Technological Strategy Maps for the Petroleum Energy Resource Field

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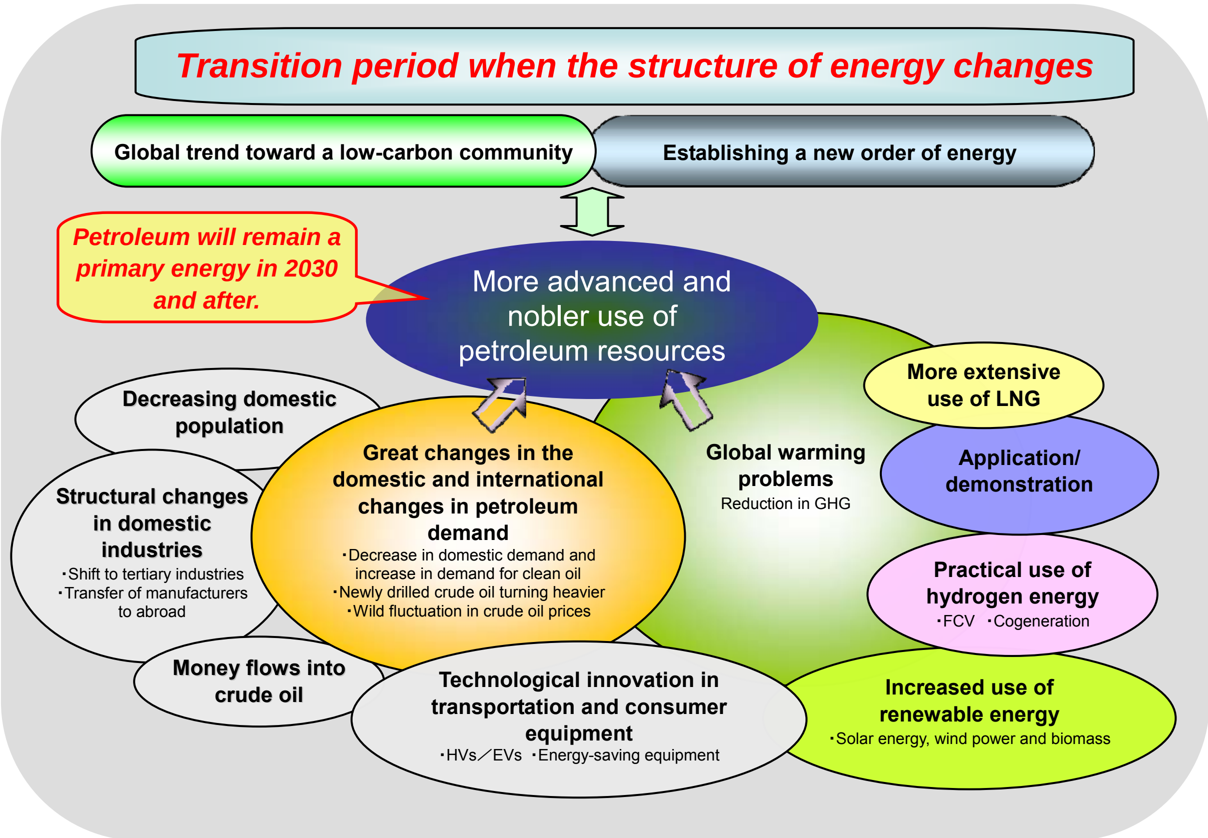
Contents

1. Recognition of changes in the environment in Japan

Although there have been many arguments and different opinions about the correlation between the concentration of CO_2 in the atmosphere, greenhouse gases (GHG), and climate change, the measures taken to cope with global warming problems have affected the entire socioeconomic situation throughout the world. This situation is expected to lead up to various technological developments and the creation of new projects in industrial and consumer fields overall, for instance, the development of such renewable energy sources as solar energy, wind power and biomass and a shift to electric vehicles and there will be medium- to long-term activities for building up a new balanced order of diverse types of energy. Thus we can recognize that we have entered a transitional period in which the structure of energy will change on an unprecedented scale in world history.

