgf/m²</td>
<td>400 kgf/m²</td>
<td>500 kgf/m²</td>
<td></td>
</tr>
</tbody>
</table>

Compound materials (CFRP etc.)

- High-speed molding technology: Application expansion to panel material to application to Structural material

Common characteristics

- Cost reduction, joint technology for different materials, recycling technology, safety design technology, transformation destruction behavior clarification, and simulation technology

The shift to smaller passenger cars

- Incentives and user consideration in the shift to smaller passenger cars

Aircraft

- The main technology for energy saving includes airframe improvement and engine efficiency improvement. 50% reduction in energy consumption is expected to unify both.
- Jet fuel will shift from the present petroleum to synthetic fuels in the future. In order to minimize reconstruction of the fuel supply network, it is preferable that synthetic fuels can be used as a mixture with petroleum fuels at an arbitrary ratio.
- A possibility of hydrogen use in aircraft will be examined when the hydrogen use for automobiles and ships, etc. is generalized in the future.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption</td>
<td>20% reduction</td>
<td>35% reduction</td>
<td>50% reduction</td>
<td></td>
</tr>
<tr>
<td>Weight reduction, aerodynamic efficiency improvement</td>
<td>(contribution to energy consumption reduction)</td>
<td>5% reduction</td>
<td>10% reduction</td>
<td>15% reduction</td>
</tr>
<tr>
<td>Performance improvement of each component, advanced control technology, innovative material applications</td>
<td>Improvement of engine form (super-high by-pass ratio and intelligent engines, etc.)</td>
<td>15% reduction</td>
<td>25% reduction</td>
<td>35% reduction</td>
</tr>
<tr>
<td>Engine efficiency improvement</td>
<td>(contribution to energy consumption reduction)</td>
<td>15% reduction</td>
<td>25% reduction</td>
<td>35% reduction</td>
</tr>
<tr>
<td>Alternative fuel for engines</td>
<td>Synthetic fuel (produced from natural gas, coal, or biomass, mixed use with petroleum fuel)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Non-technical factors

- Pursuit of thorough safety
Transport-14

Jan/04/2006

- Various energy saving techniques are synthesized, energy consumption of ships is expected to decrease by 40% in 2100.
- Ships for domestic voyages will use hydrogen fueled electric drive because they can use a domestic hydrogen infrastructure for hydrogen FC vehicles (because the efficiency of large-scale hydrogen diesel engines is excellent, the mainstream will be electric for small ships and hydrogen ICE engines for medium to large ships). The shift advances following development of equipment and infrastructure for land transportation. Because of the long life of a ship, the shift period is also long (20 years or more).
- As for foreign ships, the use of fossil fuels or synthetic fuels will be mainstream because international ships would suffer hydrogen shortage when returning. The transport system between hub ports with super ships of hundred thousand-ton class will be constructed for main lines, and given over to a local network. Development of a marine transportation system which can rationalize mixed loading and concentration on the vessel is indispensable.
- If the import of fossil fuels, which accounts for large proportions in present marine transportation, decreases in the future, a decrease in marine transport demand by half could result in reduction of energy consumption and CO₂ emissions in this sector. The amount of import biomass will also affect the demand of marine transportation.

<table>
<thead>
<tr>
<th>For domestic voyage</th>
<th>Energy consumption</th>
<th>10% reduction</th>
<th>20% reduction</th>
<th>40% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight reduction of small crafts</td>
<td>Share of Electricity/hydrogen</td>
<td>0%</td>
<td>0%</td>
<td>30%</td>
</tr>
<tr>
<td>Electric drive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vessel shape optimization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimization of decentralized propeller arrangement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimal control Two or more power</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| For international voyages | | | |
| Large freighters | | | |
| Sailing speed optimization | | | |
| Electric drive | | | |
| Diversification fossil fuel use | | | |
| Nuclear-powered ships (nuclear power maximum use case) | | | |

Transport-15

Jan/04/2006

- Development of a marine transport system with hub ports as a main component
- Integrated construction harbors, railways, and roads
- Standardization of hydrogen equipment (same as that for automobiles)

Marine transport system

- Hub port network
- Cooperation with ground transportation
- Large quantities, regularity, and low-speed operation management

Fuel

- Alternative fuels for engines
- Synthetic fuel (produced from natural gas, coal, or biomass, mixed use with petroleum fuel)
- Hydrogen
- Nuclear fuel (nuclear power maximum use case)
The utilization rate of regenerative breaking power improves with the use of aerial conductor/battery hybrid trains in the electrification section where it accounts for about 90% of energy consumption. Integrating the effect of weight reduction and motor and electric power converter improvement, energy consumption will be reduced by 30% in 2100.

- The energy consumption in the non-electrification section is reduced by introducing diesel/battery hybrid trains and FC/battery hybrid trains. Because the non-electrification section accounts for a small share in railway energy consumption in Japan, a quantitative effect will be small though the efficiency improvement of the unit is large.

- The share of electricity and/or hydrogen becomes 100% by introducing FC/battery hybrid trains.

### Transport systems

- In addition to the sophistication of transport machines such as automobiles, trains, ships and vessels, and aircraft, realization of a highly energy efficient society with a different transport system than the existing one.

- Category 1 defines the number included as reduction in energy consumption in technology specifications. Category 2 defines the number excluded as reduction in energy consumption in technology specifications (considered as additional measures).

### Category 1: Measures of social system in the transport system by land, sea and air

**Examples**

- Not only the realization of drastic reductions in the weight of automobiles but also sophistication of their safety facility by intellectual system operation
- Improvement of energy and time efficiency by further strengthening ITS and realizing optimal control of road traffic flow within the region
- Efficiency of routine transportation by steady operation although at low speed
- Reduction in traffic flow density achieved by late night transportation, using low noise technologies, and a simplified infrastructure

### Category 2: Improvement of overall energy efficiency by means of measures combining different transport systems which complement each other

**Examples**

- Reasonable combination of long-haul transportation such as ships, trains and trucks and intraregional transportation (modal shift and hybrid transportation)
- An around-the-clock automatic sorting system for containerized packages at the logistical nodal point such as ports and train terminals
1. Development procedure of the technology road map for transport sector

Energy saving technology specifications in 2050 for transport sector

Performance milestone

Leading technology in 2100

Common technology for automobiles

Bridging technology

Existing technology

Energy saving technology specifications in 2050 for automobiles

Energy saving technology specifications in 2100 for transport sector

Performance milestone

Share composition required for technological specifications achievement

Energy saving technology specifications in 2050 for automobiles

Technology composition demand performance for technology specification achievement

(1) (5) (6) (7) (2)

Hydrogen demand
Electricity demand
Fuel demand

2. Image of share according to vehicle type and secondary energy demand

Long distance vehicles (heavy-duty truck etc.)

Intraregional running cars (passenger cars and pickup trucks, etc.)

Jan/04/2006
3. Position of ICE vehicles, electric vehicles, and various hybrid vehicles

- A variety of hybrid vehicles (HV) have been designed and put to practical use. Various hybrid vehicles, conventional ICE vehicles, and pure electric vehicles (pure EV) are located in the spindle in wheel drive power (From what is driving power directly gained?) and replenishment energy (What is the energy replenished with vehicles?) on a horizontal axis. Conventional ICE vehicles and pure EVs are located in the two extreme corners.
- Though the motor assists driving power in parallel HVs, regenerative braking contributes to fuel efficiency improvement. A feature of Series-parallel HVs compared with parallel HVs is that it has a driving mode in which only the motor drives the wheel.
- In series HVs, all the engine power changes into electric power and the power driving the wheel is supplied only by the motor. FC HVs are included in series HVs. The energy replenished with the vehicle is only a fuel even here.
- Plug-in HVs, which have been recently proposed in the United States, are a modified version of series, series-parallel, or parallel HVs which are able to be charged by grid power in order to use the electricity as a supplement. If the electric power charged from the grid is used with priority, it saves on the running cost because electric power is cheaper than fuels in general.
- A range extender is a small generator to be installed in pure EVs to extend the driving range. The range extender EVs are located a little left from pure EVs.
- Vehicle efficiency rises from conventional ICE vehicles to pure EVs. On the other hand, the required capacity of batteries and the vehicle cost increases accordingly.

4. Comparison of energy storage densities of hydrogen, electric power, and liquid fuel

(Notes)
1) Lower heating value (LHV).
2) The values of storage density of hydrogen and electricity are referred to in the current performance and maximum values described in the road map.
3) The storage density of gasoline is a presumption value.
4) The volume based storage density of electricity is calculated with a specific gravity of batteries of 1.6.
5) Total weight of tank and fuel
6) The value of vehicle fuel efficiency factor is a ratio of the mileage for each LHV of stored energy compared to gasoline vehicles (Fuel cell vehicles are assumed for hydrogen and electric vehicles are assumed for electricity).

<Comments>
(1) Weight base comparison
The hydrogen storage density of 3 wt% is equivalent to energy storage density of 867 kcal/kg-tank, which is about 1/10 of that of gasoline, while it will be improved to about 1/2 with the hydrogen storage performance of 15 wt%. Taking good fuel economy of hydrogen fuel cell vehicles into consideration, 3 wt% for hydrogen storage corresponds to about 30% of energy storage performance of gasoline tanks. The fuel efficiency factor of 2 times (assumed value for heavy-duty trucks), the hydrogen storage density of 15 wt% is almost equivalent to gasoline tanks. The technology specifications for the fuel economy factor of hydrogen aircraft, hydrogen fuel cell ships, and hydrogen fuel cell trains at 2100 in this road map are about 2 times, 1.7 times, and 2 times, respectively. (They are compared to the current fossil and engine technologies.) The energy storing density of batteries is smaller than that of hydrogen by one order of magnitude. Even if it is improved to 300Wh/kg, and the fuel efficiency of electric vehicles increased by a factor of 6, it would reach only 17% of gasoline.

(2) Volume base comparison
In the volume base comparison, the values for hydrogen are lower than those in the weight based comparison, while a little higher for electricity. The relative relation among gasoline, hydrogen, and electricity doesn't change.
5. Fast charge and battery exchange as the electric power replenishment system

The fuel cell vehicle is assumed in this roadmap to be the vehicle which is capable of being used for long-distance driving as it is considered that the electric vehicle will not become mainstream easily due to restrictions of the fast charge and battery exchange (described below) although it is an option that has excellent characteristics from the perspective of energy efficiency and CO₂ reduction. It is also assumed that the lightweight electric vehicle mainly for short-distance driving demands will spread widely after a step delay as the performance of the power storage system will be improved along with the development of FCV. Also charging only when stopping at garages, parking lots, etc. is assumed as a realistic electric power replenishment for the electric vehicle.

### Fast charge

- The electric power needed for fast charge has been calculated.
- The consumption energy is 295 Mcal when running 500km by gasoline vehicles with a fuel efficiency of 10 km/L. In the case of 4 times the fuel efficiency for electric vehicles the amount of energy is 99 Mcal (~115 kWh). If it is charged in five minutes, assuming the product of charger efficiency and battery efficiency is 0.80, the required power would be 1,700 kW. Though the amount of necessary energy decreases in the case of 6 times the fuel efficiency for electric vehicles, electric power of 2,800 kW is needed for the same replenishment time as gasoline vehicles (2 minutes).
- Flow rate of gasoline of 0.42 L/sec corresponds to 14,000 kW and flow rate 170-250 L/sec of hydrogen gas corresponds to 1,800-2,800 kW.
- If it is charged in five minutes, assuming the product of charger efficiency and battery efficiency is 0.80, the required power would be

### Battery exchange

- It is not realistic from the viewpoint of equipment and operation safety to prepare charging facilities of such capacity everywhere.
- In other words, the battery exchange has a possibility to become a business which trades batteries (both brand new and used) while it is difficult to establish a business which trades only electricity.

1. There may be a possibility where a vehicle user buys and exchanges two or more battery sets. However, there are the following problems:

   1. When a quick battery exchange is required, the freedom of design on the battery arrangement is limited. The requirement will hinder a compact battery size arrangement with enough battery power.
   2. The economical efficiency decreases due to the cost of the battery for exchange.
   3. Exchange of battery with a high voltage of 100 V or more, which is common in present-day electric vehicles, by a general vehicle user is not acceptable from a safety point of view. The vehicle manufacturers will not include the changed battery in the object of the guarantee. On the other hand, if the voltage level is lowered, it becomes disadvantageous with respect to efficiency and cost.
   4. It is useless for a long distance driving.

6. Energy supplementation possibility by photovoltaics in automobiles and ships

When the performance of photovoltaics such as power generation efficiency and equipment weight improves remarkably, their use is assumed as a propulsion power supplier for automobiles and ships. Calculations for trucks with a flat roof and foreign voyage large-scale freighters with a large unemployed deck are shown here as an example.

There is a possibility that the output of photovoltaics can cover from several to 10 % of the power necessary for operation (it is assumed to be 50% of maximum engine power for trucks and 80% of that for ships) in fine weather as shown in the tables below. Though the contribution rate for ships rises further with the use of larger and lower speed ships, "self-sustenance", which means non-reliance on a commercial energy supply, will be difficult.
7. Possibility of energy consumption reduction by modal shift

- The amount of passenger transportation was 2.1 trillion people-km in 2000. The share of automobiles, trains, and aircraft is 67%, 27%, and 6% (on the left end of Fig. 2), respectively.
- The amount of transportation of the freight section in 2000 was 580 billion ton-km. Automobiles (57% share) and ships (40%) occupy the majority (on the left end of Fig. 6).
- When the amount of transportation increases by a factor of 2.1 in 2100 from the fixed share in 2000, energy consumption in the passenger section decreases by about 50% (Figure 3), the freight section decreases by 30% (Fig. 7) because of fuel efficiency improvement of each transport machine (Fig. 1 and Fig. 5).
- When a modal shift from automobiles to trains advances (the right edge of Fig. 2 for passenger section and the right edge of Fig. 6 for freight section), the sum of the energy demand of automobiles and trains decreases by about 40% (Fig. 4 and Fig. 8) *.

* Passenger section (in 2100):
  - The shift from automobiles to trains decreases energy consumption by 11 PJ per share of 1%.
  - The shift from trains to aircraft increases energy consumption by 21 PJ per share of 1%.

* Freight section (in 2100):
  - The shift from automobiles to trains decreases energy consumption by 16 PJ per share of 1%.
  - The shift from automobiles to ships decreases energy consumption by 14 PJ per share of 1%.
  - The shift from trains to aircraft increases energy consumption by 130 PJ per share of 1%.
Energy Technology Roadmap 2100
Industry Sector

Tentative Translation, Nov. 2005

Concept of technological specifications in industry sector

(1) Common constraints of all cases and sectors
- Resource constraints: Up to the production peaks (oil: 2050, natural gas: 2100), substitution of other energy resources should be realized.
- Environmental constraints: CO₂ emissions intensity (CO₂/GDP) to be reduced to less than 1/3 in 2050 and 1/10 in 2100.

(2) Technological specifications of each case
- Case A (Maximum use of fossil resources such as coal combined with CO₂ capture and sequestration) and case B (Maximum use of nuclear energy): CO₂ capture and sequestration is expected in large-scale facilities and electrification and a switch to hydrogen are expected in other facilities.
- Case B (Maximum use of nuclear energy):
  Electricity and hydrogen are used in industries. Other resources may be used as feed stock.
- Case C (Maximum use of renewable energy combined with ultimate energy-saving):
  It is expected that the necessary energy per value be reduced by 70% to overcome the resource and environmental constraints with development of the economy. Since case C was the severest from a technical point of view in industries, the technology specifications were set based on case C as follows:
  1) The average unit energy consumption for production processes is reduced by 50%. However, the energy preserved in the material is excluded.
  2) 80% of the energy preserved in the product is regenerated as material energy.
  3) "Improvement of functionality" decreases the amount of the material required to realize the effect and the function. It is quadrupled while the total product value increases in proportion to GDP.

The diversity in industries corresponded with pursuing these three technology specifications. Further potential was forecast to make huge leaps.

(3)

(4) A roadmap of technology specifications expected to meet requirements at each time

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Production) X (Value of product)</td>
<td>1 time</td>
<td>1.5 times</td>
<td>2.1 times</td>
<td></td>
</tr>
<tr>
<td>Energy supplied from transformation sector*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Production energy intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) Material/energy regeneration ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Improvement of functionality</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(functionality / amount of material)</td>
<td>1 time</td>
<td>2 times</td>
<td>3 times</td>
<td>4 times</td>
</tr>
</tbody>
</table>

*The percentage of reduction of energy per utility (production x value of product) should be supplied from transformation sector, compared with the case where total energy demand increases in proportion to GDP.
Concept of technologies for achievement of technological specifications in industry sector (1)

The industry sector supports the economic foundation of Japan, which has only poor resources, and at the same time, provides technological seeds for each sector. We sorted out innovative technologies relevant to the energy that can maintain and improve our international competitiveness while solving the resource constraints and environmental constraints, which the industries in Japan are facing.

Since there are various production processes in the industry sector, and its energy utilization systems vary, we categorize the sector into five groups (four groups of raw material industries with large-energy-consumption: iron & steel, chemicals, cement, paper & pulp, and other) for examination. The other group includes non-manufacturing industries such as agriculture, forestry and fisheries, mining industry, and building industry, and other industries such as machinery and foods.