Recognition of Changes in the Environment

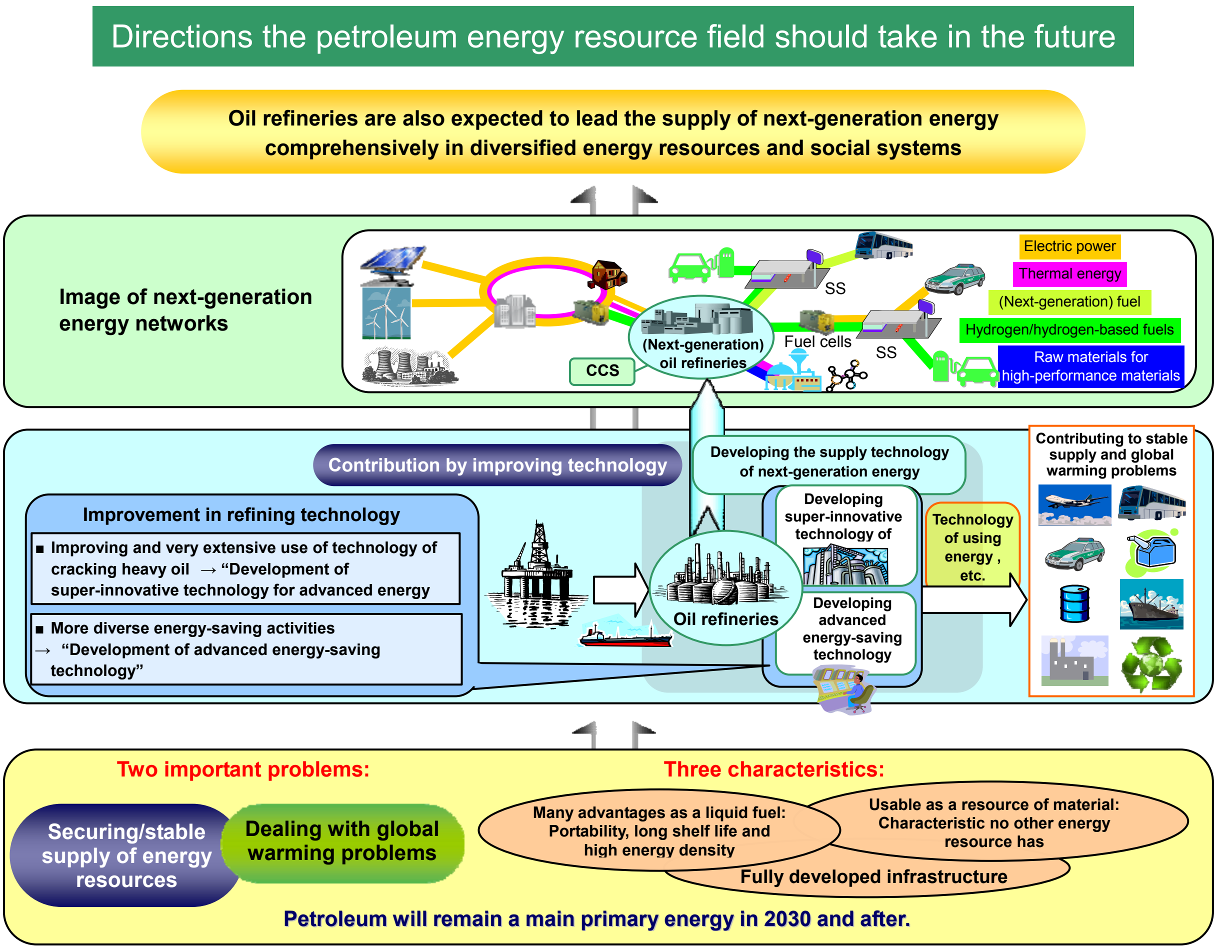


Renewable energy, such as wind power, solar energy and biomass, is not always more advantageous than petroleum considering the economic rationality and the lifecycle of reduction in CO_2 emissions. Therefore, while domestic demand for petroleum will decline over the long term, it has been forecast that the ratio of petroleum to the total demand for primary energy will remain at around 30% even in 2030. Considering that petroleum is expected to be a major primary energy source long into the future as stated above, the advanced and noble use of petroleum energy resources will remain important for many years to come.

2. Future directions for the petroleum energy resource field

While the important problems facing the petroleum industry in Japan are (1) a stable supply of energy resources and (2) reduction in GHG emissions, petroleum is expected to remain a main primary energy source even after 2030. This is because petroleum has a number of outstanding characteristics, including the fact that petroleum is a liquid fuel that is easy to handle, that petroleum has almost unlimited possibilities as a resource material and that an advanced infrastructure for petroleum production has already been developed and is available. Thus, to make the most of these notable characteristics for a stable energy supply, the petroleum industry is required to promote technological development from a medium- to long-term strategic view aiming at solving two important problems: securing petroleum energy resources and improving petroleum refining technology.

In the long run, the problem of improving petroleum refining technology will involve two traditional aspects: upgrading heavy oil and saving energy. To cope with such problems as increasing demand for clean oil in the structure of petroleum demand, the trend toward heavier crude oil drilled from newly developed oil fields and expected future dependence on untraditional extra-heavy oil, it is essential to be able to upgrade heavy oil more efficiently and at lower cost. In addition, because the petroleum refining industry is itself a high energy-consuming industry, the effective introduction of low-energy consuming processes, high-efficiency energy recovery systems, etc. is very important from the standpoint of GHG reduction and international competitiveness and ultimately ensuring a stable supply of petroleum.



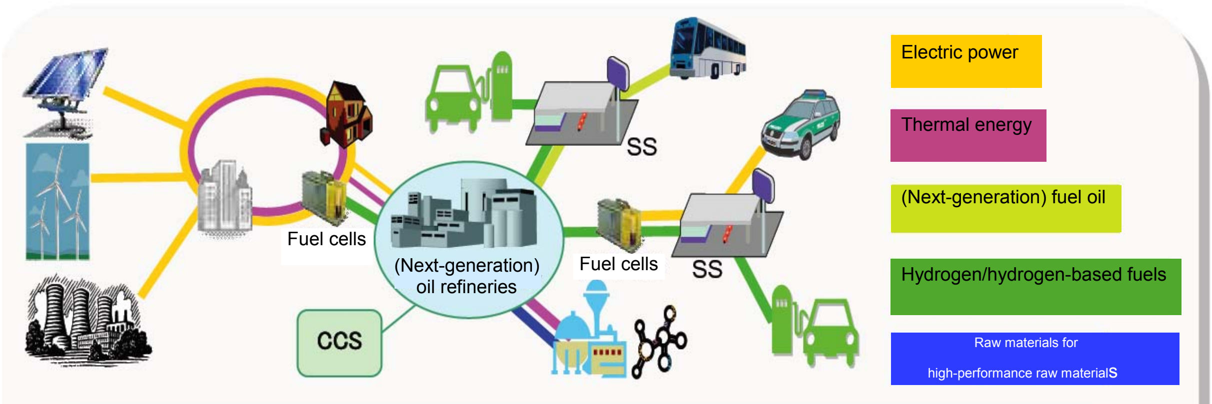
As already stated in "1. Recognition of changes in the environment," oil refineries are expected to evolve into energy conversion bases with diverse functions either in response to medium- to long-term diversification of energy supply and demand patterns, or by playing a leading role in establishing a new energy order and to become the nucleus of the next-generation energy network. Energy use in 2030 and after is forecast to be as follows.

a) The refining process will be able to refine untraditional extra-heavy oil, as well as synthetic crude oil derived from untraditional extra-heavy oil, without any restrictions. As will be discussed later, oil refineries will become large energy conversion bases and will also use biomass, coal, petrocoke, etc. as raw materials. In producing various substances and energy, i.e., steam, liquid, electric power and thermal energy, from diverse raw materials, and in supplying these substances and energy, optimal production and supply will be an important problem. Coproduction and pinch technology will have been widely introduced and optimal processes will have been secured.

b) As for automobile fuels, which are the strategic commodities of the petroleum industry, passenger cars (gasoline-fueled cars) will be considerably replaced by electric vehicles (EVs) and plug-in hybrid vehicles (PHVs), and the demand for gasoline will be greatly reduced as a result. But, the use of fuel cell vehicles (FCVs) will increase, leading to greater use of hydrogen, and for this reason, the supply of hydrogen from oil refineries will be the most important energy supply base in the community.

Image of next-generation energy networks

(enlarged version of the figure shown above)



Raw materials: Crude oil, untraditional crude oil, heavy residual oil, petrocoke, coal, biomass, etc.

c) As for the technical background of multifunctional oil refineries that supply hydrogen, incorporating innovative hydrogen production technology into existing hydrogen production processes will have become standard practice. In addition, a large supply of low-cost hydrogen is thought to become possible by, for example, producing hydrogen by combining a gasifying device with traditional production processes using low value-added surplus substances, such as heavy residual oil and petrocoke, as raw materials.

d) For trucks and other large-sized vehicles for which it is difficult to replace diesel engines with other power sources from a technical or economic viewpoint, light oil and other liquid-type fuels will remain the main fuels in use. But to increase fuel efficiency, new engine combustion systems will be introduced to both passenger cars and trucks, possibly necessitating the design of fuel quality to be revised. In addition, the mixture of biomass fuel and other changes will greatly affect the refining process.

e) Naphtha for the petrochemical industry will be fractionated more finely than today (light naphtha or heavy naphtha) according to the requirements and types of processes of the petrochemical industry, and various raw materials for highly functional materials will be supplied.

As for the technical background, it is expected that traditional energy-consuming distillation processes will be replaced with membrane separation and other innovative processes.

f) Next-generation oil refineries are expected to become entities having concentrations of so-called green innovation and core organizations in the next-generation energy network by introducing advanced energy-saving technologies and thus achieving more efficient recovery of discharged CO2 through use of carbon capture and storage (CCS) systems.

3. Technological strategy maps for the future (up to 2030)

3.1 General discussion

Future directions for the petroleum energy resource field were discussed in the previous section. The main areas of technical development needed to create next-generation oil refineries that will play a central role have been organized as technological strategy maps, and the schedule of the technical development and other related matters have been summarized as road maps (attached on the last page).

An essential point in establishing next-generation oil refineries is to improve refining technology, and improving and developing the technology for cracking heavy oil and energy-saving technology are the most important problems oil refineries should address. In the technological strategy maps, these problems are shown as super-innovative technology of advanced energy use and advanced energy-saving technology. The maps also state that biofuel production technology and super-innovative hydrogen production technology are important technical fields in oil refineries enabling them to evolve into multifunctional energy supply bases and also include the recovery of CO_2 discharged from hydrogen production processes by highly efficient CCS technology.

Technological strategy maps for the future (up to 2030)

Oil refineries are also expected to lead the supply of next-generation energy comprehensively in diversified energy resources and social systems

Improving oil refining technology

- ■ Super-innovative technology for advanced energy use
  - ・Technology for online analysis of crude oil composition
  - ・Technology for efficient cracking of heavy oil
  - ・Technology for converting low-quality distillates into high quality ones
  - ・New high-efficiency cracking technology (e.g., supercritical aqueous pyrolysis)

- ■ Advanced energy-saving technology
  - ・New energy-saving process technology (e.g., PSA and membrane separation)
  - ・Total optimization of substances and energy by co-production and pinch technology

Developing the supply technology of next-generation energy

- ■ Biofuel production technology
  - ・Production technology for producing the second-generation biofuel (non-edible) and the third-generation biofuel (gasified).