The characteristics of four groups of raw material industries are that products are generated from natural resources and that various energy conversions are simultaneously executed in production processes, so we can call raw material industries the material production (material conversion) sector.

High level of energy use at production process "create skillfully"

We show energy consumption structure in the material production (material conversion) sector. Provided energy is categorized in the following three areas:

1. Chemical energy stored in material
2. Exergy loss mainly in burning process
3. Waste heat in processes

(2) and (3) are consumed in the processes. The required energy can be reduced by the reduction of these two. When we recover electricity or hydrogen from (2), we use the method called co-production.

Regeneration of material/energy "use skillfully"

As can be seen in (1), a product (material) has chemical energy inside. After the life of a product terminates, we can regenerate this (1) as material or energy. In the processes of chemical and paper production, 60% or more of the energy is stored in the material. In these processes, large improvement effect by material/energy regeneration is expected. Moreover, the action of cross-boundary becomes important in addition to the collaboration between industries, by utilizing waste for production plants across sectors and to use co-produced electricity and/or hydrogen across boundaries.

Energy reduction for production with few resources "create good things"

Improvement of functionality of products is not only essential to maintain and expand our nation’s international competitiveness, but also important tasks to provide seeds for technological innovation in each sector.

Concept of technologies for achievement of technological specifications in industry sector (2)

Iron & steel

The current processes by a blast furnace collect and utilize by-product gas and waste heat efficiently and their energy efficiency is extremely high. We assume that in first half of this century, improvement and updating of existing processes, introduction of new generation processes and primary energy reduction by use of waste (waste plastic, waste tire, biomass) will be realized. Also, until the supply of hydrogen using renewable energy becomes possible, by-product hydrogen becomes one of the supply sources of hydrogen. We imagine that in the latter half of this century, based on technological innovation and resources or environmental constraints, the non-carbonization process of reducing and innovative iron-making processes to replace the blast furnace-converter technology will emerge. Moreover, in order to use coal as a reducer while satisfying environmental constraints, technology, which enables separation and capture of CO₂ generated in iron-making processes with low temperature waste heat, is also effective.

Chemical

Since petroleum (naphtha) is used as raw material and fuel in chemical industries, it is necessary to develop a new process that does not consume oil by 2050. The current processes consist of the basic pigment (such as ethylene, propylene, and BTX) production process by thermal decomposition of naphtha, and the process to produce thousands of chemicals by synthesizing basic pigments.

We think it is rational to establish a new process in which biomass, waste and coal are resolved to synthetic gas of CO and H₂ to produce basic pigment, and to utilize the existing production infrastructure after the synthesizing processes. Since 60% of used energy is stored as material in the chemical production, we have to reduce 40% of the energy consumed in the production processes with energy-saving technologies or co-production, and reduce required energy by gasification to regenerate 60% energy stored in material. This system is named System of Sustainable Carbon Cycle Chemistry (SC3).

Cement

Cement is produced from limestone as raw material, using coal etc. as major fuel. At present, waste and by-products (blast furnace slag, coal ash, sub-production gypsum, and scrap tire, etc.) are used as raw material and fuel. This system contributes to the stabilization of waste. In the future, using various waste such as slag from gas furnaces (which is supposed to be used in each sector or other industries) and non-reproductive paper from paper & pulp industry as pigment or fuel, “zero emission cement” processes without limestone and fuel is expected.

Paper & pulp

60% of products are regenerated, and they are recycled about three times generally. Black liquor from a pulp factory is utilized for a paper factory in the form of energy such as electricity and heat along with crude oil and coal. In the future, by utilizing biomass gasification combined cycle power generation facilities, we expect production processes that need no fossil fuels and can provide electricity outside. We also expect that technology that can bring forward fast-growing timber as biotechnologies will be deployed across the industries.

Common Technologies

Biomass and waste will become important materials and fuel mainly in the industries utilizing carbon (C) as a material. Therefore, management technology of materials will become important in the future.
High level of energy use at production process "create skillfully"

<table>
<thead>
<tr>
<th>Energy saving in process</th>
<th>Development of innovative production process</th>
<th>Zero-emission process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cogeneration &amp; cascade use of heat</td>
<td>Use of bio/nano catalyst etc</td>
<td>Integration and cooperation of material and energy</td>
</tr>
<tr>
<td>Regeneration of material/energy &quot;use skillfully&quot;</td>
<td>Biomass/hydrogen use</td>
<td></td>
</tr>
<tr>
<td>Cross-boundary measures beyond sectors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design technique for easy separation &amp; sorting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability improvement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvement of functionality of material and parts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material saving of products</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Energy reduction for production with few resources "create good things"

<table>
<thead>
<tr>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 time</td>
<td>1.5 times</td>
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<td>2.1 times</td>
</tr>
</tbody>
</table>

*The percentage of reduction of energy per utility (production x value of product) should be supplied from transformation sector, compared with the case where total energy demand increases in proportion to GDP.
### Energy saving processes

**Iron & steel:** It will take a long time to develop a new steel making process. It is important to prompt improvement of efficiency of the conventional processes and development and construction of improved processes until about the middle of this century. That is, improvement of efficiency in the conventional process based on blast furnaces + converters + electric furnaces will be major development work in around 2050. An improved process based on the conventional process such as SCOPE-21 may be introduced at the right time. It is thought that the materialization of the innovative process responding to various restrictions of the natural resources and the environment, etc. and changes of product needs will be expected in the latter half of this century. It should be considered that non-carbon material may be used as a reducing agent depending on the situation of these restrictions toward 2100. New energy saving processes such as highly-effective drying technologies and electric power reduction in paper making units will be developed. In this industry, fuel such as coal or electricity purchased will not be used toward 2100.

**Paper & pulp:** New energy saving processes such as highly-effective drying technologies and electric power reduction in paper making units will be developed. In this industry, fuel such as coal or electric power purchased will not be used toward 2100.

**Common:** Analysis of effectiveness in energy use, promotion of ESCO (Energy Service Company), local efficient use of unutilized waste heat, utilization of heat and electricity through coupling operation among industries, highly efficient industrial furnaces and boilers, heat recovery and storage technologies, and innovative production processes by use of biocatalysts and nano-catalysts will be adopted for energy saving. Conventional boilers will be replaced by units of highly efficient industrial combined heat and power.

### Energy saving technologies

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Energy conservation of conventional process, development of next-generation rolling mill technology</td>
</tr>
<tr>
<td>2030</td>
<td>SCOPE-21, introduction of innovative sintering technology</td>
</tr>
<tr>
<td>2050</td>
<td>Recovery of unutilized waste heat (medium- and low-temperature waste heat, sensible heat in slugs)</td>
</tr>
<tr>
<td>2100</td>
<td>Innovative steel production facility</td>
</tr>
<tr>
<td>2000</td>
<td>Gasification technology of heavy oil and coal for chemical feedstock</td>
</tr>
<tr>
<td>2030</td>
<td>Energy conservation in synthetic reaction process by new innovative catalysts</td>
</tr>
<tr>
<td>2050</td>
<td>Development of sustainable carbon cycle chemistry (SC3)</td>
</tr>
<tr>
<td>2100</td>
<td>Creation of new reaction field (supercritical fluid, micro-reactor, integration of reaction and separation)</td>
</tr>
<tr>
<td>2000</td>
<td>Energy conservation of existing cement production processes (recovery of wasted heat, development of highly efficient mills)</td>
</tr>
<tr>
<td>2030</td>
<td>Use of non-equilibrium reaction process (microwave, supersonic wave, plasma, laser technologies)</td>
</tr>
<tr>
<td>2050</td>
<td>Energy saving production technology of petrochemical feedstock (fluidized catalytic cracking (FCC) of naphtha)</td>
</tr>
<tr>
<td>2100</td>
<td>Energy saving separation technology (HIDiC (Heat Intergrated Distillation Column), membrane technologies)</td>
</tr>
</tbody>
</table>

**Industry-6**

**Industry-7**

### Non-technical factors

- It is difficult only for private organizations to develop a new process, because a large-scale demonstration plant has to be built to gather engineering data including operational know-how. The new process should be developed as a national project in the future.
Co-production (Material & Energy)

The lost exergy (workload that can be effectively utilized) in the conventional process will be recovered as electric power or hydrogen for energy saving.

**Common:** Gasification technologies and their related gas separation technologies like membrane will be introduced. A gas turbine integration technology and heating systems by waste heat from gas turbines and fuel cells will be developed. Finally, industrial furnaces combined with fuel cells where high-temperature waste heat after power generation by fuel cells is used for heating will be introduced.

**Iron & steel:** The technology of increasing hydrogen production by reforming and utilizing sensible heat of high-temperature raw COG and a hydrogen supply system for vehicles will be established in around 2030. Moreover, highly effective conversion technologies based on a steel making process such as thermal cracking of wastes including biomass will be established. More biomass and waste will be used by a combination of gasification units and steel making plants after 2030.

**Chemical:** Co-production of electricity, hydrogen, and chemicals will be introduced.

**Paper & pulp:** Biomass and waste will be widely used. Black-liquor boilers and other conventional boilers will be replaced by biomass IGCC or IGFC to efficiently produce material and energy.

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**Non-technical factors**

- It is expected that the energy in waste etc. be strongly used in a mid/long term though technologies for efficient energy use so-called waste heat utilization etc. play an important role for the short term. Therefore, development of institutions, including collection of biomass and waste, and reform of the legal system such as the "Wastes Disposal and Public Cleaning Law" will become more important in addition to technological development for effective use of biomass and waste.
Regeneration of material/energy "use skillfully"  

The preserved material energy in the product is regenerated as material and/or energy. For instance, the systematized techniques by which chemical products are gasified and synthesized and the technology to convert waste to feedstock will be expected.

Common: Coupling operations among industries for efficient energy use, material cascade management, eco-materializing, and so on will be introduced.

Iron & steel: Use of energy of waste by the steel making process, expansion of material regeneration, utilization of by-products like slag in addition to use of scrap iron will be promoted. The regeneration rate of material/energy is assumed to be 50% in 2030, 60% in 2050, and 80% in 2100. The 3R technology of chemicals is the basic technology for the material/energy regeneration and will be enhanced until the establishment of the technology. Effective use of biomass is also important.

Cement: Recovery and recycling technologies of heavy metals and use of waste as fuel become important. Finally, cement will be produced only by waste energy without any fossil fuel.

Paper & pulp: The paper-recycle ratio of 60% at present will be improved to 75% and solve several issues. It covers the demand for paper while maintaining the consumption of wood chip at the current level. The use of biotechnologies such as the search for excellent genes and genetic engineering etc. are expected to increase the amount of wood for each unit area.

<table>
<thead>
<tr>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
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<td>Material cascade management</td>
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<td>Regeneration, utilization, gasification, and recycling of chemicals</td>
<td>Gasification of non-conventional fossil fuel, waste material and biomass</td>
</tr>
<tr>
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<td>Use of waste material for raw material (Regeneration of material/energy)</td>
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<td>Regeneration and utilization of by-products (slag and dust)</td>
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<td>Cement</td>
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<td>Complete (100%) use of waste as feedstock</td>
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<td>Paper &amp; pulp</td>
<td>Recycling of Papers</td>
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<td>Yields</td>
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Regeneration rate of material/energy = \[\frac{\text{(Amount of energy held in the regenerated material) + (Amount of energy regenerated)}}{\text{(Amount of energy preserved in product)}}\]

Non-technical factors

- The wide use of sustainable resources such as biomass will be required to diversify the material and energy sources in the first half of this century.
- Development of institutions including collection of biomass and waste and reform of the legal system such as the "Waste Disposal and Public Cleaning Law" will become more important in addition to technological development for effective use of biomass etc.
**Energy reduction for production with few resources “create good things”**

**Improvement of functionality of material and parts**

Since industries offer seeds of technical development in various fields, improvement of functionality is the major issue. Intensive and continuous efforts toward this issue are required to maintain and enhance the global competitiveness of our country.  

**Iron & Steel:** High tension steel and electrical steel with high performance should be improved. New materials which are far beyond present performance will be developed towards 2100.  

**Chemical:** High-efficiency and high-tension plastic, etc. will be introduced. The chemical products will change from basic chemicals and materials to specialty chemicals such as high-performance engineering plastic and components. The advanced-component industry will dominate chemical industry.  

**Paper & pulp:** Because the reduction in weight has already been sought to a large degree, the efforts will be focused on development of high performance paper.  

**Material saving of products**

Material will be saved by means of modular structure and compact products.

---

![Diagram showing improvement of functionality of material and parts](image)

**Miscellaneous (common to the whole industry)**

**CO₂ capture and sequestration:** Especially in the Iron & steel industry, separation of CO₂ from by-product gas containing high concentrations of CO₂ (blast furnace gas) is efficient and should be addressed first. If the CO₂ concentration in the by-product gas decreases by improvement of production processes in the future then the recovery of CO₂ in the flue gas of the by-product gas combustion should be considered.

**High efficiency utilization technology in hydrogen and electricity:** Electricity and hydrogen are supplied from the transformation sector. The technology for efficient combustion of hydrogen such as in a hydrogen-combustion turbine becomes important.  

**Material management system:** Social systems will be important to utilize technologies.

---

![Diagram showing miscellaneous (common to the whole industry)](image)
Industry-14

Material management system

- Eco-materials, eco-design
  (Design technique for easy separation, easy recycling and regeneration)
- Material cascade management
- Induction to community
  (Feasibility study)
- Optimization for material transportation
  (System design)
- Optimization for regeneration of material
  (Social system design)
- Non-technical factors
  - It is important to establish a recycling system to recover used products from end users and utilize them as feedstock for raw material. Therefore, it has to be considered from a design point of view that products should be easily dismantled and separated and can be regenerated.
  - On the other hand, a social, common principle to efficiently recover the products that have spread widely among the public is required. The system to recover the unused material produced from industries can be established. Optimization for material transportation, induction to a regional community, and enlightenment to citizens and small businesses are also important to efficiently recover used products from end users and utilize them.

Jan/04/2006
Method and Strategy to Reduce CO2 Emission in Industry Sector

1. Characteristics of industry sector

The industry sector has mainly 5 categories: (1) iron and steel; (2) chemical (including chemical fiber and petroleum product); (3) cement; (4) paper and pulp (including paperboard); (5) other. The group of "(5) other" includes non-manufacturing industries such as agriculture, forestry, fisheries, mining industry, and building industry, and other industries such as machinery and foods. Energy consumption ratio for each group is 25%, 33%, 4%, 6%, and 32% in 2000, respectively. Since energy usage style of each sector differs largely, methods to reduce energy consumption and reducible quantity for each sector are also different. Therefore, it is necessary to set an individual method for each sector. The target of CO2 emission/GDP in 2100 is 1/10 of 2000 in the whole industry, but not in each sector.

First, we draw a model of internal energy flow for each category (1) - (4) and show how each model has to be changed in order to achieve the goal in 2100. The group "(5) others" is considered that it is changed in the same way as the total amount of (1) - (4).

Also, there is a limit to improve energy efficiency for each industry sector. Cross-boundary efforts across sectors such as recycling wastes of the residential/commercial sector for the industry sectors or utilizing electricity and hydrogen generated in the industry sectors for the residential/commercial sector or transport sector, become more important in addition to the current collaboration between the industry sectors.

2. Reduction of energy consumption in the productive process

Figure 2-1 shows energy consumption structure in material production (material transformation) area. Input energy is divided into (1) Chemical energy stored in material, (2) Exergy loss mainly in burning process and (3) Waste heat from processes.

(1) Conserved in Materials
(2) Exergy Loss
(3) Waste Heat

Chemical Processing

Regenerated as materials and/or energy (Material/energy regeneration)

Recovered as electricity or hydrogen (Co-production and energy creation)

Minimizing waste heat from processing (Energy saving)

Figure 2-1. Reduction of energy consumption in material production (material transformation)

(2) + (3) shows energy consumed in the processes. In order to utilize energy effectively and to reduce energy consumption, there are three methods such as:
1) Regeneration of material/energy: recycling as material or energy
2) Co-production: capturing lost exergy as electricity and hydrogen
3) Energy saving: reducing process waste heat by energy saving of processes, or utilizing waste heat effectively by cascade use of heat and so on.

With combination of these 1) - 3), we can reduce energy consumption. At the same time, we can also reduce materials and energy required for production vastly by improving capability or functionality of materials and products.

Each concept of (1) material-saving and energy-saving by improved capability and functionality of materials and products, (2) regeneration of material/energy, (3) co-production and (4) energy-saving, is shown below.

Exergy: There are various types of energy, such as heat energy, electric energy, chemical energy and mechanical energy. Even if energy quantity is same, quality is different according to the styles, and effective extraction ratio is different. Among the total energy volume, work volume, which can be extracted, is called "exergy", and extraction rate is called "exergy rate". According to the first law of thermodynamics, energy is stored when there is no release of energy, but exergy is lost and decreased with irreversible changes or in the energy transformation processes.

2.1 Material-saving and energy-saving by improved capability and functionality of materials and products

It is most important to improve quality of materials and products in order to maintain international competitiveness and acquire a market. Simultaneously, we can also achieve vast energy-saving and resource-saving with improved capability and functionality of materials and products from the long-term point of view. For example, when strength of a material becomes twice, we can get the same feature and efficiency with half amount of the material. Also, when half amount of the material can provide the same effect by downsizing and structuralizing, energy consumption becomes 1/4 (1/2 \times 1/2 = 1/4).

4-times improvement can reduce required energy per utility vastly. If required energy per producing volume is not increased because of improved functionality, required energy per utility becomes 1/4 (75% reduction). We have set technology specifications with 4 times the upgrade of functionality, aiming at 70% reduction per utility as a goal. Since slightly more energy may be required to produce the improved product, the combination with other technology specifications is necessary.

In order to improve capability and functionality of materials and products, research and development of high tension steel, innovative structural material and welding material for reducing required steel or for weight reduction of an automobile, or plastics with improved capability and
functionality, and also paper technologies to reduce weight, to make opaque and to improve quality will become important. Using such capable materials to reduce required materials for products is also important technology universally.

2.2 Regeneration of material/energy
Materials and energy are stored but degraded in utilization processes. When we try to regenerate degraded wastes materially, energy is required for separation and refinement of impurities. When considering constraints on material circulation (constraints on quantity of material resources and on discarded amount of wastes) in addition to constraints on energy resources and CO2 emission, it is important to regenerate materials and to reduce required energy as much as possible, and to restrain consumption of material resources and production energy. In case of wastes, which are not regenerated materially, energy in the material should be extracted (energy regeneration).

![Figure 2-2. Concept of material/energy regeneration](image)

Energy belonging to material is obtained when the material is completely oxidized. We call it material/energy. For example, iron has 7.4 GJ/ton of material/energy. The regeneration ratio to transform material/energy stored in a product to a material for reproduction, or to energy is called material/energy regeneration ratio, and is expressed with the following formula:

\[
\text{Material/energy regeneration ratio} = \frac{(\text{energy quantity in the material regenerated materially}) + (\text{regenerated energy quantity})}{(\text{material/energy quantity stored in product})}
\]

In the extreme case that material/energy is all stored in a product, we can achieve 70%, which is a technology specification for energy consumption per utility, when we realize 70% as the material/energy regeneration ratio.

Considering that there is exergy loss and waste heat loss in a product except energy stored in it, it is desirable to set the material/energy regeneration ratio as more than 70%. Therefore, we have set 80%, slightly higher than 70%, as a technology specification.

In order to increase material/energy regeneration ratio, systematized technologies for gasification synthesis of chemical product or technologies to materialize wastes are required.

2.3 Co-production
According to the first law of thermodynamics, energy is stored when there is no release of energy, but energy is lost and decreased with irreversible changes or in the energy transformation processes. In Japan, only 30% or less of the primary energy is utilized effectively and more than 60% is lost. Most of the lost energy is exergy loss. This occurs mainly because chemical energy is transformed to heat energy (burning), which has low exergy.

Considering exergy, in order to utilize energy effectively,
1) trying to reduce exergy loss in the energy transformation and utilization processes;
2) trying to stop producing waste heats, not trying to utilize waste heat;
3) using heat pumps and cogeneration instead of fuel combustion for low level of heat; are important.

In order to reduce exergy loss, create heat with generation of electricity or material production (exothermal reaction) possibly, or utilize transformed hydrogen that has low exergy rate as fuel by using waste heat, and burn it to obtain energy. Review existing energy and material production systems, try to produce material, and energy simultaneously (co-production) in order to restrain consumption of energy and material as much as possible. For example, aiming at co-production of chemical products and energy, develop a process design creation method using thermochemical heat transformer technology and energy integration to minimize exergy loss.

2.4 Energy-saving
It is necessary to promote the current energy-saving, to reduce energy required for processes and to reduce waste heat, however, vast energy reduction is difficult with them. It is required to develop an innovative process to build systematized technologies, to advance the energy reduction more effectively.

We have set up the technology specifications with which can reduce 50% of energy required to produce a good (excluding energy stored in the good) by co-production and energy-saving. However, it is impossible to reduce 70% of energy per utility only by that, and combination with other technology specifications is required for rational implementation.

We provide further insights into the each sectoral model of industries described later on the assumption that we realize approximately 33% of energy-saving and regenerate approximately 33% of exergy that is lost during co-production processes.

In the iron and steel industry, a next generation metal rolling technology is developed, and an innovative technology such as a new sintering process is introduced. Also, it is required to develop innovative iron and steel making processes. In the chemical industry, not only energy-saving of synthetic processes based on a new catalyst development, but also chemical systems to recycle carbon that enables material/energy regeneration are required.
3. Sectoral methods

Concerning iron and steel, chemical, cement and paper and pulp, we have set a model of energy flow for each sector to show actual performance in 2000 and estimated performance in 2100, and propose ideal transition toward 2100.

3.1 Iron and steel industry

(1) Current iron and steel processes

Figure 3.1-1 shows the overview of iron and steel processes. Iron and steel processes have two big categories: blast furnace–converter method based on iron ore as main raw material; and electric furnace method based on scrap iron as main raw material. The current ratio of converter steel and electric furnace steel in basic steel production in Japan is around 7:3. Various kinds of steel products, such as thick plates, steel pipes, thin plates, metal finishing steel plates, wire rods and shape steel, are produced, and about 35% is exported as steel lumber, and about 23% is exported as a product such as automobiles.

Characteristics of energy usage on iron and steel processes are: (1) around 80% of energy is consumed in iron and steel process that reduce iron ore; (2) by-product gas is generated in coke oven–blast furnace–converter processes and it is used for fuel, electricity and other utilities in cascade; (3) waste heat is recovered completely; (4) supply for outside system such as electricity and industrial gas is executed; (5) waste material such as waste plastics are utilized in processes.

Figure 3.1-1. Overview of iron and steel processes

(2) Scenario till the middle of this century

Since the iron and steel industry improved process efficiencies (typical example is a continuous casting facility), developed and introduced waste heat capturing facilities actively after oil crisis in 70’s, those facilities became widely used in almost all sites in 90’s. Improvement of process efficiency after that has been focused on renewal of iron and steel processes and on effective use of wastes, and that trend will continue during the first half of this century.

Iron and steel processes need a large scale of facility and their lives are long, which are the characteristics of iron and steel processes. For example, in Japan, there are 28 blast furnaces in operation, and each needs upgrades once 15 - 25 years, requiring several ten billion yen. Although the basic process of a blast furnace is not changed in the upgrades, the latest technologies are introduced in the control system and peripherals, and energy efficiency is improved reliably. Also a coke oven, currently 44 are running in Japan, will come to the end of their lives during the coming quarter century. In renewal of a coke oven, installation of the next generation coke oven (SCOPE-21), having unique features such as coal pre-treatment process, highly effective devolatilization process and coke reforming process is expected. Until the middle of this century, in addition to improvements and renewal of the existing processes, drastic improvements by installation of the next generation processes according to the facility renewal timing is expected in some processes. Figure 3.1-2 shows the overview of the next generation coke oven (SCOPE-21), which first plant is planned to be installed.

A blast furnace and coke oven have excellent conditions as a reactor or converter including high temperature/reduction atmosphere, so they are applicable for recycling wastes, such as waste plastics. Moreover, since gas, hydrocarbon oil and coke, generated in thermal cracking processes of waste plastics can be all utilized for the existing processes effectively, it is possible to obtain extremely high material/energy utilization efficiency. From now on, in addition to waste plastics, use of various wastes such as scrap tires and biomass will reduce primary input energy. Figure 3.1-3 shows the overview of waste plastics at coke oven. When coke is produced from original coal and waste plastics, coke oven gas is generated. The gas includes large volume of hydrogen, which can be separated and captured easily by the PSA method and others. Before hydrogen supply by reproducible energy becomes possible, it is expected that this by-product hydrogen can be one of main supply sources of hydrogen for the residential/commercial and transport sectors. Also, hydrogen production using waste heat, which is currently not used, is an important task from energy-saving point of view. Figure 3.1-4 shows the overview of by-product hydrogen supply.

Figure 3.1-2. Overview of the next generation coke oven (SCOPE-21)

Figure 3.1-3 shows the overview of waste plastics at coke oven. When coke is produced from original coal and waste plastics, coke oven gas is generated. The gas includes large volume of hydrogen, which can be separated and captured easily by the PSA method and others. Before hydrogen supply by reproducible energy becomes possible, it is expected that this by-product hydrogen can be one of main supply sources of hydrogen for the residential/commercial and transport sectors. Also, hydrogen production using waste heat, which is currently not used, is an important task from energy-saving point of view. Figure 3.1-4 shows the overview of by-product hydrogen supply.
(3) Scenario of the latter half of this century

By the latter half of this century, there is a chance that non-carbon or non-fossil reducer becomes available, which is now difficult to obtain economically and technologically, and that an innovative iron and steel process instead of blast furnace-converter method is developed. However, such innovative process may affect the current energy cascade utilization system based on coking coal as starting material, and waste utilization system across the sectors. Therefore, it is also necessary to consider supporting technologies to overcome these tasks. At a full-scale steel plant, about 90% of carbon brought from coking coal becomes by-product gas. Low level waste heat still not in use also exists. Therefore, it is also effective to use a technology to capture CO₂ generated from iron and steel processes by utilizing unused middle-low temperature waste heat in order to strike a balance between coal use as a reducer and environmental constraints. Figure 3.1-5 shows the overview of capturing CO₂ at a full-scale steel plant.

(4) Importance of improvements of product capability

Not for the iron and steel industry alone, but for all manufacturing industries, capability of a product is fundamental factor for competition. If we try to maintain national power through the future with poor natural resources in Japan, it is essential to maintain and improve international competitiveness of industries. Moreover, industry sectors bear responsibility for providing excellent products so that each sector can realize effective use of energy resources and solutions for environmental constraints, which are the themes of this report.

Figure 3.1-6 shows weight reduction effect of automobile and accompanying mileage improvement effect when high-tension steel becomes widely used. Figure 3.1-7 shows remediation effect of iron loss and accompanying reduction of CO₂ emission brought by improved capabilities of electromagnetic steel plate. Each case shows a final product capability after improvement of material quality. Such high level technologies will enable acquiring international competitiveness, and provide foundations to utilize energy resources in production and to support environment in the residential/commercial, transport and transformation sectors.
Therefore, in order to solve natural resource constraints and reduce CO2 emission, we have to generate the by-product gas of raw materials. This process involves the energy generated from the by-product gas and the energy generated in producing and processing phase. However, with the existing technologies described above, it is possible to reduce wastes volume but not possible to solve the problems of emission, generated in producing and processing phase.

In the chemical industry, 60% of energy in raw material is stored in the material. 30% is exergy loss and waste heat is approximately 10%. If we try to reduce large energy consumption, it is fundamental to settle a system to regenerate and utilize material/energy stored in the material, which occupies 60% of energy.

Figure 3.2-1 shows the current material flow of plastics as an example. The materials storing energy, so called “wastes” are decomposed into monomer and polymerized again, or re-molded as plastic materials. Otherwise, they are reused directly without any processing. Also, they are burned and transformed to energy.
settle system, which generates almost no wastes. Then, material/energy regeneration is required to create gas from wastes and to produce goods by synthesizing materials such as plastics from the synthetic gas (carbon monoxide and hydrogen), generated in the gasification process. Materials for this gasification can be wastes and biomass.

Figure 3.2-2 shows the above concept quantitatively. As shown in (1), in the current petrochemical processes, 60 are stored in the material, 30 is exergy loss and 10 is waste heat in the total input energy 100. If required energy is saved by process improvements, it is possible to reduce exergy loss and quantity of waste heat. For example, if exergy loss and waste heat at (1) can be reduced to 2/3, on the assumption that a product remains at 60, raw materials can be reduced from 100 to 87 as shown in (2). In addition, when co-production is introduced, it is possible to reduce exergy loss and to regenerate it as electricity and hydrogen. (3) shows 7 electricity and hydrogen is produced when 1/3 of exergy loss is restored by co-production.

In the chemical industry, even if energy-saving and co-production become widely available, 87 materials are required to produce 60 goods. Therefore, in order to achieve energy-saving goal, material/energy regeneration concept has to be introduced. On the assumption that 80% of 60 energy stored in material (which means 48 energy) can be restored as raw materials, it becomes possible to reduce materials to 39, as shown in (4).

![Figure 3.2-2. Model of chemical industry](image)

Finally, we have to produce 60 goods by the new 39 exergy and the captured 48 exergy, and therefore generate 7 electricity and hydrogen. In order to realize this concept, it is required to accept wastes to create gas from them with gasification, and at the same time, to develop process technologies for producing chemical products by synthetic gas created by gasification.

(2) Exergy capturing by co-production

We will explain how to produce ethylene by thermal cracking as a sample of co-production with gas turbine integration.

When chemical goods are created from materials by thermal cracking from an endothermal reaction, usually fuel is burned to generate heat required for the reaction. For producing electric power, fuel is burned to generate steam, and it is transformed to electric power. Figure 3.2-3 shows a flow of the time when a gas turbine is installed to produce electric power and its waste heat is utilized for thermal cracking. The upper numbers are enthalpy level, and the lower numbers are exergy level.

With the existing methods, 4 electric power was created from 10 fuel, and 120 chemical goods were produced from 20 materials. 30 materials/fuel is pressurized and burned so that exergy loss becomes small. Then, high temperature and pressure gas drives a gas turbine to generate the 10 electric power. Besides, exhaust gas from a high temperature gas turbine is used for thermal cracking to produce 120 chemical goods. As a result, 6 electrical powers can be generated. These integration processes enable reduction of exergy loss.

![Figure 3.2-3. Co-production by gas turbine integration](image)

(3) Transition of technologies

Until 2100, there will be a period when we can use oil and natural gas as materials. During that period, we have to promote energy-saving and develop technologies, which enable soft landing toward the coming society in 2100. Considering that meaning, we studied transition of technologies from now till 2100. Since the main methods to produce ethylene currently are thermal cracking processes of naphtha, which consumes extremely vast energy, it is necessary to install energy-saving type of processes into the basis (ethylene, propylene and BTX) production process in order to save large amount of energy in the chemical industry. Considering transition of technologies from the material point of view, we illustrated Figure 3.2-4.
The thermal cracking processes in which main material is naphtha, will change to energy-saving type of new thermal cracking processes, and finally transit to the catalytic cracking processes (the increased propylene production type of FCC, then the processes with further yield of ethylene). They will continue to exist until crude oil production passes its peak. On the other hand, a direct transformation technology from natural gas that is comparably rich in resources among the fossil fuels will be developed, and olefin production processes by a methane coupling method\(^1\) will be introduced.

From long term point of view, synthetic gas (CO, H\(_2\)) created by gasification of various carbon resources will transit to olefin production based on SC3 chemistry (Sustainable Carbon Cycle Chemistry, including C1 chemistry system). Moreover, in this transition process, cracking of heavy oil and reforming of natural gas (steam reforming, partial oxidation, and auto thermal reforming) will be included, and finally, they will be integrated into synthetic gas production by gasification of reproducible resources such as biomass or wastes.

Considering current coverage of petrochemical products through the whole market and utility of consumers, it is rather difficult to synthesize all kinds of chemical goods by synthetic gas, so many chemical goods will be produced by the current production flow continuously. On the other hand, it is required to develop an innovative synthetic process according to the change of method to transform or obtain materials.

Secondly, when we review chemical synthesis flow from the aspect of product, we can see the following factors:

1. **Gasification**: simultaneous production of chemical material IGCC/IGFC

\(^1\) By the methane coupling method, 2 methane molecules are combined under existence of various oxygen such as gas phase oxygen, catalyst grid oxygen and catalyst absorption oxygen, and transformed into ethane or ethylene.

Various materials including fossil fuels are transformed to gas by gasification (synthetic gas production) and electric power is generated by IGCC/IGFC. Besides, synthetic gas is also used as chemical materials. Materials for gasification are switched to biomass and others finally.

2. **SC3 chemistry** (Sustainable Carbon Cycle Chemistry): Direct synthesis technology of ethylene, propylene and BTX from synthetic gas

In order to maintain the current production system of petrochemical product, which starting point is ethylene and propylene, ethylene and propylene production from synthetic gas is implemented. Although various kinds of technologies including direct synthesis from synthetic gas and propylene production via methanol, they are finally integrated into a process having economical reasonableness.

3. **Innovative production process**: Innovation of integrated production process of chemicals

Although the existing petrochemical flow based on ethylene and propylene is maintained, development of innovative catalyst enables energy-saving in each production process of chemical product.

4. **Catalytic cracking**: From thermal cracking to low-temperature catalytic cracking

In the transition period to the final petrochemical system based on biomass /SC3 chemical (until 2050), bases are produced by the same kind of catalytic process currently used for oil refinery.
According to GDP increase, production volume of petrochemical products also increases. The roadmap of production technologies of olefin, which is a material of petrochemical products, is shown below:

- **2010 - 2020**: Although energy-saving of thermal cracking process is improved, gradually the process is changed to catalytic process.
- **2010 - 2020**: GTL, methanol and DME, using inexpensive natural gas from overseas are imported and a part of them is used for petrochemical feedstock.
- **2040 -**: Gasification/SC3 chemical processes are sequentially developed and introduced in 2020 - 2040, and after 2040, they are installed on a large scale.