- ■ Super-innovative hydrogen production technology
  - ・Technology for high-efficiency, high-purity hydrogen production and CO_2 recovery
  - ・Technology for producing, transporting and recovering high-purity hydrogen

- ■ CCS technology
  - ・Super-innovative membrane separation technology (Membrane separation technology for recovering CO_2 from heating furnaces and boilers)

Steps taken with the cooperation of petroleum companies

- ■ Virtual one refinery using advanced ICT
- ■ Innovation of off-site technology (introduction of local JIT into petroleum refining and distribution)
- ■ Technology for introducing IGCC by regional cooperation and using IGCC at a high efficiency

Technology of using fuels

- ■ Development of measures for fuel oil quality and technology of using fuel oil
  - ・Technology for coping with next-generation automobiles (HVs, HCCI) → Fuel oil for new-type engines
  - ・Steps for environmental controls and use of nontraditional fuels
- ■ Technology for assessing the quality of fuels containing biomass fuel
- ■ Technology for distributing petroleum-based hydrogen

Turning SSs into green stations

Compliance with environmental laws and ordinances

- ■ Technology of managing chemicals

Security technology

- ■ Steps for new production technology
- ■ Steps for medium-term environmental changes
- ■ Steps for natural disaster risks

Securing a stable supply of petroleum energy resources | **Measures against global warming problems**

The figure above notes the main problems regarding the development of process technology and includes steps taken with the cooperation of petroleum companies so that oil refineries may make greater contributions to green innovation as their functions increase. These steps involve great difficulty in that they have to overcome the barriers of capital, which are higher than the technological hurdles. Specifically, the main purpose of these measures is to maximize the efficiency of operations by multiple oil refineries that exist in neighboring or the same industrial complexes and are doing their refinery operations jointly.

Regarding the technology for the energy they use, oil refineries are expected to take measures for so-called next-generation energy, that is, fuel cells to increase the efficiency of energy use remarkably and biomass fuel which is a promising renewable energy. They will also need to take strategic steps for internal combustion engines because conversion to more efficient versions of existing engines is likely to take place.

Compliance with environmental laws and ordinances and security technology are also mentioned in the above figure as factors affecting the operation of oil refineries. It is considered that by introducing these strategies comprehensively, oil refineries will be able to secure a position as leaders in next-generation energy.

3.2 Requirements and important problems of technological development

3.2.1 Development of super-innovative technology of advanced energy use

As noted above, the technology for cracking heavy oil and improvement of energy-saving technology are the two areas that oil refineries should tackle traditionally. The processes of cracking heavy oil can roughly be classified into hydrocracking, fluid catalytic cracking, thermal cracking, etc. and the steps to deal with changes in the structures of fuel oil demand and changes in market needs for oil products quality and property, cost reduction and measures for heavier crude oil (feedstocks) are common to all of these processes. Fluid catalytic cracking, which has been greatly improved recently and has been effectively operating and is regarded as a major source of earnings at almost all oil refineries, has made rapid progress. However, considering the great changes in the environment of domestic oil refining expected in the future, many additional improvements in these existing processes and the development of new cracking processes will be definitely required.

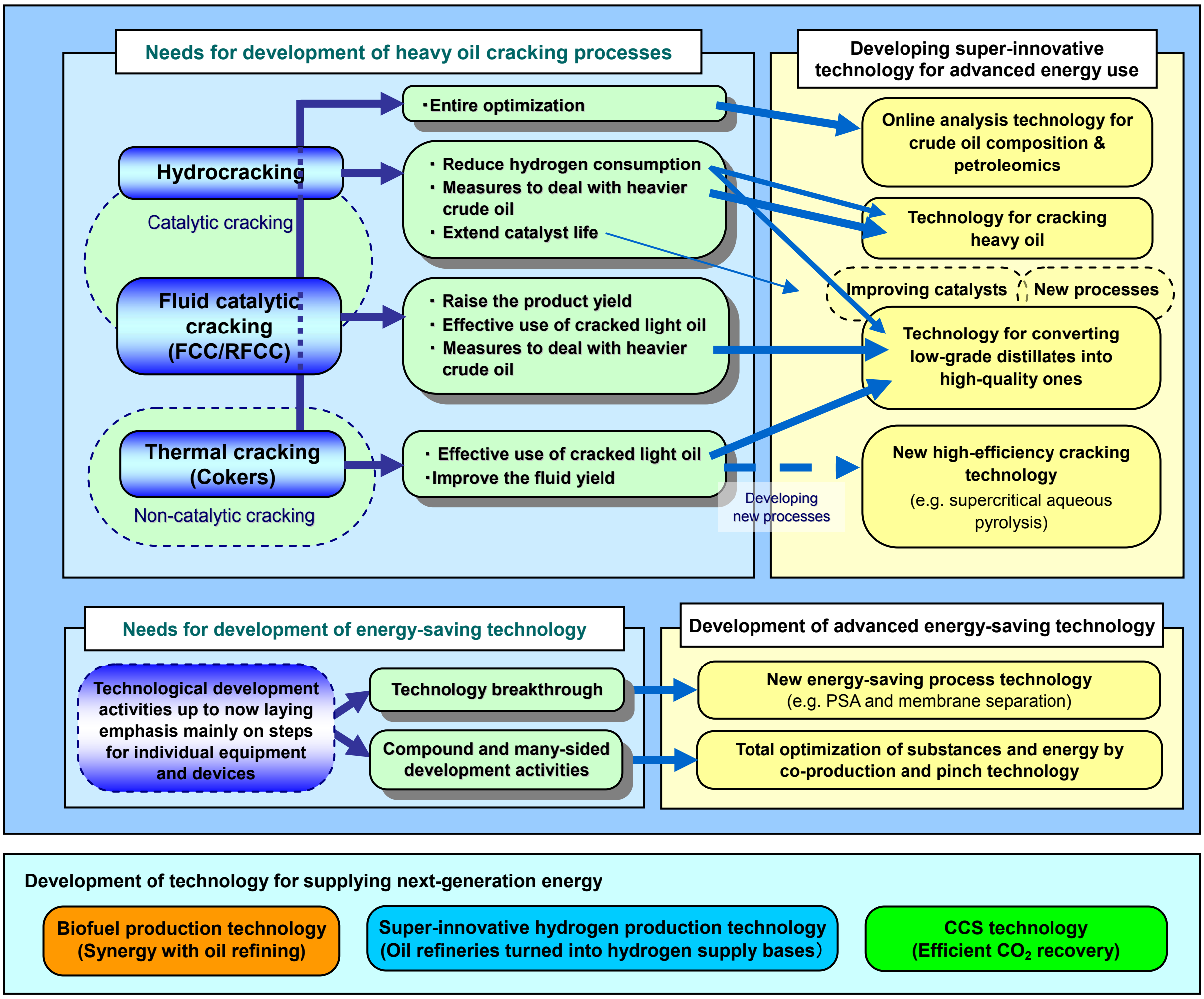
The process technology of oil refining has almost entirely been introduced from abroad, but Japan is as excellent as overseas licensors in catalyst technology to fully utilize process performance, process control technology and quality control technology. In addition, in the fields where Japan's fuel oil quality is a world leader, such as sulfur-free diesel oil, Japanese process technology using a catalyst as a core naturally excels, and high severity fluid catalytic cracking (HS-FCC), a large-scale process development in Japan, has reached the stage of demonstration. Therefore, it is expected that projects will be carried out to develop a technology that involves a technical breakthrough not just an extension of the past and can gain an advantage over competing technologies abroad.

(1) Online analysis of crude oil composition and petroleomics

Crude oil is composed of a very large number of molecular-level components and has unlimited combinations of reactions. Because of this, analyzing these components and studying the reaction paths were fairly unexploited fields. But the surprising progress of computer technology and improvements in analyzing technology in recent years have been making these analyses and study possible. One of the novel ideas is this: if it is possible to analyze the composition of crude oil (this analysis does not always need to be a detailed one; even a rough analysis will be valuable) at the entrance of the topper, the atmospheric distillation unit, on a real-time basis and to adjust and control the instrumental variables in a feed-forward way for not only the topper but also the downstream secondary units and the establishment of final product lots by blending base components, optimization will be achieved in a dimension not attainable in the past.

This technology consists mainly of continuous crude oil sampling technology, field-type near-infrared ray spectroscopic analysis technology, identification technology of the results of spectroscopic analysis, and composition and distillation property simulation technology, and it is not trivial to create the main technology because all of these component technologies have high hurdles to be surmounted. There have been reports that some major oil refiners in Europe and America have already put this technology into practical use but the technology itself has not been disclosed yet. Thus it is supposed that the technology is still at an initial stage.

Needs for development of advanced technology and important issues in technological development



While online analysis is an ideal method, offline analysis is expected to bring about very great effects in such areas as process design, catalyst design and adjusting the instrumental variables, if it is possible to analyze crude oil composition, especially heavy residual fuel oil, and further to study the main reaction routes. This type of systematized technology that combines detailed analyses of molecular structure and molecule based kinetic modeling is called petroleomics* and began to be used mainly in the U.S.

* A coined word combining petroleum and omics (combination of two Greek words, ome (perfection) and ics (learning)) that means a system of learning that covers all parts of a particular field.

Much expectation has been placed on petroleomics technology, especially as a basic research and development technology for the advanced use of heavy oil. For example, heavy oil, which is a crude oil or a residual of crude oil distillation, is a mixed substance containing hundreds of thousands of different types of molecules as well as molecules of a huge and complex structure having a molecular weight as great as 10,000, such as asphaltene. What traditional analysis technology was capable of was only to fractionate heavy oil into saturated parts, aromatic compounds, resin and asphaltene and to estimate averaged structural parameters of them. But Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR-MS), a state-of-the-art method, can make a qualitative and quantitative analysis of the chemical formation of the molecules composing heavy oil and can also analyze heterocompounds, such as sulfur and nitrogen parts, both qualitatively and quantitatively. Although this analysis method is still at a developmental stage, it has changed the thinking from "it is impossible to analyze crude oil and heavy oil at a molecular level" to "it is possible to analyze the detailed structure of crude oil and heavy oil" and is an innovation that will have very important effects in the oil refining field.

Computing science has also made rapid progress. For example, the attribute reaction model (ARM) technique of dividing huge molecules into reactive attributes and turning the parts into a reaction model has recently reached the stage of practical use. As a result, it has become possible to efficiently analyze the reaction mechanism of the real device, create models, perform reaction simulations and estimate product properties.

As stated above, there is an increasing possibility that development of processes and catalysts for heavy oil at a far more rapid pace than in the past will start in several years through the molecular-level analysis of the detailed structure of heavy oil and molecule-based kinetic modeling. The online analysis of crude oil and petroleomics technology both have a very high hurdles to overcome, and thus oil refineries must also consider a more realistic alternative: dividing the development process into several stages and starting the practical use of the stages as soon as development has been completed.

(2) Technology of advanced cracking of heavy oil

In Japan, it is standard practice to hydrotreat feed oil in the fluid catalytic cracking unit in the indirect (direct) desulfurization unit in the previous process. Hydrocracking takes place even in this process and the cracking performance in (R) FCC changes according to the degree of hydrocracking. Therefore, it is important to achieve optimization by regarding these processes as one system. In particular, to increase the cracking capacity while dealing with heavier crude oil (feedstocks), there is a need for comprehensive technical expertise for improving and effectively combining the latest technology for analyzing the heavy oil structure, simulation technology based on computational science, technology for analyzing the catalyst structure, technology for flow dynamics, etc. For example, as a result of these studies, it becomes possible to relax aggregated asphaltene molecules in vacuum distillation residuals (VRs) using CLO, the bottom oil from the fluid catalytic cracking unit, and there arises a good possibility of making VRs into a material for direct desulfurization. Thus there is ample room for super-innovative technical development.