### 3.3 Cement industry

1. **Estimated image in 2100**
   - Reviewing the cement industry in 2100 from the view of resource constraints and CO2 emission reduction, we estimate that materials used in the industry will be final wastes such as residue of gasification from the other industries and sectors, without using limestone and fossil energy such as coal.

2. **Technology roadmap**
   - We estimate the technology roadmap of the cement industry as follows. The existing portland cement is produced with limestone as a main material by burning clay, silica and iron. Ash of wastes includes elements required for producing cement, and actually it is already put into practical use although there are some restrictions. As you see, the cement industry is a venous type industry, in which vast wastes and by-products (blast furnace slag, coal ash, by-product gypsum, and scrap tire) can be utilized as materials, and it can utilize wastes from each industry and the residential/commercial sector effectively in the future.
   - We particularly expect the new type of cement, Eco cement, which is constructed from city garbage, ash, and sewage sludge, as one of solutions for wastes problems. Currently, its usage is limited because of chlorine included in material wastes (1%), however, it will be possible to develop cement having almost the same quality with the current one by dechlorination technology.
   - Promoting use of wastes, we can introduce another new type, zero-emission cement (almost 100% of its materials are wastes). It is expected that this cement can contribute to the vast scale of waste reduction, not only in the cement production, but also in the other industry sectors.
   - As you see in Figure 3.3-1, we estimate that in the cement industry, beside more energy-saving will be promoted, zero-emission cement produced from wastes, will become a main stream in the future recycling-oriented society.

3. **Energy balance transition**
   - Figure 3.3-2 shows the current cement production system, using limestone as material and wastes as fuel. In this figure, domestic consumption and amount of export show sales volume, so total of them does not match the production volume.
   - We estimate that GDP will become twice in 2100, and cement production volume will be got under control within 1.6-time with improvements of product capabilities. As we described before, cement produced in 2100 will be entirely the zero-emission type. In order to produce 1.6-time volume of zero-emission cement compared with the current volume, wasted cement and wastes will be input as materials. Although required energy here will become 1.6-time of the current volume, we estimate that 33% of energy can be reduced with installing energy-saving type of processes. Beside, since material wastes contain chlorine and heavy metals, it will be required to utilize chlorine and rare metals captured effectively with highly effective dechlorination technology and heavy metal capturing technology.
### 3.4 Future technology estimation in the paper and pulp industry

#### (1) Current paper and pulp industry

In the paper and pulp industry, 60% of products are recycled as resources. They are circulated approximately three times, which realizes almost true recycling-oriented society. 50% of input chip becomes black liquor and remaining 50% becomes pulp as paper material. Although black liquor is transformed to steam or electric power required for production processes and utilized as fuel, black liquor energy cannot cover all requirements, therefore, fossil fuels (heavy oil and coal) are additionally input.

#### (2) Estimated image in 2100

In the paper and pulp industry, biomass is already utilized as material currently, and circulation of waste paper is increasingly utilized. In the future, we estimate that fossil energy supply input currently will become zero for lack of energy and excessive energy can be supplied to the other industries. Other than black liquor, if we add waste biomass and wooden biomass for gasification to apply high effective biomass IGCC/IGFC, we can supply electric power outside the industry without fuel input from the outside.

#### (3) Paper and pulp industry in collaboration with energy industry

In 2100, the production volume will become 1.6-time like the other manufacturing products, and recycling rate will go up to 75%. When recycling rate increases, pulp fiber becomes short and is discharged as paper sludge, then utilized for regenerating energy. If sludge contains a lot of inorganic substance, it is used as cement fuel.

Although heat and electric power required for production processes is generated by IGCC/IGFC with using black liquor as fuel, it is not enough for all energy demands, so additionally 2.1 MJ/t of biomass fuel is input. Also, if we generate heat required for production processes by IGCC/IGFC, excessive electric power of 2.4 MJ/t of products can be supplied to the other industries, so the paper and pulp industry can also undertake a role in the energy transformation industry.
Energy Technology Roadmap 2100
Transformation Sector

_Tentative Translation, Nov. 2005_
### Concept of technological specifications in transformation sector

**1. Common constraints in all cases and sectors**
- Resource constraints: Up to the production peaks (oil: 2050, natural gas: 2100), substitution of other energy resources should be realized.
- Environmental constraints: CO₂ emissions intensity (CO₂/GDP) to be reduced to less than 1/3 in 2050 and 1/10 in 2100.

**2. Basic concept of technological specifications**
- The amount of energy required by the demand sectors should be adequately supplied in each case.

<table>
<thead>
<tr>
<th>Total energy demand on the demand side</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
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<tbody>
<tr>
<td>(Maximum case)</td>
<td>1</td>
<td>1.5</td>
<td>2.1</td>
<td></td>
</tr>
</tbody>
</table>

**Case A: Fossil fuel use with CCS**
- Share of electricity and/or hydrogen: 1 time, 2 times, 4 times (ca. 8 PWh)

**Case B: Nuclear energy use**
- Share of electricity and/or hydrogen: 1 time, 3 times, 4 times (ca. 8 PWh)

**Case C: Energy saving & Renewable energy use**
- Share of electricity and/or hydrogen: 1 time, 2 times, 3 times (ca. 2 PWh), 0.3 times of energy saving rate in demand sector

**CO₂ intensity**
- 270 g-CO₂/kWh (2/3 times)
- 120 g-CO₂/kWh (1/3 times)
- 370 g-CO₂/kWh (1 time)

**Total energy demand on the demand side**

<table>
<thead>
<tr>
<th>Case A</th>
<th>Fossil fuel use with CCS</th>
<th>2000</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1.5</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Case B</td>
<td>Nuclear energy use</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Case C</td>
<td>Energy saving &amp; Renewable energy use</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

- The amount of power generation in each case = (Total energy demand on the demand side) x (Share of electricity and/or hydrogen in final energy)
- In case C, the rate of energy saving in the demand sector is multiplied, additionally.

**Case A & B:** (The amount of power generation) = (about 1 trillion kWh in 2000) x 2.1 x 4 = (about 8 PWh)
**Case C:** (The amount of power generation) = (about 1 trillion kWh in 2000) x 2.1 x 3 x 0.3 = (about 2 PWh)

- (3) Each individual target in 2030 is set by backcasting from the targets in 2100 and 2050.

**Example:** Case B (Maximum use of nuclear energy)
- About 8 times as much electricity and/or the hydrogen in 2100 will be needed, same as case A.

**Case C (Maximum use of renewable energy combined with ultimate energy-saving)**
- Total amount of energy supply of electricity and/or hydrogen in 2100 is required to be twice of that in 2000 under the assumption that energy saving and equipment efficiency improvement fully progress on the demand side. However the energy demand would be 2.1 times in proportion to GDP and the share of electricity and/or hydrogen would be 3 times, which is relatively low compared to case A and B because the share of energy other than electricity and hydrogen is relatively high, the energy saving and equipment efficiency improvement will decrease the demand by 0.3 times.

(4) The technological specifications and the time, etc. expected to meet the individual requirement at each time are arranged as the roadmap.

---

**Concept of technologies to achieve technological specifications in the transformation sector**
In order to satisfy the energy demand with reducing CO₂ intensity, the following three technology groups have to be prepared.

#### 1. Efficient use of fossil resources
In preparation for the oil production peak, we will execute a fuel switch to natural gas, and to coal, which has a comparably rich volume of resources. However, since coal is also a finite resource, it is important to improve effectiveness of use of fossil resources such as power generation (conversion) efficiency. Therefore, gasification power generation (fuel production) technologies and highly effective power generation technologies combined with fuel cell are required. Also, since fossil fuel generates CO₂ emission, CO₂ capture and sequestration (CCS) technologies are essential.

#### 2. Nuclear power utilization technologies
Effective use of nuclear fuel resources is required. Therefore, it is fundamental to improve the efficiency of the current light-water reactor, and to establish nuclear fuel cycle.

#### 3. Renewable energy utilization technologies
It is important to improve effectiveness of power generation (conversion) by renewable energy such as solar power, geothermal, wind power and biomass. Since utilization ratio of facilities for solar or wind power is low, and these facilities need large installed capacity, technologies for easy installation are also required. Since natural energy is dependent on weather conditions, it is essential to establish large scale storage technologies and network system technologies including system control (energy management).
**Fossil fuel use + CO₂ capture and sequestration technology**
- This technology is necessary to cover the fossil natural resources such as coal and non-conventional fossil natural resources which are relatively abundant reserves.
- The technology to capture and sequestrate CO₂ generated along with the use of the fossil fuels and to improve the power generation efficiency etc. is necessary.
- The required amount of energy supply increases to about 3 PWh (11,000 PJ) in 2050 and to about 8 PWh (29,000 PJ) in 2100 from the current amount of about 1 PWh (3,800 PJ) of total power generation in 2000, because the energy demand is 1.5 times in 2050 and 2.1 times in 2100, the share of electricity and/or hydrogen in final demand becomes twice as much and 4 times respectively, under the assumption that there is no energy saving by the equipment efficiency improvement on the demand side.

- **CO₂ capture and sequestration technology**
  - The capture and sequestration technology of CO₂ is indispensable so that the use of fossil fuels may accompany CO₂ exhaust. In the case of maximum use of fossil resources, securing the amount of CO₂ sequestration of 4 billion tons/year is needed.
  - It is necessary to develop clean coal technologies such as preprocessing technologies for ash reduction and reforming, exhaust gas processing, effective use of coal ash, etc.
  - Further improvement of power generation and the fuel production efficiencies is important as an effective use for fossil resources.
  - It starts from integrated coal gasification combined cycle power generation (IGCC), and then highly effective processing is aimed at, with IGFC combined in fuel cells and a chemical reproduction type IGFC that also the exergy can be utilized effectively.
  - It is necessary to develop clean coal technologies such as preprocessing technologies for ash reduction and reforming, exhaust gas processing, effective use of coal ash, etc.

**Securing the required amount of fossil fuels such as coal**
- To cover the energy supply of about 3 PWh (29,000PJ) in 2100, securing the required amount of fossil fuels such as coal is needed.
- The present power generation by coal is about 200 TWh (600PJ), and the installed capacity is about 35 GW. The amount of coal imported for power generation in 2000 is about 60 million tons (40 Mtoe, 1,700 PJ). It is necessary to procure about 700 million tons (45 Mtoe, 19,000 PJ) in 2050, 2 billion tons (1.3 Gtoe, 54,000 PJ) of coal in 2100, if the fossil fuel covers the entire power supply, even if power generation (conversion) efficiency improvement is considered. Therefore it is necessary to develop a natural resource exploration technology, preprocessing technologies such as the selection of coals and deashing, and mass transportation technologies.
- The technology which combines a large-scale heat supply system and social systems effectively is also important for total efficiency improvement.

**Conventional power generation**
- Ultra super-critical pressure thermal power generation
  - Power generation efficiency: 42%
  - Material technology (main steam/reheat steam temperature): 600/10 ºC, 700/720 ºC, 800/800 ºC

**Non-technical factors**
- However the importance of coal is recognized because of large reserves compared with other fossil fuels, the introduction of a large-scale thermal coal power with high CO₂ exhaust even with high efficiency is not advanced easily, because (i) the progress of economy and growth of electricity demand, (ii) the extension of electricity deregulation, and (iii) CO₂ environmental restrictions with global warming in the future are unpredictable.
- The potential of geologic CO₂ sequestration: The potential of geologic CO₂ sequestration in Japan is assumed to be about 3.5 - 90 billion tons (ENAA estimation). The amount of cumulative CO₂ sequestration will exceed around 2085 if CO₂ sequestration will start in 2030. The assessment of sequestration influence and safety, and international agreement are necessary.
- The technology which combines a large-scale heat supply system and social systems effectively is also important for total efficiency improvement.
**Nuclear power technology**
- This technology is necessary to supply nuclear energy without CO₂ emissions during operation.
- Efficiency improvement and the establishment of nuclear fuel cycle technology are important due to the constraint of uranium resources.
- The required amount of energy supply increases to about 4 PWh (14,000 PJ) in 2050 and to about 8 PWh (29,000 PJ) in 2100 from the current amount of about 1 PWh (3,800 PJ) of total power generation in 2000. This is due to the estimates that the required amount of electricity or hydrogen would be 1.5 times in 2050 and 2.1 times in 2100, under the assumption that there would be no significant improvement in energy efficiency in the demand side because the share of electricity and/or hydrogen in the demand side would be 3 times in 2050, which is relatively high for further introducing electricity or hydrogen in the demand sector such as industry, and 4 times in 2100.

### Table: Nuclear power generation

<table>
<thead>
<tr>
<th>Year</th>
<th>Power Generation (PWh)</th>
<th>Uranium Use Efficiency</th>
<th>Share of Electricity and Hydrogen in Final Demand (%):</th>
<th>Uranium Use Efficiency:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>ca. 1 PWh (3,800 PJ)</td>
<td>CA. 1%</td>
<td>20%</td>
<td>1%</td>
</tr>
<tr>
<td>2050</td>
<td>ca. 4 PWh (14,000 PJ)</td>
<td>30%</td>
<td>60%</td>
<td>20%</td>
</tr>
<tr>
<td>2100</td>
<td>ca. 8 PWh (29,000 PJ)</td>
<td>80%</td>
<td>80%</td>
<td>30%</td>
</tr>
</tbody>
</table>

**Efficiency improvement**
- It is necessary to improve the power generation efficiency by developing a new type of reactor, etc. to overcome the constraint of uranium resources.

**Establishment of nuclear fuel cycle**
- The establishment of nuclear fuel cycle technology is indispensable due to the constraint of uranium resources. Moreover, to achieve 8 PWh (29,000 PJ) of power generation in 2100 in Case-B with the maximum use of nuclear power, early deployment (around 2030) of fast breeder reactors (FBR) and shortening the plutonium doubling time (from the current time of 35 years to 20 years) are needed.

**Efficiency improvement of nuclear reactors**
- **Power generation efficiency**
  - Japanese type next generation LWR
  - Fourth generation LWR (supercritical pressure reactors)
- **Load following operation with electricity and hydrogen storage, co-generation, co-production**
- **Nuclear hydrogen production** (thermo chemical cycle, LWR-electrolysis, high temperature steam electrolysis, etc.)

**Nuclear fuel cycle technology**
- **Fast breeder reactors, FBR (Nuclear fuel cycle)**
- **Nucleus conversion of minor actinide and long-life FP**
- **Nucleus conversion of long-life FP** (Fission Product)
- **Upgrading (gas cooling FBR)**

**Non-technical factors**
- In order to increase nuclear power generation significantly, the following concepts should be established and promoting social understanding and acceptance is essential as well as an increase in generation capacity and efficiency improvements.
- **Improvement in efficiency of resource use**
- **Recycling (breeding of plutonium)**
- **Decrease in radioactive waste quantities**
- In order to secure the necessary power generation capacity in 2050 and 2100, measures to promote social acceptability are essential to solve the siting issue.
- The early establishment of radioactive waste management technology is essential from the view point of social acceptance because the radioactive waste issue might become a major barrier for nuclear power generation.
- The establishment of an international management system of nuclear fuel including nonproliferation efforts is necessary in order to secure social acceptance.
- International cooperation such as Generation IV International Forum (GIF) is essential for the development of new technologies including fast breeder reactors (FBR).
- In order to use nuclear power effectively, the expansion of applications such as hydrogen production, heat supply, desalination, etc. and the expansion of users in developing countries might be achieved through the development of small and medium-sized reactors.
- In order to improve the total efficiency of the nuclear power system for the rational use of nuclear energy, large-scale supply and effective use of heat combined with social system integration might be necessary.
Renewable energy technology
- This technology is necessary for maximum use of renewable energy such as solar, wind power, geothermal (that emit no CO₂ during operation and carbon-neutral biomass energy) in combination with the reduction of energy demand by ultimate energy saving, efficiency improvement, and then self-sustainability in demand sectors.
- Total amount of required energy supply in 2100 would be about 2 PWh (7,200 PJ) as a results of energy saving, etc. in the final demand sectors.
- It is necessary to improve the conversion efficiency to secure the amount of supply for energy needed in 2100, which is about 20 times the current renewable energy supply (about 90 TWh (320 PJ)).
- As for solar and wind power, etc., the supply and demand matching is difficult because the output changes according to time and meteorological conditions, and energy management by energy storage and networking technologies with the cooperative use of biomass energy (which enables power supply adjustment) are important.

Solar
- Because large space is required for installation, the conversion efficiency improvement is important.
- The development of two or more methods, such as crystal silicon, thin film silicon, compound semiconductors, and the dye-sensitized types, etc. continues for some time, and they will be selected based on power generation efficiency, productivity, durability, etc. For a very high efficiency solar cells over 30% of power generation efficiency, based on a new design, structure, and material are necessary.
- Technological development is also necessary to enable wider application of PV systems in addition to current applications in residential/commercial sector, which includes the development of a wider variety of PV modules applicable to various locations, patterns of use and purposes (light-weight, flexible, bifacial, inverter integrated, etc.) and PV modules with diverse functions (sound and heat insulation and anti-reflections), and integration of PV modules with building materials and components.
- Large-scale hydrogen production would use technologies such as water electrolysis by photovoltaic generation, water splitting by photo-catalyst, or a thermo-chemical process using solar heat. The technologies would be selected based on production efficiency and cost, etc.