On the other hand, while a large quantity of hydrogen is consumed in hydrocracking, hydrodesulfurization, etc., the hydrogen is consumed not only in quantities needed for reaction but also for side reaction, too. In addition, cracked gas and hydrogen cannot be separated completely in the separation processes in the downstream of the reaction system and thus valuable hydrogen is lost into the fuel gas system at a certain ratio. A considerable part of this hydrogen (50% or more at some oil refineries) is produced at the hydrogen production unit in the steam reforming method using naphtha, LPG, etc. as raw materials, and this process discharges a substantial quantity of CO_2 into the atmosphere. But oil-producing countries mostly produce hydrogen using associated gas from crude oil and natural gas as a raw material, thus their cost of hydrogen production is much lower, providing them with a source of competitiveness. Therefore, it is desirable to make super-low hydrogen consumption a precondition in the development of catalysts for hydrocracking, hydrodesulfurization, etc. and in process development from the standpoint of controlling CO_2 emissions and strengthening international competitive power.

(3) Technology for converting low-grade distillates into high-quality distillates

The middle distillates from the fluid catalytic cracking unit and thermal cracking unit contain large quantities of the polycyclic aromatic series, and to make these distillates into a product, the distillates must be converted into hydrocarbon molecules with a high level of hydrogenation, such as BTX, paraffin and naphthene, by a secondary hydrocracking treatment. Unless this treatment is performed fully, cracked light oil can be used only as the component of fuel oil, which will pose a serious obstacle to activities for changing supply-demand structures. Thus it is desirable to perform the treatment completely and achieve various types of technical development, such as the development of catalysts for obtaining high-quality products with a high yield by minimizing hydrogen use as much as possible and the development of a super-innovative process for causing reactions at one stage using a moving bed instead of two-stage reaction with a fixed bed used in the existing process, thereby reducing hydrogen consumption drastically.

(4) New technology for high-efficiency cracking (supercritical aqueous pyrolysis process)

A representative non-catalyst thermal cracking unit is a coker. Because this unit has a relatively simple process for cracking VRs, cokers have been introduced and are in operation at many oil refineries in the world. But as noted in (3) above, the middle distillates obtained from this unit have problems of quality and a coke yield of as high as tens of percent, and cannot contribute to the prevention of global warming as they discharge much CO2 when the coke is burned. Although the process for directly hydrocracking heavy oil of the VR class has been developed recently, this process is not always more advantageous than cokers in economic terms because it consumes a large quantity of hydrogen and needs relatively high construction costs, thus the introduction of units for this process has been limited.

In this situation, the development project for a new process for thermal cracking of VRs and other types of very heavy oil using supercritical water as a reforming media has been planned as a totally new concept, and scientific studies on reaction mechanisms are now underway as preparatory research. In the water in a supercritical state, water and organic reactants form a homogeneous phase and the hydrogen in the water contributes to the hydrogen transfer reaction, and thus it is possible to create a hydrogen supply from outside the system unnecessary and to prevent coke generation. Therefore, this process is expected to be a landmark one capable of meeting a number of needs, including the treatment of very heavy oil and the prevention of global warming. Studies and technical development efforts should be continued vigorously with the aim of establishing Japan's original and highly advantageous process for very heavy oil cracking.

3.2.2 Development of advanced energy-saving technology

While saving energy is a basic measure against global warming, it seems that energy-saving efforts for individual equipment or units have reached their limit. Oil refineries in Japan have a history of at least 35 years and are inferior to the newest refineries overseas both in scale and in the equipment of the latest technology, but their specific energy consumption ranks lower in general. This is proof that each of these oil refineries has persevered in their efforts to introduce energy-saving technology, but it is undeniable that their efforts to save energy have tended to slow down recently. Therefore, they should work toward developing and introducing new technology instead of depending on an extension of traditional technology. In other words, oil refineries now should make their energy-saving efforts in two aspects: technical breakthroughs and compound and diverse activities utilizing the latest software technology.

(1) Development of new energy-saving processes and equipment

At oil refineries, a large number of so-called distillation columns, including toppers, are in operation. The thermal energy consumed by these columns is recovered and used by heat exchangers, but because of physical limitations, so-called low-temperature exhaust heat is discharged in huge quantities without being recovered. Thermal energy is much more difficult to recover than electric energy and power energy, and one of the ultimate energy-saving processes will be a separation process that requires no distillation. For example, membrane separation and pressure swing adsorption (PSA) are possible processes of this type.

Membrane separation uses the difference in the transmittance of molecules in a mixture. Organic membranes have already been put into practical use for gasses, such as for the separation of hydrogen and carbon dioxide, and technical development of such membranes has been in progress for the separation of hydrocarbon. Inorganic membranes, which are expected to be more advantageous than organic membranes with a longer useful life, have higher separation capacity than organic membranes because they have greater differences in the transmittance among molecules in general, and the hollow fiber membranes of carbon are approaching the stage of practical use.