Power generation
- Photovoltaic generation
- Solar photovoltaic generation
- Thin film type
- Poly crystalline type
- Super highly effective new model
- Power generation efficiency
- 13%
- 22%
- 38%
- 40%
- Small scale, independent distributed power system
- MW class large scale power generation
- Transformation-10

Hydrogen production
- Solar light (electrolysis)
- Production efficiency
- 10%
- 20%
- Solar light (photo-catalyst)
- Production efficiency
- 0.17%
- Efficiency improvement and downsizing of solar furnaces
- Solar heat (thermo-chemical)
- Thermal efficiency
- 30%

Geothermal
- Geothermal power generation advances from shallow systems that use underground high temperature steam and hot water to the deeper systems including hot dry rock power generation that uses heat conduction of high temperature rock to secure the geothermal energy resources.
- Geothermal inquiry technology is necessary for accurate estimation of the exothermal fluid reservoir deep underground (5,000 m class in hot dry rock) etc.

Non-technical factors
- Introduction assistance that cancels out price differences with fossil fuel.

Wind power
- The cumulated capacity of wind power generation is about 700 MW (FY 2003), and the introduction on land advances due to the scale-up and cost reduction for the time being.
- Because enough power cannot be supplied by land, offshore wind power generation is also needed.

Non-technical factors
- Development and introduction of large-scale wind turbines that suit the natural environment in Japan (wind, thunder, and typhoons) and are easy to construct in the narrow, steep land of Japan.
- It is necessary to establish quality standards and an accreditation system for wind turbines that suit the environment of Japan that is different from Europe.
- Clarification of social burdens over cost to harmonize fluctuating output due to wind conditions with operation of the power grid.
Biomass
- Biomass energy conversion technology would shift from the currently commercialized production of electricity and heat by direct combustion of wood etc. to production of gas and liquid fuel by gasification and gasification reforming.
- In wet biomass use, the methane fermentation is put to practical use, and used for co-generation etc.
- Efficiency improvement of collection, transportation and use of biomass is important to secure the amount of the resources to cope with the increased use in the industry sector.
- It is necessary to improve production efficiency, when direct hydrogen production is put into practical use in the future.

Centralized biomass uses

<table>
<thead>
<tr>
<th>Year</th>
<th>Direct fuel use</th>
<th>Gasification and gasification reforming</th>
<th>Fuel crops production</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Methane fermentation and ethanol fermentation</td>
<td>- Electricity and heat</td>
<td>Large-scale biomass fermentation hydrogen production</td>
</tr>
<tr>
<td>2030</td>
<td>Gasification reforming</td>
<td>- Gaseous fuel</td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td>Gasification reforming</td>
<td>- Solid fuel</td>
<td></td>
</tr>
<tr>
<td>2100</td>
<td>Gasification reforming</td>
<td>- Efficiency improvement</td>
<td></td>
</tr>
</tbody>
</table>

Biomass gasification fuel synthesis
(hydrogen, synthetic fuel, etc.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Cold gas efficiency (wood)</th>
<th>Biomass gasification fuel and hydrogen production</th>
<th>75 - 80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>65 - 75%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Biomass fermentation
(hydrogen production)

<table>
<thead>
<tr>
<th>Year</th>
<th>Basic research stage at laboratory level</th>
<th>Yield of hydrogen, 100 times</th>
<th>1000 times</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>(generation rate: 0.2 x 10^-3 Nm3/L·h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Non-technical factors
- A social system that enables collection and transportation of biomass resources (unused biomass such as wood residues) efficiently and at a low-cost, and the establishment of a recycling oriented community, in which biomass is produced and used locally, are important.
- It is necessary to secure biomass resources through international cooperation (technical cooperation and use of CDM mechanism, etc.) with Southeast Asia etc.
- Deregulation in the field of waste handling and favorable tax breaks which facilitate the use of biomass are also important.
- Supply and demand correlations of biomass resources would alter in the long run by the competing demand for food and fodder use, material use, and energy use, etc.

Energy storage and transportation
- In both Cases A and B (fossil and nuclear), energy storage and transportation becomes important for efficient mass energy supply from distant generation plants.
- In the case of renewable energy use (Case-C) where an ample amount of electricity or hydrogen is expected to be produced by renewables, energy storage and transmission is indispensable to match the supply and demand by leveling the diversified renewable energy sources and connecting generators (such as photovoltaic and wind generators.)
- Energy storage and transportation technologies are important for the energy supply in the transport sector and for energy creation and networking in the residential/commercial sector, etc.

Electric power and fuel storage technology
- Technologies to efficiently store electricity and/or fuels such as hydrogen on a large scale are necessary.
- Application of energy storage will extend from instantaneous load leveling to hourly and daily storage that uses technologies such as a new rechargeable battery, capacitor, SMES, and flywheels. The storage technology by chemical energy such as hydrogen becomes important as the leveling period and the amount of energy storage increases.
**Electric power and fuel transportation technology**
- In both Cases A and B (fossil and nuclear), mass energy transportation technologies becomes important.
- In Case-C (renewables), energy transportation technologies are important to keep the balance of energy supply and demand over differences in region and time.

### Power transmission/distribution technology
<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Transmission/distribution loss: 5.6%</td>
</tr>
<tr>
<td>2030</td>
<td>Mass power transmission technology (AC/DC power transmission)</td>
</tr>
<tr>
<td></td>
<td>UHV AC</td>
</tr>
<tr>
<td>2050</td>
<td>High temperature superconducting power transmission technology</td>
</tr>
<tr>
<td>2100</td>
<td>The new mass power transmission technology (multi-phase AC and UHV DC power transmission, etc.)</td>
</tr>
<tr>
<td></td>
<td>Normal temperature superconducting power transmission technology</td>
</tr>
</tbody>
</table>

### Non-technical factors
- Securing transmission line routes is extremely difficult because of environmental and siting problems. The construction of large capacity and long distance transmission lines in the future are also difficult for both cable and overhead. It is important to minimize the requirements of large capacity and long distance power transmission by adjustment of the demand-and-supply balance and by site selection of power plants.
- In preparation for the stage when a portion of the distributed and/or renewable generators are outstanding and the number of their owners or operators becomes large, it is necessary to establish system connection rules to clarify each entity’s rights and responsibilities (including restoration after failure).
- To secure power supply quality such as voltage, frequency and restoration after failure within a specified range by controlling generators and transmission and distribution systems, a new method will be necessary as part of the system connection service, along with a method to evaluate the cost and a proper social cost bearing system.
Appendix

1. The necessary amount of carbon dioxide capture and sequestration (CCS)

The table below shows the estimation of the potential of geological CO₂ sequestration of Japan by the Engineering Advancement Association (ENAA) of Japan. The potential of geological CO₂ sequestration is about 3.5 billion tons in categories 1 and 2, and 91.5 billion tons in categories 1 to 4.

CO₂ capture and sequestration will begin in 2030, and the amount of CO₂ required to achieve the target of each CO₂ intensity per kWh (1/3 in 2050 and 1/10 in 2100) should be captured and sequestered. The annual and cumulative sequestration per year and the amount of accumulation is shown in the figure below.

If 500 million t-CO₂/year in 2030, 1,500 million t-CO₂/year in 2050, and 4,000 million t-CO₂/year in 2100 assume to be sequestered, the amount of the accumulation sequestration exceeds 91.5 billion tons (including categories 1 - 4) around 2085.

### The potential of geological CO₂ sequestration by each category

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Storage potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oil and gas reservoirs and neighboring aquifers that exist in large scale oil and gas fields already discovered.</td>
<td>ca. 2 billion t</td>
</tr>
<tr>
<td>2</td>
<td>Aquifers in confirmed anticlinal structures in which drillings have been done by the government.</td>
<td>ca. 1.5 billion t</td>
</tr>
<tr>
<td>Subtotal</td>
<td>Storage potential of confirmed trap structures.</td>
<td>ca. 3.5 billion t</td>
</tr>
<tr>
<td>3</td>
<td>Offshore Aquifers in monoclinic structures offshore in the sedimentary basins.</td>
<td>ca. 16 billion t</td>
</tr>
<tr>
<td>4</td>
<td>Aquifers in monoclinic structures offshore in the sedimentary basins.</td>
<td>ca. 72 billion t</td>
</tr>
<tr>
<td>Subtotal</td>
<td>Storage potential of confirmed aquifers.</td>
<td>ca. 88 billion t</td>
</tr>
<tr>
<td>Total</td>
<td>Geological CO₂ storage potential in Japan (onshore and offshore)</td>
<td>ca. 91.5 billion t</td>
</tr>
</tbody>
</table>

2. Uranium resources

Uranium resource availability will differ in power generation efficiency due to the difference of reactor types and nuclear fuel cycles because of uranium limitations. The establishment of nuclear fuel cycle technology is important to overcome the constraint of uranium resource.

<table>
<thead>
<tr>
<th>Resource</th>
<th>Years of nuclear resource availability (based on the nuclear electricity output and efficiency at 2002)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LWR (Once-through)</td>
</tr>
<tr>
<td>Known conventional resources</td>
<td>4.59 million t-U</td>
</tr>
<tr>
<td>Total conventional including undiscovered</td>
<td>14.38 million t-U</td>
</tr>
</tbody>
</table>

3. The amount of renewable energy power generation in 2000

The following is arranged from integrated energy statistics and economic statistics handbooks, etc. in 2000. The amount of renewable energy power generation including hydropower is about 90 billion kWh.

<table>
<thead>
<tr>
<th>Package</th>
<th>Amount</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro-power</td>
<td>87.2 TWh (785 PJ)</td>
<td>General Energy Statistics of Japan</td>
</tr>
<tr>
<td>Photovoltaic generation</td>
<td>0.35 TWh (3.1 PJ)</td>
<td>Handbook of Energy &amp; Economic Statistics in Japan</td>
</tr>
<tr>
<td>Geothermal power generation</td>
<td>0.33 TWh (30 PJ)</td>
<td>General Energy Statistics of Japan</td>
</tr>
<tr>
<td>Wind power generation</td>
<td>0.11 TWh (0.98 PJ)</td>
<td>General Energy Statistics of Japan</td>
</tr>
<tr>
<td>Biomass power generation</td>
<td>0.10 TWh (0.91 PJ)</td>
<td>International Energy Agency report</td>
</tr>
<tr>
<td>Waste-power generation</td>
<td>2.1 TWh (19 PJ)</td>
<td>Without black liquor General Energy Statistics of Japan</td>
</tr>
<tr>
<td>Total</td>
<td>90 TWh (840 PJ)</td>
<td>General Energy Statistics of Japan</td>
</tr>
</tbody>
</table>

*The numerical values in parentheses are primary energy requirements based on the average thermal power generation efficiency because of the comparison with fossil resources.

4. Photovoltaic generation

(1) Classification examples and features

There are many kinds of photovoltaic generation. The development of two or more types of solar cells like crystal silicon, amorphous silicon, compound semiconductors, organic semiconductors, and the dye-sensitized type, etc. continues now, and they are selected by their power generation efficiency, productivity, and durability, etc. However, a super effective new structure and new material solar batteries are necessary so that power generation efficiency may exceed 30%.

(2) Potential of photovoltaic generation

The power generation potential of the photovoltaic generation in Japan with an efficiency of 15% is 208 TWh/year in comparison to the electric power demand in 2000 of 968 TWh/year. The required amount of power generation in case C, 2,000 TWh/year, corresponds to the necessary so that power generation efficiency may exceed 30%.

### Classification and feature of solar cells

<table>
<thead>
<tr>
<th>Classification</th>
<th>Feature</th>
<th>Reference power generation efficiency</th>
<th>Practical level</th>
<th>Research level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-crystal silicon</td>
<td>A monocrystal cell is made from a thin-die cut from a single crystal of silicon. The generation efficiency is high, however the manufacturing cost is also high.</td>
<td>-18%</td>
<td>-25%</td>
<td></td>
</tr>
<tr>
<td>Polycrystal</td>
<td>The cell consists of polycrystalline grains. The production cost is lower than single-crystal through the generation efficiency is low.</td>
<td>-16%</td>
<td>-20%</td>
<td></td>
</tr>
<tr>
<td>Silicon</td>
<td>Amorphous silicon</td>
<td>The manufacturing process is comparatively easy, and it is suitable for making to a large area. It is used as a thin film.</td>
<td>12%</td>
<td>-18%</td>
</tr>
<tr>
<td>Group III-V compound semiconductor</td>
<td>Because it is highly effective and the radiation resistance is excellent, it is put to practical use as a solar cell for space. In addition, making to highly effective has been achieved for the compound. (GaAs, InP, etc.)</td>
<td>22%</td>
<td>-37%</td>
<td></td>
</tr>
<tr>
<td>Group II-VI compound semiconductor</td>
<td>Practical use starts from the cell of the polycrystal thin film type to the second generation solar cell  because the manufacturing cost is low. (CdTe/CdS, Cu2S/CdS, Cu2S/CuS, etc.)</td>
<td>-</td>
<td>-17%</td>
<td></td>
</tr>
<tr>
<td>Chalcogenide semiconductor (CIS, CIGS)</td>
<td>Because the photocatalyst coefficient is large, it is suitable for the thin film type. It is small-scale, and the proof of principle (Cu2SMe2, Cu2S/CdS, Cu2S/CdS, Cu2S/CdS, etc.)</td>
<td>-14%</td>
<td>-19%</td>
<td></td>
</tr>
<tr>
<td>Organic semiconductor</td>
<td>The conversion efficiency is low though it is light and low-cost.</td>
<td>-</td>
<td>-5%</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>Dye-sensitized type (net type)</td>
<td>Using the electron transfer method, the light of the semiconductor compound (dye) is sensitized, and a structure to confine and to accumulate them (TiO2) with the photocatalyst reaction and the dye.</td>
<td>-</td>
<td>-11%</td>
</tr>
</tbody>
</table>

**Potential presumption of photovoltaic generation in the world**

<table>
<thead>
<tr>
<th>Region and country</th>
<th>Available area (km²)</th>
<th>Average solar radiation (kWh/m²/year)</th>
<th>Potential of photovoltaic generation (TWh/year)</th>
<th>Electric power demand in 2000 (TWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>3,852</td>
<td>1.85</td>
<td>2.35</td>
<td>3.13</td>
</tr>
<tr>
<td>Western Europe</td>
<td>6,152</td>
<td>1.35</td>
<td>1.95</td>
<td>2.78</td>
</tr>
<tr>
<td>Japan</td>
<td>350</td>
<td>1.40</td>
<td>0.65</td>
<td>0.98</td>
</tr>
<tr>
<td>Oceania</td>
<td>77,700</td>
<td>2.00</td>
<td>21,190</td>
<td>207</td>
</tr>
<tr>
<td>Other Asia</td>
<td>81,200</td>
<td>1.65</td>
<td>20,070</td>
<td>1,881</td>
</tr>
<tr>
<td>Middle East and South Africa</td>
<td>81,200</td>
<td>2.00</td>
<td>22,796</td>
<td>207</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>253,700</td>
<td>2.47</td>
<td>99,789</td>
<td>984</td>
</tr>
<tr>
<td>Latin America</td>
<td>42,080</td>
<td>1.78</td>
<td>15,540</td>
<td>1,203</td>
</tr>
<tr>
<td>Former Soviet Union and Eastern Europe</td>
<td>30,000</td>
<td>1.60**</td>
<td>7,200</td>
<td>1,023</td>
</tr>
</tbody>
</table>

**Potential of photovoltaic generation in Japan**

- **In FY 2010**
  - Geothermal power generation: 0.33 TWh (30 PJ)
  - Photovoltaic generation: 0.35 TWh (3.1 PJ)
  - Wind power generation: 0.11 TWh (0.98 PJ)
  - Biomass power generation: 0.10 TWh (0.91 PJ)
  - Waste-power generation: 2.1 TWh (19 PJ)

**Total power generation capacity**: 90 TWh (840 PJ)

Source: IEA, "Energy Balances of OECD Countries" and "Energy Balances of Non-OECD Countries"
5. Geothermal power generation

Our country is volcanic, and there are abundant geothermal resources. By estimation, about 10% of the world geothermal energy exists in Japan.

The possible amount of geothermal energy which can be developed at the moment is assumed to be 5.27 GW as shown in the table below. Geothermal energy can be used as a base load, in contrast with wind power and photovoltaic generation which fluctuates by weather conditions.

<table>
<thead>
<tr>
<th>Development potential in terms of resource density and verification</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range 4 km² or less of development</td>
<td>2.47</td>
<td>1.33</td>
<td>0.95</td>
</tr>
<tr>
<td>Outside of &quot;Natural Parks Law&quot; regulation</td>
<td>0.39</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>The main road exists within 2km</td>
<td>0.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apart from hot spring region at 3 km or more</td>
<td>0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apart from hot spring region at 5 km or more</td>
<td>0.17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A possible amount of geothermal energy which can be developed at the moment in Japan

<table>
<thead>
<tr>
<th>Unit: GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.27</td>
</tr>
</tbody>
</table>

5. Geothermal resource

6. Wind power generation

According to the "Wind Energy Map" of NEDO, the predicted wind power potential is 35 GW in scenario 2, "10D x 3D" (the accumulated area of land with a wind velocity of 5 m or more is 3,599 km², which is 1.0% of the land of Japan). It becomes 77 TWh per year when assuming the capacity factor of about 25%.

Because an adequate power supply cannot be supplied only onshore, offshore wind power generation is needed. It becomes 252.9 GW (400 TWh/year) when assuming the installation is within 3 km of the coastline. However, a wind energy map on the sea remains a future task.

### Deployment potential of wind power generation in Japan (Onshore)

<table>
<thead>
<tr>
<th>Physical potential amount</th>
<th>Practical potential amount</th>
<th>Target value in 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind velocity 5 m</td>
<td>Wind velocity 5 m</td>
<td>2.5 GW</td>
</tr>
<tr>
<td>Capable area 3,600 km²</td>
<td>Capable area 939 km²</td>
<td>3 GW</td>
</tr>
<tr>
<td>Installation number 70,000</td>
<td>Installation number 8,300</td>
<td></td>
</tr>
<tr>
<td>Wind velocity 6 m</td>
<td>Wind velocity 6 m</td>
<td></td>
</tr>
<tr>
<td>Capable area 394 km²</td>
<td>Capable area 394 km²</td>
<td>1.1 GW</td>
</tr>
<tr>
<td>Installation number 3,700</td>
<td>Installation number 3,700</td>
<td></td>
</tr>
</tbody>
</table>

7. An estimation of potential and available supply of biomass in Japan and the world

### Potential and available use amount of biomass in Japan Biomass (PJ/year)

<table>
<thead>
<tr>
<th></th>
<th>Potential</th>
<th>Available use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>471</td>
<td>395</td>
</tr>
<tr>
<td>Paper</td>
<td>523</td>
<td>254</td>
</tr>
<tr>
<td>Agricultural waste</td>
<td>141</td>
<td>84</td>
</tr>
<tr>
<td>Animal dung, sludge</td>
<td>247</td>
<td>247</td>
</tr>
<tr>
<td>Food waste</td>
<td>285</td>
<td>285</td>
</tr>
<tr>
<td>Total</td>
<td>1,667</td>
<td>1,261</td>
</tr>
<tr>
<td>Crude oil equivalent</td>
<td>43.34 million kl.</td>
<td>32.78 million kl.</td>
</tr>
</tbody>
</table>

### Amount of available supply of bioenergy in Japan (PJ/year)

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Ultimate available amount of supply</td>
<td>1,011</td>
<td>1,017</td>
<td>959</td>
</tr>
<tr>
<td>(2) Practical available amount of supply</td>
<td>678</td>
<td>678</td>
<td>640</td>
</tr>
<tr>
<td>Crop residue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Ultimate available amount of supply</td>
<td>536</td>
<td>525</td>
<td>495</td>
</tr>
<tr>
<td>(2) Practical available amount of supply</td>
<td>195</td>
<td>188</td>
<td>177</td>
</tr>
</tbody>
</table>

### Potential amount of biomass in the world (EJ/year, 10^3 PJ)

<table>
<thead>
<tr>
<th>Waste system</th>
<th>Wood</th>
<th>Agriculture</th>
<th>Animal</th>
<th>Subtotal</th>
<th>Plantation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>5.9</td>
<td>27</td>
<td>15</td>
<td>49</td>
<td>38</td>
<td>87</td>
</tr>
<tr>
<td>Oceania</td>
<td>0.4</td>
<td>1.0</td>
<td>1.1</td>
<td>2.6</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Europe</td>
<td>5.0</td>
<td>8.0</td>
<td>3.8</td>
<td>17</td>
<td>24</td>
<td>41</td>
</tr>
<tr>
<td>North America</td>
<td>7.7</td>
<td>9.5</td>
<td>3.1</td>
<td>20</td>
<td>21</td>
<td>41</td>
</tr>
<tr>
<td>South America</td>
<td>1.9</td>
<td>5.2</td>
<td>5.4</td>
<td>13</td>
<td>18</td>
<td>30</td>
</tr>
<tr>
<td>Africa</td>
<td>2.0</td>
<td>3.3</td>
<td>5.6</td>
<td>11</td>
<td>27</td>
<td>38</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>55</td>
<td>34</td>
<td>112</td>
<td>142</td>
<td>288</td>
</tr>
</tbody>
</table>

### Amount of available supply of bioenergy in the world (EJ/year)

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Ultimate available amount of supply</td>
<td>32.0</td>
<td>58.3</td>
<td>97.3</td>
</tr>
<tr>
<td>(2) Practical available amount of supply</td>
<td>17.2</td>
<td>33.0</td>
<td>58.8</td>
</tr>
<tr>
<td>Crop residue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Ultimate available amount of supply</td>
<td>51.5</td>
<td>22.5</td>
<td>188.2</td>
</tr>
<tr>
<td>(2) Practical available amount of supply</td>
<td>17.2</td>
<td>4.7</td>
<td>72.6</td>
</tr>
</tbody>
</table>


A Glossary of Terms - Energy Technology Roadmap 2100 - (Tentative Translation, Jan. 2006)

<table>
<thead>
<tr>
<th>Terms</th>
<th>Res/Com</th>
<th>Trans-port</th>
<th>Indust-ry</th>
<th>Trans-forma-tion</th>
<th>Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Resource Constraint</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>Supposing that the peak of fossil resources (oil and natural gas) production will come in 2050 and 2010 respectively, our committee screened out technologies enabling other natural resources to replace oil and gas by then. However, projections for fossil fuel reserves vary from pessimistic to optimistic. Furthermore, the projections may change due to various factors including international relations and socio-economic reasons. Thus, the years of peak oil and gas production may change accordingly. So does the period of time for R&amp;D, demonstration, introduction and widespread use of the technologies. The time frame set in this study must be flexible.</td>
</tr>
<tr>
<td>Environmental Constraint</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>Our committee set environmental constraint as curbing CO2 emission per GDP (CO2/GDP) under one-third to 2000 in 2050, one-eighth to 2000 in 2100. To overcome this constraint, CO2 emissions both in 2050 and 2100 must be as much as that in 2000, namely 7 - 8 Gt, which calculated based on a scenario to stabilizing the atmospheric concentration of CO2 at 550 ppm.</td>
</tr>
<tr>
<td>Backcasting</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>One of the strategic approaches. In the backcasting approach, the target and tools to realize the desired vision in the future is set first. The vision setting is the starting point unlike the forecasting approach under which the target in the future is set based on a forecast from the current situation. Our committee first set technological spec to overcome resource and environmental constraints in the long-term perspective until 2100. Then, plotting technology cluster required to realize the spec on the time frame resulted in a road map.</td>
</tr>
<tr>
<td>%Carnot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>An ideal heat-engine cycle driven by temperature-differential between high and low temperature heat sources is called Carnot Cycle. The efficiency of the heat-engine is called Carnot Efficiency. The ratio of efficiency of heat-engine against Carnot Efficiency is called % Carnot, which shows how much the heat-engine comes close to the ideal heat engine. Like a steam engine, the cycle receives heat from high temperature heat source and converts a part of the heat into working force, then dumps the rest into a low temperature heat source called Carnot Cycle. On the other hand, pumping up heat from a low heat temperature source by adding working force to high temperature heat source is called reverse Carnot Cycle. The ideal for a heat pump or magnetic refrigeration system is the reverse of the Carnot Cycle.</td>
</tr>
<tr>
<td>3Rs for chemical products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>An effort to build Sound Material-Cycle Society. 3Rs mean &quot;Reducing,&quot; &quot;Reusing,&quot; and &quot;Recycling.&quot; On the stage of &quot;Reducing,&quot; the volume of disposal wastes are curbed through improving output to the input ratio by resource-savings and extending life. On the stage of &quot;Reusing,&quot; used products are reused with proper treatment if needed. On the stage of &quot;Recycling,&quot; used products or by-products are used as raw materials or as fuels for thermal recycling.</td>
</tr>
<tr>
<td>90/45/22 nm Processes</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>One of the semiconductor manufacturing processes. 90 nm, 45 nm and 22 nm are the width of circuit pattern. Most of the current microprocessors like Pentium 4 or Pentium M are manufactured on 90 nm processes technology. According to Intel Corporation, manufacturing of the microprocessor on 65 nm process technology is scheduled to begin between the end of 2005 and the beginning of 2006. Manufacturing on 45 nm process technology is scheduled to begin in the second half of 2007. The width of the circuit pattern will go down to 32nm, 22nm. Narrowing the width of the circuit pattern enables smaller microprocessor, greater chip density, higher clock speed and a lower priced microprocessor.</td>
</tr>
<tr>
<td>Actuator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A generic name for the parts of driving machines such as electromagnet, motor, hydraulic cylinder, or air-driven cylinder. Robots need more compact actuators with higher precision. For use, many actuators including piezoelectric actuators based on new mechanisms have been developed.</td>
</tr>
<tr>
<td>Advanced Secondary Battery</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>Next-generation secondary batteries such as nickel-hydrogen battery, lithium-ion battery. Developments on the following types are being propelled; Lithium-polymer, sodium-sulfur, zinc-chlorine, zinc-bromine and redox flow batteries.</td>
</tr>
<tr>
<td>BEMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>An abbreviation for Building Energy Management System. BEMS is the management system for keeping track of the interior environment and energy consumption, and for reducing energy consumption by operational management of devices or facilities according to the interior environment in buildings for commercial use. BEMS is usually composed of instruments for measuring, controlling, monitoring, and devices for storing, analyzing and diagnosing data.</td>
</tr>
<tr>
<td>Binary Power Generation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A power generation system that generates electric power by turning steam turbines with vapor obtained by heating low boiling liquid. The system consists of two thermal cycles, namely, heat source line and heating medium line. This is why the system is called &quot;binary power generation.&quot; The system is applied to geothermal power generation. Currently geothermal plants use hot steam underground for generation, and returns accompanying hot water to the underground without being exploited. The binary power generation system enables effective use of hot water.</td>
</tr>
<tr>
<td>Biochemical Luminescence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bioluminescence. Light-emission like the light produced by firefly luciferase. Light-emission efficiency is quite high. Because it doesn't utilize heat, it is called cold light.</td>
</tr>
<tr>
<td>Terms</td>
<td>Res/ Com</td>
<td>Transport</td>
<td>Industry</td>
<td>Trans-formation</td>
<td>Meanings</td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------</td>
<td>-----------</td>
<td>----------</td>
<td>----------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Bio-photoelectron</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Photonic device that uses organic molecules instead of semiconductor devices. In a biological system, bio-photoelectron shows very high efficiency as the quantum yield of optoelectric transduction reaches 100%. Fundamental research is being propelled aimed at applications including ultra-super energy-saving optical sensor, exploiting three-dimensional structure of protein.</td>
</tr>
<tr>
<td>Black Liquor</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Liquor discharged from pulp production like craft pulp common in Japan. The main ingredient is lignin other than fibers processed into pulp. By concentration, black liquor can be used as biomass energy. According to the 2002 report published from Japan Paper Association, one-third of the total consumption energy in the Japanese paper industry.</td>
</tr>
<tr>
<td>BTL</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>An abbreviation for Biomass to Liquid, which is made from biomass. BTL is obtained through gasification of biomass or Fischer-Tropsch (FT) synthesis. BTL is used for transportation fuel. Biomass-origin BTL is almost carbon-neutral.</td>
</tr>
<tr>
<td>BTX</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A generic name for benzene, toluene and xylene, which are base materials for chemical products. BTX is constantly retrievable from various used-plastic products. BTX is promising for the recycling process of chemical products.</td>
</tr>
<tr>
<td>Bypass Ratio</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>The ratio of the weight of air for combustion to weight of air sent by fans. A higher bypass ratio means the increase of air mass sent by fans. With a higher bypass ratio, fuel efficiency is better and the condition is suitable for subsonic flight.</td>
</tr>
<tr>
<td>By-product Hydrogen</td>
<td>✓ ✓</td>
<td></td>
<td></td>
<td></td>
<td>Hydrogen gas generated as a by-product from the production process at steel-making plants, soda manufacturing factories and oil refinery plants. Until the time when hydrogen production using renewable energies is realized, by-product hydrogen is promising as a hydrogen supply source.</td>
</tr>
<tr>
<td>Capacitor</td>
<td>✓ ✓</td>
<td></td>
<td></td>
<td></td>
<td>A device used to store electricity temporarily. With the expectation for next generation storage batteries, the capacitor stores electricity without chemical reactions unlike lead-acid battery or lithium-ion battery. Recharge time is so short that the life of the capacitor is theoretically semi-permanent with no degradation during charging and discharging. The expectation is that capacity increase and resistance reduction of capacitor will enable a new device to drive motor and charge regenerated energy for electric cars or hybrid cars. In addition, since the capacitor mostly consists of carbon and aluminum foil, it is environmentally friendly.</td>
</tr>
<tr>
<td>CCS</td>
<td>✓ ✓</td>
<td></td>
<td></td>
<td></td>
<td>An abbreviation for Carbon dioxide Capture and Storage (or Sequestration). A technology that captures CO2 originating from fixed sources through chemisorption or membrane separation, and stores CO2 into a water-bearing layer underground. In this study, CCS is an essential technology when using fossil fuels such as coal.</td>
</tr>
<tr>
<td>CFRP</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>An abbreviation for Carbon Fiber Reinforced Plastics. To obtain dry carbon-type one, carbon fiber dampened with resin is affixed on a cast, then baked in an oven while adding pressure. This type of plastics is light and very strong because unnecessary resin is removed. Difficulty in downstream processing is one of its disadvantages.</td>
</tr>
<tr>
<td>Chemical Luminescence</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A phenomenon where energy is emitted as light when exited molecules by chemical reactions go back to the ground state. Bio-luminescence is one of chemical luminescence using enzymatic reaction. Because of its low calorific value, application for low-power lighting is under development.</td>
</tr>
<tr>
<td>Closed Hydrogen Diesel</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Engine combined diesel engine with steam turbine. To collect the driving force, a steam turbine is spun by high-temperature and high-pressure steam from a diesel engine.</td>
</tr>
<tr>
<td>Closed Hydrogen Engine</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Emitting only steam from hydrogen combustion, this engine uses recycled argon and the part of steam, while oxides of nitrogen are emitted from the hydrogen combustion engine with oxygen. The hydrogen combustion engine with oxygen diluted by argon or steam emits no oxides of nitrogen.</td>
</tr>
<tr>
<td>Cluster Light-emission</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A light-emitting mechanism using heat radiation in irradiating microwaves with cluster, collected nucleuses or molecules of metals for the source of light. The mechanism receives attention as a next generation light source for its high color rendering and long-life brought by higher heat-up than incandescent lamps.</td>
</tr>
<tr>
<td>CNT Transistor</td>
<td>✓ ✓</td>
<td></td>
<td></td>
<td></td>
<td>A transistor using Carbon Nano Tube (CNT) for components. Depending on its chirality and diameter in carbon bond, CNT has properties like metals or semiconductors, both of p-type and n-type. As the diameter of CNT transistor is at nanometer scale, it is expected to be the promising substitute for silicon chips when downsized silicon chips reach their physical limit.</td>
</tr>
<tr>
<td>COG</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>An abbreviation for Coke Oven Gas. COG is the gas generated during coke production. The main composition is hydrogen and methane. The amount of COG generation is 300-350 Nm3 per ton of coal. With conventional technologies, COG is refined by recovering tar and water after applying water-cooling. It has been a fuel for industrial use. Development of the technological production of hydrogen from reforming gases at high temperature is being accelerated.</td>
</tr>
</tbody>
</table>
A photovoltaic cell that has plastic film, instead of glasses, for its circuit board. Light in weight and rich in flexibility enable installation free from site or design constraints. Challenges including hydrogen supply, traveling distance and lowering costs.

An abbreviation for Coal To Liquid. Liquid fuel made from coal. CTL can be obtained through gasifying coal or Fischer-Tropsch(FT) synthesis. Among the uses is transportation fuel. Needing no additional infrastructure investment, CTL can be treated as light oil or kerosene. Mixed use with gasoline is also possible.

A technology that analyzes and forecasts the time zone and necessary energy supply by aggregating various energy demands or loads. Combining patterns of heat and power demands or consumers with different heat-to-power ratio makes a high efficient energy supply possible. Demand aggregation is the basic technology in energy management.

See Nitride Device.

A solar cell not using silicon semiconductors but using an electrical-chemical cell structure through an iodine solution. With cheap raw materials and no need of large scale facilities to manufacture, the expectation is that dye the sensitized solar cell will be a solar cell with low production cost. However, the current conversion rate of light energy is only 7 - 8%. Development for higher efficiency of conversion is being propelled.

A displaying technology using substance emits visible light when charged. EL display can achieve high brightness with low power. It has advantages in visual recognition, response speed, life, power consumption, EL display technology enables a thin and flat panel like liquid crystal display. Inorganic EL display, once the mainstream technology, used inorganic substance like zinc sulfide. However, difficulties such as displaying in colors limited wide application. On the other hand, organic EL display is easier to display in colors, and works with much lower power in direct current. Application for portable devices is expected.

A system established in 2000 for indicating energy-saving performance. To know instantly whether home appliances meet national energy-saving targets and which appliance is better in energy-savings than the others, the data are on the label. The data help to make the right choice for appliances allowing comparison among many appliances. The intended home appliances are 13 appliances including air conditioners, refrigerators, freezers, fluorescent tubes and TV sets.