For PSA separation, a good chance of using this process has appeared for the separation of substances with similar boiling points, such as propane and propylene, because a new adsorbent has been developed. With the development of new adsorbents and the development of an advanced control technology of the entire PSA, the application scope for this process to hydrocarbon mixtures will expand.

As noted above, it is expected that in the future, the scope of the practical use of membrane separation (including molecular sieves) and PSA separation of liquid hydrocarbons will grow and that a combination of these new separation systems will be used to create highly energy-saving oil refineries in which the distillation process is reduced greatly.

(2) Total optimization by co-production and pinch technology

At oil refineries, in many cases, the main focus is placed on the production of fuel oil while the supply of hydrogen and utilities is regarded as a subordinate task. However, CO_2 is also discharged from the production and supply of these subordinate materials, and from the viewpoint of preventing global warming, efforts are required to reduce total CO_2emissions. Therefore, it will be very important for oil refineries in the future to adopt a concept of total optimization and realize operation systems that minimize the total CO_2 discharge while achieving the goals of fuel oil production (optimum combination of fuel oil production units, hydrogen production units, utility equipment, etc.). Co-production and pinch technology are methods for achieving total optimization of substances (e.g., fuel oil and hydrogen) and energy (e.g., electric power and steam), and oil refineries should put these methods into practical use on a large scale.

As the demand for fuel oil decreases in the years ahead, room will be made for the capacity to supply hydrogen and utilities. This situation is likely to create, for example, a supply of surplus hydrogen to FCVs and supply of unused electric power, steam, etc. to the community near the oil refinery. The optimization of multiple supplies of substances and energy in such a way is just where co-production and pinch technology can be utilized fully. This idea is now only at a trial calculation level, and it is strongly anticipated that full-fledged and large-scale activities will be conducted to put this concept into practical use.

3.2.3 Next-generation energy-supply technology

(1) Biofuel production technology

The future direction of biofuel production is not clear now in terms of both technology and the procurement of raw materials. Thus, in the years ahead, there will be a need to continue research and examination further and to develop and put to practical use the technology that will meet government policy.

Petroleum companies have started to study the production of biofuels, especially next-generation biofuels made from non-edible raw materials in anticipation of an increased global demand in the future.

Several studies have already pointed out that Japan has a number of problems with biomass as to the procurement of its raw materials. On the other hand, some other countries are promoting biomass strategies on a national level by linking them to agricultural and other policies Therefore, it is hoped that in implementing technical development activities for biomass with a long-term outlook, Japan will also take strategic steps considering requirements for feasible biomass projects.

(2) Super-innovative hydrogen production technology

Taking account of the full-scale introduction of FCVs, there is a need to hasten the pace of development of high-efficiency production technology for high-purity hydrogen at oil refineries as well as stable and large-volume transportation technology for hydrogen to green SSs (bases for supplying various types of renewable energy to the general consumer) as the activities that meet government policy.

Hydrogen production at oil refineries adopts steam reforming processes that use naphtha, LPG and off gases from oil refineries (e.g., methane and ethane) as raw materials, except the hydrogen produced as a by-product in the naphtha reforming process, which aims at producing base gasoline materials with a high octane number. By combining membrane separation with each of the steam reforming processes, shift reaction processes and hydrogen recovery processes, it is possible to substantially reduce the specific energy consumption necessary for hydrogen production. At present, membrane made from palladium (Pd), which has hydrogen permeability, is progressing at the research stage, but there is a high hurdle to overcome before putting this membrane into practical use because of high costs. It is hoped that the cost of membranes will be reduced by, among others, the development of membrane materials other than Pd and thus membranes will be incorporated into hydrogen production units.

For the transportation of compressed hydrogen, the development of containers made of compound materials has made possible the transport of a large quantity of high-pressure hydrogen, while there has also been progress in development aiming at establishing technology for a safe transportation system for organic hydrides, in the study on improvements in the efficiency of liquid hydrogen transport and in the development of a low-cost supply system for high-pressure hydrogen at green SS's.

(3) CCS technology

The Basic Energy Plan includes a scenario stating that a concrete action plan should be developed promptly for full-scale introduction of CCS by the second half of the 2020s, and there is a very fair possibility that the component technologies, whose development is expected to be accelerated according to the scenario, will be applied to oil refineries, the future bases of hydrogen production. In addition, while CO_2 recovery from combustion exhaust gas, one of the functions of oil refineries, is a problem commonly faced by other industries, the development of the technology of more efficient recovery of high-concentration CO_2 produced as a by-product in the hydrogen production unit is the problem the petroleum industry should tackle independently considering the conspicuously large share the industry has in hydrogen production. The development of this type of technology will speed up the introduction of CCS, and fuel oil derived from fossil resources or hydrogen can become an energy equivalent to or more advantageous than renewable energy according to lifecycle assessment (LCA), too.

3.3 Other important problems

(1) Steps taken with the cooperation of petroleum companies

Petroleum companies are under an obligation to stockpile petroleum, and the petroleum industry has been called an inventory trade traditionally because it holds and manages a large amount of inventory by, among others, securing an inventory of crude oil and intermediate products (e.g., raw materials for secondary units and base materials for products) for the stable operation of oil refineries, an inventory of products for ensuring a stable supply to the market and a large stock at distribution bases where products being transported are stored. If individual oil companies continue to stockpile such products, they will have an increasing excessive inventory and inefficient distribution in the economy where domestic demand for fuel oil is declining.