An abbreviation for Energy Service Company. A business that provides clients comprehensive energy saving measures, not sacrificing convenience. The business takes part of the benefits from energy savings for compensation. This business appeared in the US just after the second oil crisis. In the middle of the 1990s, Japanese ESCO business started and began to expand in mainly public facilities.

An abbreviation for Energy Service Provider. A business entity that supplies customers with power and heat instead of utilities. ESP guarantees customers benefits from utilities by contracting operations combined various services including ESCO, Energy Management and Facility Management (FM).

An abbreviation for Ethyl Tert-Butyl Ether. It is produced through synthesized ethanol and isobutylene, and can mix with gasoline for automobiles. Unlike bio-ethanol, ETBE’s advantages are curbing the evaporation, no separation and corrosivity due to water contamination. In Europe, use of ETBE mixed with gasoline has begun.

A technology that retrieves energy lost in the expansion process of gases. This technology is effective for improving COP (Coefficient Of Performance) of heat pumps.

An abbreviation for Fast Breeder Reactor. A nuclear reactor designed to maintain nuclear fission by not reducing the speed of fast neutrons and allows the neutron to hit the next nuclear. In a light water reactor, heat from nuclear fission is retrieved by water. In FBR, the heat is retrieved by liquid sodium, less decreasing the speed of fast neutron. In addition, FBR raises the uranium utility rate dramatically in the following way: (1) put uranium-238 as a blanket fuel around plutonium fuel at the reactor core, (2) uranium-238 transforms into plutonium, absorbing neutron from plutonium fuel, (3) produce more plutonium than consuming plutonium as fuel. FBR takes its name because it makes plutonium breed using neutrons.

An abbreviation for Fuel-Cell Vehicle. Fuel-Cell is usually a device to generate electric power through chemical action between hydrogen fuel and oxygen in the air. A fuel-cell vehicle runs a turning motor by electricity generated in a fuel cell, emitting no gases. However, there are challenges including hydrogen supply, traveling distance and lowering costs.

A photovoltaic cell that has plastic film, instead of glasses, for its circuit board. Light in weight and richness in flexibility enable installation free from site or design constraints.
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Flywheel</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>A kinetic energy storage technology using disk or rotary objects. With the supply of electric power, a disk rotates. When the supply is cut, the disk continues to rotate with stored kinetic energy or inertial force. This rotation of the disk can generate electricity. This technology is commercialized for trains or an interruptible power supply. While the flywheel is suitable to short-time energy storage, it is difficult to keep the energy loss in rotation zero. Some obstacles are noted for capacity increase and long-time storage.</td>
</tr>
<tr>
<td>Forecourt Hydrogen production, Centralized Hydrogen production</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Forecourt hydrogen production is a system of producing hydrogen through reforming town gas and oil-origin fuels or electrolysis of water at the site where hydrogen is supplied to hydrogen based devices such as fuel-cell vehicle. Centralized hydrogen production is a system of transporting hydrogen produced at the site where hydrogen can be produced in much volume.</td>
</tr>
<tr>
<td>FT Synthesis</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A technology developed by F. Fischer and H. Tropsch, to produce hydrocarbon mixture from synthesis gas, or a mixture of hydrogen and carbon monoxide. As synthesis gas can be obtained easily from natural gas, coal or biomass, FT Synthesis Oil is expected to be a substitute to oil. As FT Synthesis Oil's ingredient is straight-chain hydrocarbon, it has a large cetane number and zero octane number, it is suitable to use as a diesel fuel. However, it is not yet a substitute to gasoline.</td>
</tr>
<tr>
<td>GT Integration</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A power generation system that combines high-temperature energy conversion and Rankine Cycle. As fossil resources like oil and gas are finite, highly efficient energy conversion from lower calorie resources such as coal, biomass and waste disposal will be required. To do so, GT integration is a promising technology that exploits the lower calorie resources in the form of synthesis gas or fuels through gasification into hydrogen, carbon monoxide or methane.</td>
</tr>
<tr>
<td>GTL</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>An abbreviation for Gas To Liquid. Liquid fuel is obtained through reforming natural gas, or FT Synthesis. It is used as a transportation fuel. Like CTL and BTL, GTL can be treated as light oil or kerosene without additional infrastructure investment. Mixed use with gasoline is also possible.</td>
</tr>
<tr>
<td>HCCI Engine</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>An engine with a form of Homogeneous Charge Compression Ignition in which well-mixed fuel and an oxidizer (typically air) are compressed to the point of auto-ignition. This form has advantages each of homogeneous charge spark ignition (gasoline engines) and stratified charge compression ignition (diesel engines). HCCI engines have been shown to achieve low emissions of oxides of Nitrogen or particulate matter. HCCI is expected to enable engines to achieve high thermal efficiency as well.</td>
</tr>
<tr>
<td>Heat Pump</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>An instrument transferring heat from a low temperature storage tank to a high temperature storage tank through the use of properties of heating medium, namely, absorbing heat and liberating heat in phase transformation. The heat pump is used for air conditioning or hot water supply. Fuels like electric power or gas are required to drive the compressor for calculating the heating medium. A motor-driven heat pump achieves high efficiency because it is used as a driving force to transfer heat, not as thermal energy.</td>
</tr>
<tr>
<td>Heat Transformer for industrial use</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>An absorption-type heat pump using absorbed latent heat of coolant vapor at the absorber. The coolant is previously evaporated by a low temperature heat source. Absorption type heat pump is a heat pump driven physically and chemically. In the compressing process, it does not use mechanical compressors, but the increase of partial pressure of coolant vapor caused by variations in concentration of absorbent.</td>
</tr>
<tr>
<td>HEMS</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>An abbreviation for Home Energy Management System. HEMS is a management system for keeping track of the interior environment and energy consumption, and for reducing energy consumption by operational management of home appliances (such as refrigerators and air conditioners) according to the interior environment. In the future, operational management will include coordination between distributive power sources and batteries. Just like BEMS, HEMS is composed of instruments for measuring, controlling, monitoring, and devices for storing, analyzing and diagnosing data.</td>
</tr>
<tr>
<td>HIDiC</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Heat Integrated Distillation Column. With a form of internal heat exchange, HIDiC is an energy-saving distillation system that recycles internal heat. The distillation process consumes approximately 40% of all heat consumption in the chemical industry. HIDiC is a new technology, applicable to the distillation process and aims at energy-savings of more than 30%.</td>
</tr>
<tr>
<td>High Operating Temperature Fuel Cells</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Fuel cells with a high operating temperature such as SOFC (solid oxide Fuel cells), MCFC (molten carbonate fuel cells). Heat along with power generation can be used effectively as well. Applications to self-generation for buildings and factories, co-generation is on the rise. For utility generation, the expectation is that high temperature operating fuel cells are applicable to IGFC (Integrated Coal Gasification Fuel Cell Combined Cycle).</td>
</tr>
<tr>
<td>House Performance Indication System</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A system which gives home-buyers reliable information based on evaluations on house performance including stability in structure, fire safety and consideration to elderly people. This system is a pillar for a law regarding promotion of ensuring qualities in houses enacted in 2000. Since August 2002, the law has been applicable to the resale of houses.</td>
</tr>
<tr>
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<tr>
<td>Hybrid Car</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>An automobile with multiple driving forces. Typically it combines an engine and electric driven motor. Selective and efficient use of engine and motor gives high mileage. With different combinations of a power source, various systems are proposed. Mild HB: A relatively simple system with idling-stop when stopping, and restarting engine by motor when moving the car. Parallel HB: Two power sources engage in driving in parallel. For example, the engine is mainly for running the car and occasionally works for charging the battery. The motor works on moving and acceleration. Series Parallel HB or Split HB: Depending on the situation, either the series system or the parallel system is selected, and one or both of them are selected. The motivity splitter controls the ratio between electric power generation and driving. Series HB: With the connection of the engine, generator, inverter and motor in series, the car runs while generating electric power. This system was created for extending driving distance of electric cars. Pug-in HB: A system that enables the driving of a genuine electric car by the addition of battery units to a hybrid car.</td>
</tr>
<tr>
<td>Hybrid Heating</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>A heating technology that performs two or more heating methods, for example, Joule heating and high frequency heating at the same time. This technology is commercialized in steam-oven ranges.</td>
</tr>
<tr>
<td>IGCC</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>An abbreviation for Integrated coal Gasification Combined Cycle. In most of the present coal-fired thermal power plants, steam turbines generate electric power by the force of high-temperature and high-pressure steam. The steam is gained by burning coal in a boiler. IGCC aims at higher electric efficiency (gross) using coal gas as input to the cycle combined gas turbine with waste heat recovery boiler. A demonstration project is being propelled at the scale of 250 MW in Japan. Its efficiency target is 46 - 48% in the commercial plants.</td>
</tr>
<tr>
<td>IGFC</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>An abbreviation for Integrated coal Gasification Fuel Cell combined cycle. A system adding fuel cells to IGCC. Through partial oxidation, coal gas is transformed into carbon monoxide and hydrogen for fuel cells. After being used at the fuel cell, unreacted carbon monoxide and hydrogen go into a gas turbine to generate electric power. Then, flue gas goes into a steam turbine to generate electric power. A development project with 55% net efficiency target is being propelled.</td>
</tr>
<tr>
<td>Intelligent Engine</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>A jet engine enabling functions such as incompatibility sensing, operational maximization, maintenance point forecast by exploiting engine controlling technology. This technology integrates active control, advanced diagnosis and forecast control.</td>
</tr>
<tr>
<td>In-wheel Motor</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>Motor installed into wheels of electric vehicles which enables separate control of the wheel. Loss of energy from motor to wheel is minimum because energy is transmitted to the wheel directly. It has an advantage of fewer number of parts and lighter body due to reduction of the deceleration system.</td>
</tr>
<tr>
<td>Kraft Pulp</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>A kind of chemical pulp made through extraction of fibers in the mixture of wood chips and solvent. Most printing papers are made of this pulp. On the other hand, ground pulp is made of wood chips grounded by machines. News print papers use ground pulp. In the paper milling process, lignin contained in wood can be used as bio-fuel. While the total CO₂ emission (of biomass-origin and fossil fuel origin) is more than that of de-inked pulp, CO₂ emission of fossil fuel origin can be less than that of de-inked pulp.</td>
</tr>
<tr>
<td>Latent Heat Recovery Gas Water Heater</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>A gas water heater which is more efficient and reduces CO₂ emissions through the use of a secondary heat exchanger designed specifically to recover heat and latent heat in flue gas that was released into the atmosphere when using conventional gas water heaters.</td>
</tr>
<tr>
<td>Latent Heat Storing Construction Material</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>A construction material that stores latent heat, which is absorbed in the transformation of materials from solid state to liquid state, and which is emitted in the reverse transformation. The construction materials use materials that can transform between the solid state and liquid state in temperature range for use. Compared to thermal storage materials (like concrete) using sensible heat, the storage value is larger per a certain area.</td>
</tr>
<tr>
<td>LCD</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>An abbreviation for Liquid Crystal Display. A monitoring device that uses liquid crystal cells. It is made up of a liquid crystal that is sandwiched between two glass layers and becomes opaque when electric current passes through it. The contrast between the opaque and transparent areas forms visible images. Liquid crystal itself does not emit lights. Images are displayed by reflected light in bright light, and back light in the dark. LCD is used in many laptop computers, calculators and digital watches because it is lighter and thinner than other monitoring devices such as CRT display or PDP (Plasma Display Panel).</td>
</tr>
<tr>
<td>LED</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>An abbreviation for Light-Emitting Diode. It is a semiconductor emitting light when charged. When the electric current flows in one direction on a semiconductor made of silicon, gallium, phosphorous, arsenic and others, with crystal in p-n junction, energy generated in the crystal emits lights. As blue LED has been developed recently, additive primary colors - red, green, and blue - are now ready. Displays in white or full color is possible.</td>
</tr>
<tr>
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</tr>
<tr>
<td>Light Emission Efficiency</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Value that indicates how many pencils of light are generated by 1 [W] electric power. The value for incandescent lamps is approximately 15 [lm/W], and for fluorescent tubes is approximately 60 [lm/W].</td>
</tr>
<tr>
<td>Light Storage</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A storage technology to store ultraviolet light in sunlight or lamps. Stored light is emitted in the dark and at night. The technology has been already commercialized in specialized lighting fixtures for identifying stairs or switches.</td>
</tr>
<tr>
<td>Light Transportation (for lighting)</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A technology that transports light obtained by gathering natural light or assembled light-emission, by way of optical fibers or light transporting path with photoreflective surface, to where the light is needed.</td>
</tr>
<tr>
<td>Light-gathering Technology</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A technology that gathers natural light effectively by instruments made up of, for example, convex lenses and concave mirrors. The technology includes a technology that levels the light-gathering amount in daytime like sun-tracking technology, dust-resistant or self-cleaning technology.</td>
</tr>
<tr>
<td>Load Following Operation</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>An operation in power plants that adjusts actual generating power to load fluctuations. Load is electric power withdrawn from power plants. In Japan, this operation is performed mainly in thermal power plants, other than nuclear power plants which supply to base load. In France, nuclear power plants perform this operation because of the huge share of nuclear power in the total power supply.</td>
</tr>
<tr>
<td>Local Energy Network</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A coinage made by our committee. It is an energy network for consumers to make mutual exploitation of energy or surplus generated by individuals, housing complex, local utilities or non-utility suppliers. Mutual exploitation of energy with charges promotes HEMS and BEMS.</td>
</tr>
<tr>
<td>Long half-life FP Nuclear Conversion</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A technology that converts radioactive fission product (FP) into non-radioactive nuclide through the use of nuclear reaction. FP includes nuclide generated in nuclear fission of uranium or plutonium, and nuclide left after a series of radioactive decay of nuclide generated in the above. Application of neutrons to long-life FP, FP with strong radioactive toxicity and FP that keeps the toxicity for a long time converts them into non-radioactive nuclides or short-life nuclides.</td>
</tr>
<tr>
<td>Low Operating Temperature Fuel Cell</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>Fuel cells with low operating temperature such as PEFC (Polymer Electrolyte Fuel cells). Operating temperature for PEFCs is approximately 80 degrees C. A low operating temperature makes the fuel cells applicable to the use of frequent switching. Applications to co-generation for home use, automobiles, and power source of mobile devices are receiving attention.</td>
</tr>
<tr>
<td>Magnetic Refrigeration</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A refrigeration system through the use of magnetocaloric effect, which is a phenomenon of rise and fall of temperature when a magnetic object is put on and off the magnetic field. The cycle is Carnot Cycle and theoretical efficiency is Carnot Efficiency. Properties of magnetic refrigeration include no-use of chlorofluorocarbon for coolant, possibility of energy savings due to no compressor, which results in no energy loss accompanying the compressing or expanding gases.</td>
</tr>
<tr>
<td>Magnetostrictive Transduce</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A technology that transforms distortions in crystalline structure caused by electric or magnetic field outside into mechanical force or vice versa. It is applied to an actuator or a torque sensor.</td>
</tr>
<tr>
<td>Material Cascade Management</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A shared society-wide philosophy, or building and implementing the philosophy that reduces materials emitted or accumulated as much as possible. To be concrete, efforts to manufacture industrial products easier to separate or discard them as raw materials afterwards are created, while collecting products dispersed over the society effectively.</td>
</tr>
<tr>
<td>Micro-cavity Light Source</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A technology that realizes various luminescent properties by forming a micro-cavity as large as the wavelength of light in the vicinity of reactive phases of light-emitting devices like LED. Light emission in red, green and blue is applicable to monitoring instruments.</td>
</tr>
<tr>
<td>Minor Actinide Nuclear Conversion</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>High-level radioactive wastes are generated from the reprocessing of spent nuclear fuel. The high-level radioactive wastes include long half-time minor actinide with high radioactive toxicity such as neptunium, americium and curium. Converting those long life and toxic radioactive nuclides into non-radioactive or short life nuclides is called nuclear conversion processing, which can reduce high-level radioactive wastes and shorten the quarantine duration dramatically. In the field of nuclear conversion, the subject of research includes methods using nuclear reactors or accelerators.</td>
</tr>
<tr>
<td>Multiple-phase Power Transmission</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A power transmission method for overhead transmission. Unlike power transmission on a three-phase alternating current, the method reduces the insulation distance required among phases by, for example, transmission on a six-phase alternating current. It is said that transmission capacity can increase in a certain transmission route.</td>
</tr>
<tr>
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<tr>
<td>Nanocatalysis</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>A technology that gives a single catalyst the required functions by controlling a nano-structure in three dimensions. For example, integration of functions incompatible with each other like acid site, base site, oxidative activity, reducing activity, affinity for water, hydrophobicity on a single catalyst is possible. A new catalysis process emitting no disposals by nanocatalysis would bring a radical change to the current production processes.</td>
</tr>
<tr>
<td>New Sintering Process</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>In the steel industry, reduction of raw material, or sintered iron ore (Fe2O3), to iron is performed in a blast furnace. With the help of coke as a reducing agent, reaction between carbon monoxide and Fe2O3 brings iron for the product. In the new sintering process, pulverized iron ore transforms into Fe/FeO through partial reduction and briquetting. Introduction of this process is expected to reduce the amount of carbon materials such as coke for blast furnaces which reduces CO2 emissions.</td>
</tr>
<tr>
<td>New Steel-making Process Forum</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>An environmentally friendly basic technology for regenerating metallic materials. Along with the sophistication of steel making, steel products become sophisticated with a higher content of additives including zinc, copper and tin. In addition, trace metallic materials, accumulated during dozens of times recycling, give an adverse effect on the quality of steel products. A new steel-making process forum regenerates those degraded scraps with a higher content of metallic additives.</td>
</tr>
<tr>
<td>Nitride Device</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>For saving electric consumption, the challenge is more reduction of loss in electric conversions. The currently wide-used switching device is one using silicon, which is reaching the limit of physical properties. On the other hand, wide bandgap semiconductors like SiC (silicon carbide), III-IV group nitride semiconductor of GaN (gallium nitride), AlN (aluminum nitride) and diamond semiconductor have not only a wide bandgap, but are also stable thermally and chemically. For these properties, wide bandgap semiconductors are receiving attention as materials for hard electronics. In addition, they are reported to be superior to silicon in breakdown field, and thermal conductivity.</td>
</tr>
<tr>
<td>Optical Duct</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>A technology that uses sun light for lighting or supporting lighting by sending sun light to designated sites. Sunlight is captured in mirror ducts. This technology enables lighting in rooms or basements where direct lighting by the sun is difficult.</td>
</tr>
<tr>
<td>Organic EL Lighting</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>EL (electro-luminescence) is one of the luminescent phenomena caused by energy-exited substances. For example, placing a voltage on a semiconductor induces electro-luminescence. Organic EL is a technology of inducing EL by applying electric current to organic compounds. As organic EL works in low voltage, energy-savings are achieved. Furthermore, development on application to display or lighting because indication in colors are possible according to the kinds of organic compounds to use. Application to lighting requires higher luminance and efficiency than application to display. However, unlike LED, organic EL has the ability to emit light on a very thin plane. With a plastic circuit board, this property gives lighting systems with the freedom of shaping, not allowed before.</td>
</tr>
<tr>
<td>Organic Thin Layer Photovoltaic Cell</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td>A photovoltaic cell that generates power using thin organic layers. It has the properties of plastic such as light, soft, colorful and cheap. The expectation is on applications impossible by conventional silicon-used photovoltaic cells, namely, use as a power source for wearable or ubiquitous electric devices.</td>
</tr>
<tr>
<td>Papermaking Additive</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>Inorganic agents that increase opacity of paper or acceptability of printing ink in the process of papermaking. Additives are mostly calcium carbonate, titanium oxide or clay. Regenerated used papers requires washing out these additives. These washed-out additives and fibers become paper sludge.</td>
</tr>
<tr>
<td>Passive Solar</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td>A technology that uses solar energy for thermal storage, ventilation or daytime lighting through architectural designs, while active solar technology retrieves solar energy using instruments or driving force such as solar power generation or solar water heater.</td>
</tr>
<tr>
<td>PDP</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>An abbreviation for Plasma Display Panel. A monitoring device that displays images by charging high pressure gas like helium or neon sandwiched between two glass layers. The mechanism of light emission is the same as fluorescent tubes. Contrast is higher and vision angle is wider than those in other methods. While PDP is not suitable to laptop computers because of the required high voltage, it is applied to wall mountable TVs because of its easiness of scaling-up.</td>
</tr>
<tr>
<td>Piezoelectric Transduce</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td>A technology that transforms strains against piezoelectric objects into voltage or vice versa. It is used for oscillators, filtering circuits in analog electronic circuits as well as actuators and sensors. Along with technologies like thermo-electric transduce, piezoelectric transduce is expected to apply to ultra-super low electric devices.</td>
</tr>
<tr>
<td>Power Regenerative System</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>A system that regenerates reduced kinetic energy into, for example, electric energy by a spinning electric power generating motor when reducing the driving force from motors or engines. Deceleration by brake releases the force as heat.</td>
</tr>
<tr>
<td>Terms</td>
<td>Res/Com</td>
<td>Transport</td>
<td>Industry</td>
<td>Transformation</td>
<td>Meanings</td>
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<tr>
<td>Radiation Cooling</td>
<td>✓</td>
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<td></td>
<td>A cooling system using radiation generated when flowing cold water over ceiling-mounted radiation panels for cooling people in the room. Compared to a convection system, the degree of comfort is higher, the temperature can be set higher in cooling and lower in heating. There is a proposal of combining radiation cooling and ice thermal storage equipment.</td>
</tr>
<tr>
<td>Regenerative Combustion</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>A technology of power generation by firing hydrogen collected from carbon energy resources such as biomass and coal in a hydrogen combustion combined cycle. With conventional technologies, hydrogen is obtained from carbon energy resources through partial oxidation, gasification and reforming. With regenerative combustion, hydrogen is obtained from the same carbon energy resources through gasification and reforming using solar heat or low-level exhaust heat. This process is a kind of thermo-chemical heat pump which low-level heat energy transforms into low-exergy hydrogen energy by carbon chemical energy. This technology enables dramatic increase of the energy utility rate.</td>
</tr>
<tr>
<td>Regenerative Paper Additive</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>Inorganic agents retrieved from used paper. Printing paper contains additives such as limestone or clay as much as 10 - 30% other than fibers. In the current process of making paper from used paper, only fibers are retrieved and additives are discharged. A technology of retrieving and refining those additives enables recycling additives in used paper.</td>
</tr>
<tr>
<td>RPF</td>
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<td></td>
<td>An abbreviation for Refuse Paper &amp; Plastic Fuel. One of the thermal-recycling methods. Solid fuel made through crashing or mixed molding industrial wastes such as used paper not for reproduction and composite plastics. Limitation of raw materials gives RPF stable quality as a fuel. High in calorie and easiness to handle give RPF an expectation as a substitute to fossil fuel.</td>
</tr>
<tr>
<td>SC3</td>
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<td>An abbreviation for Sustainable Carbon Cycle Chemistry. A coinage made by our committee. SC3 is a system in which chemical products are made by synthesizing hydrogen and carbon monoxide obtained through gasification of unnecessary chemical products in addition to recycling chemical products. The system is for building Sound Material-Cycle Society.</td>
</tr>
<tr>
<td>See-Through Photovoltaic Cell</td>
<td>✓</td>
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<td></td>
<td>A photovoltaic cell allowing the light to pass through, which can be used for windows. Types having micro slits or holes are on the market. Research and development is being propelled on a type that has transparent photovoltaic cells.</td>
</tr>
<tr>
<td>SiC</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>Silicon Carbide. Its properties include wide bandgap, high breakdown field, high electron saturation velocity, and high thermal conductivity. Controlling valence electrons in p-type and n-type is easy. For these properties, it is one of the most promising semiconductor materials for next generation devices like high-power and high-frequency devices. Other semiconductor materials such as silicon or alloy of gallium and arsenic compound (GaAs) cannot be used for those devices due to the limit in properties.</td>
</tr>
<tr>
<td>Single Electron Transistor</td>
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<td>An ultimate low-power electronic device that controls electrons even at the level of one electron. The current memory device memorizes 1 bit of information by charging and discharging approximately a hundred thousand electrons over a capacitor. The single electron memory device memorizes 1 bit of information by controlling one or several electrons through the quantum-effect. Theoretically, the power consumption by a single electron memory device is approximately one-hundred thousandth compared to the conventional memory devices. The challenges include a technology to mold quantum dots less than several nanometers stably and go into volume production, a technology to detect a fine current passing over transistors.</td>
</tr>
<tr>
<td>SMES</td>
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<td>An abbreviation for Super Conducting Magnetic Energy Storage. A technology that stores electric power in magnetic energy by keeping the electric current on superconducting coil. For its advantages including high energy efficiency (90 - 95%) and high response speed, a high capacity increase is expected.</td>
</tr>
<tr>
<td>String Cables-battery Hybrid</td>
<td>✓</td>
<td></td>
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<td></td>
<td>A technology keeping regenerative braking ready to work by storing regenerated electricity in an advanced battery. Recently, most trains are equipped by a regenerative brake, which converts kinetic energy in motion into electric energy, and returns it to string cables. However, a regenerative brake requires running trains nearby to consume regenerated electricity. String cables-battery hybrid technology solves this problem.</td>
</tr>
<tr>
<td>Superconducting Fault Current Limiter (SFCL)</td>
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<td>An electric device that controls electric current in short circuit accidents on power systems. As distributed generation has been increasing recently, the current limiter receives attention for controlling the current, by which the scale of such accidents do not exceed capacities of the existing breaking devices. SFCL takes advantage of the S/N (superconducting state to normal conducting state) transition. In ordinary cases, SFCL is in low impedance. In cases of short circuit accidents, it reduces fault current by high impedance.</td>
</tr>
<tr>
<td>Superconducting Power Transmission</td>
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<td>A power transmission technology that exploits superconductivity, namely, zero in electrical resistance. Zero electrical resistance enables reduction of transmission loss and increase of capacities.</td>
</tr>
<tr>
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<tr>
<td>Superconducting Transformer</td>
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<td></td>
<td>✓</td>
<td>A transformer that exploits superconducting phenomena. The expectations are on efficiency improvement, safety in over-current, miniaturization and weight reduction.</td>
</tr>
<tr>
<td>Supercritical-Water-Cooled Reactor</td>
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<td>✓</td>
<td>A Generation IV water reactor, one of the concepts of next generation nuclear reactors. Taking advantage of operation under 25 MPa and 500 degrees C, the critical point of water, and thermal efficiency as high as approximately 45%. Adoption of a once-through cycle eliminates the need for a steam separation system and recirculation system, and makes simplification of equipment possible.</td>
</tr>
<tr>
<td>Task-ambient Air-conditioning System</td>
<td>✓</td>
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<td>An air-conditioning system aimed at both comfort and energy-savings. In the case of cooling, for example, the system keeps the temperature in the task area (occupied) comfortable and the temperature in ambient area (unoccupied) as high as accepted, not cooling the whole areas. Sense of heat and cold varies greatly between sex and ages. With the use of personalized local-area air-conditioning, energy for air-conditioning could be reduced without loss of comfort for individuals.</td>
</tr>
<tr>
<td>TEMS</td>
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<td>✓</td>
<td>An abbreviation for Town Energy Management System. A coinage made by our committee. TEMS manages energy demand and supply on the town level through collaboration among HEMS, BEMS and power systems by exploiting IT and networks. TEMS supports power system management by suppliers over frequency, power flow, and so on.</td>
</tr>
<tr>
<td>Thermal Energy Storage Air-conditioning</td>
<td>✓</td>
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<td>An air-conditioning technology that curbs power consumption for air conditioning during daytime by storing heat during nighttime when electric power rates are low. Air-conditioning that uses a concrete frame as thermal storage, and an ice thermal energy storage cooling system are included in this technology. The technology also contributes to load leveling.</td>
</tr>
<tr>
<td>Thermo-electric Transduce</td>
<td>✓</td>
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<td>A technology that transforms thermo energy into electric energy. With no moving parts, the technology generates electric power causing no noise or vibration. It is commercialized in products like thermo-electric wrist watches, and &quot;candle radio,&quot; which is driven by flames of candles in emergencies such as earthquakes. In the future, applications are possible to ultra-super low power devices along with piezoelectric transduce.</td>
</tr>
<tr>
<td>Thorium (Th)</td>
<td>✓</td>
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<td>The chemical element with atomic number 90. An actinide. In nature, the radioactive element consists of Th-232 only. Its half-life is 1.4 x 10^9 years. By absorbing neutrons, thorium transforms into Uranium-233, a nuclear fuel, through beta decay.</td>
</tr>
<tr>
<td>Top Runner System</td>
<td>✓ ✓</td>
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<td>A measure that promotes energy savings regarding energy-consuming products, specified by the law for energy savings. The law sets the energy-saving standard as high as that of each of the best products on the market. As of April 2003, the specified products numbered 18, including passenger cars, air-conditioners, fluorescence lamps, TV sets, VCRs, copiers, personal computers, magnetic disk devices, refrigerators, freezers, hauling trucks, stoves, gas ranges, gas instantaneous water heaters or bath boilers with hot-water supplier, oil water-heaters, stools with hot water rinsing, vending machines, and transformers.</td>
</tr>
<tr>
<td>UHVAC</td>
<td></td>
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<td>✓</td>
<td>A power transmission technology in Ultra High Voltage Alternating Current in the level of 1000 - 1500 kV. The higher voltage is, the less the loss is.</td>
</tr>
<tr>
<td>Ultra-super Critical Pressure Power Generation</td>
<td>✓</td>
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<td>A thermal power generation with inlet steam-temperature condition of 565 degrees C or higher and the pressure of 240 atm or higher. While water transforms into a state of gas, namely, steam at 100 degrees C and 1 atm, it becomes indifferent in the state of liquid and gas at the temperature of 374 degrees C or higher and the pressure of 218 atm or higher. This state is called the critical state of water. Designed gross efficiency of 30% in sub-critical power generation rose to 40% in critical power generation, then up to 42% in the advanced ultra-super critical power generation.</td>
</tr>
<tr>
<td>Underground Thermal Utilizing Heat Pump System</td>
<td></td>
<td>✓</td>
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<td>The system for heating and cooling through heat exchange exploiting the temperature differential between above ground and underground. In the underground more than 5 - 10 m deep in Japan, the temperature remains constant at 10 -15 degrees C. While the system is expanding in the United States, the effort of introduction is not enough in Japan because of the high cost of drilling, and so on. Underground thermal is differentiated from geothermal in the deeper underground.</td>
</tr>
<tr>
<td>VOC</td>
<td>✓</td>
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<td>An abbreviation for Volatile Organic Chemicals, which is ascribable to sic-house syndrome. Development of construction materials containing less VOC and new ventilation systems is being propelled.</td>
</tr>
</tbody>
</table>
"Energy Technology Vision 2100"

As of 2005/10/5

Organization

METI

IAE (secretariat)

Steering Committee

General WG

SWG Transformation

SWG Industry

SWG Res/Com

SWG Transport

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Kashiwagi, Takao  Tokyo University of Agriculture and Technology

Masada, Eisuke  Tokyo University of Science

Matsumi, Kazuaki  The Institute of Applied Energy

Nishio, Shigefumi  The University of Tokyo

Oto, Toru  Nippon Steel Corporation

Ota, Ken-Ichiro  Yokohama National University

Sata, Yutaka  Toshiba Corporation (until March, 2005)

Sugiyama, Taishi  Central Research Institute of Electric Power Industry

Toshiba, Takao  Matsushita Electric Industrial Co., Ltd.

Tsutsumi, Atsushi  The University of Tokyo

Yamaji, Kenji  The University of Tokyo

 METI

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General WG (inauguration in October, 2004)

(Chairman)
Akai, Makoto  National Institute of Advanced Industrial Science and Technology

Fujimura, Koutaro  Mitsubishi Heavy Industries, Ltd.

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Kondo, Yasuhiko  National Institute of Advanced Industrial Science and Technology (from November, 2004)

Nishio, Shigefumi  The University of Tokyo

Ogimoto, Kazuhiko  Electric Power Development Co., Ltd. (from November, 2004)

Okumura, Norihiko  The Institute of Energy Economics, Japan

Okuzumi, Naoki  Toshiba Corporation (from April, 2005)

Sata, Yutaka  Toshiba Corporation (until March, 2005)

Setoguchi, Yasushi  Mizuho Information & Research Institute, Inc.

Shigetomi, Norio  Mitsubishi Research Institute, INC.

Sugiyama, Taishi  Central Research Institute of Electric Power Industry

Touma, Kiyoshi  Osaka Gas Co., Ltd.

Tsutchiya, Haruki  Research Institute for Systems Technology

Tsutsumi, Atsushi  The University of Tokyo

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Ogimoto, Kazuhiko  Electric Power Development Co., Ltd.

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Munakata, Tetsuo  
National Institute of Advanced Industrial Science and Technology

Nihei, Hiraku  
Japan Paper Association *(from July, 2005)*

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Ono, Toru  
Nippon Steel Corporation

Watanabe, Yutaka  
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Hoshi, Hirohiko  
Toyota Motor Corporation

Otsubo, Katsushi  
New Energy and Industrial Technology Development Organization

Shina, Takanori  
Honda R&D Co., Ltd. *(from June, 2005)*

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Ogimoto, Kazuhiko  
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(Touma, Kiyoshi  
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National Institute of Advanced Industrial Science and Technology

Hatori, Hiroaki  
National Institute of Advanced Industrial Science and Technology

Ikaga, Toshiharu  
Nikken Sekkei Ltd.

Ishikawa, Toshihiro  
Matsushita Electric Industrial Co., Ltd.

Kato, Tohru  
National Institute of Advanced Industrial Science and Technology

Kang, Yoon Myung  
Daikin Air-Conditioning and Environmental Laboratory, Ltd.

Otsubo, Katsushi  
New Energy and Industrial Technology Development Organization

Sugiyama, Taishi  
Central Research Institute of Electric Power Industry

Tamura, Tetsuya  
NEC Corporation

Yamashita, Yukari  
The Institute of Energy Economics, Japan *(from April, 2005)*