If petroleum companies cooperate with one another and share their entire inventory at several oil refineries and oil tanks in their neighborhoods, thereby achieving an optimization of inventory and distribution overall, they will be able to improve their business management, and the impact on reduction in CO_2 emissions will become substantially great. To share the inventory completely and to optimize the operation of the unit and distribution as noted above, a precondition will be to use the latest ICT represented by cloud computing. Because in this concept, multiple oil refineries are operated by regarding them virtually as only one refinery on the computer network, we have provisionally given the idea the name "virtual one refinery." To introduce this concept, however, barriers of capital must be overcome, and the map adopts the category "Steps taken with the cooperation of petroleum companies." If this concept is elaborated further and information and communication technologies (ICT) are used fully, it will also be possible to plan the introduction of just in time (JIT) into the petroleum industry. To convert oil refineries into a virtual one refinery before closing them down in the future may be very effective means to secure a stable supply.

Similarly, as a step taken with the cooperation of oil companies, it can be planned to establish an integrated gasification combined cycle (IGCC) and create cogeneration bases through the cooperation of petroleum companies operating in a given area. As raw materials for IGCC, there are heavy residual oil and petrocoke, and the waste from other industries offers a good possibility, too. By utilizing co-production and pinch technology, it is possible to secure optimal IGCC operations, as well.

(2) Technology for using vehicle fuels

The Ministry of Economy, Trade and Industry (METI) and the Ministry of the Environment have charted programs for the introduction of next-generation vehicles as the steps to prevent global warming and air pollution and also regard these programs as an important factor for the growth of Japanese industry.

While control of the fuel efficiency will continue to be strengthened gradually in the years ahead for existing vehicles equipped with internal combustion engines, petroleum-based fuels are expected to remain the main fuels in 2030. But it is predicted that the distribution of new types of fuels containing untraditional crude oil-based fuels and fuels derived from biomass will be started on a full scale. It is also thoughts that the optimization of fuel quality design will be newly required to cope with the introduction of plug-in hybrid vehicles now at a research and development stage and vehicles equipped with homogeneous charge compression ignition (HCCI) engines, which are considered promising engines for the future.

In addition, for FCVs that will are expected to enter an initial stage of introduction to general users in 2015, high hopes have been placed on petroleum-based hydrogen in quantitative and economic terms in order to secure a stable hydrogen supply for such vehicles. The supply of hydrogen in this case has two patterns, transporting hydrogen from oil refineries to hydrogen stations where the hydrogen is supplied to FCVs and producing hydrogen from a petroleum-based fuel at hydrogen stations, and technical problems should be solved for each of the cases.

As stated, the government has concluded that in introducing and expanding the use of next-generation vehicles, which will be cornerstone for the growth of the Japanese economy and environmental measures, it will be important to turn SSs into green stations so as to enable the supply of various types of fuels to minimize the environmental load. Considering this, the petroleum industry should positively work on technical problems at each stage of production, distribution and supply.

(3) Compliance with environmental laws and ordinances

The environmental controls affecting the petroleum industry cover many areas: atmosphere, soil and water quality. Japan designed its own environmental legal structure for the risks of chemicals, which were the basis of such controls. But in recent years, after the U.S. enforced the Toxic Substances Control Act (TSCA) and the EU, the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), a move toward international cooperation in the management of chemical risks has been increasing. In this situation, Japan amended the Law concerning the Examination and Regulation of the Manufacture and Handling of Chemical Substances (Chemical Substances Examination Law) and promulgated the amended law in May 2009.

As noted, for the management of chemicals, international debates on the appropriateness of risk decisions will continue into the future with the progress of analysis and evaluation and other technologies. Thus, the petroleum industry in Japan should prepare to promptly deal with any matter regarding the management of domestic and international distribution of petroleum products.

(4) Security technology

The advance of oil refining technology mentioned above is likely to bring about a more diversified and harsher environment for the use of refining equipment. Thus, there will be a need to further improve security technology to ensure the safe and secure operation of oil refineries. Measures must also be taken to increase the equipment ratio of heavy oil cracking units, which have already been discussed at petroleum companies, to cope with control on sulfur contained in fuels for vessels, to deal with the aging of equipment and to minimize trouble caused by natural disasters.

When taking these measures, the petroleum industry should recognize the importance of examining steps toward reform by analyzing complex factors. For future activities for the field of security technology, it is important for the industry to work, based on this recognition, on systematic and continued activities aimed at ensuring highly safe and secure operations. What is especially significant will be to use the collective wisdom of the industry to improve the capacity to protect plants by reforming security technology to make the most of security bases (e.g., operation of equipment and machines, maintenance and security) and safety culture (corporate culture for revitalizing the security bases).

4. Road maps of technological strategies for the petroleum energy resource field (attached on last page)

The road maps show an outline of the schedule for technical development in the years ahead. The points that lay emphasis on continued activities aimed at putting into practical use rather than on the deepening and development of technology are described individually using specific expressions.

For the problems of technical development shown in the maps, "Basics" is defined as the "preparatory studies to basic studies," "Application/demonstration," as "establishing the technology on an application study and laboratory level," and "Practical implementation," as the "practical use on a commercial basis," and rough schedules are shown including anticipated schedules. But all of these problems have a high hurdle to be overcome and have many uncertain elements. In the future, the maps will be revised as concrete activities for the problems become visible, while taking the opinions of specialists into consideration.

5. Quantitative goals in the vision of the future

Clearly, when conducting a technical development project, it is important to definitely determine what realistic results are to be accomplished as a result of the project. But it can be said that technical development itself is not the ultimate goal but only one of the means to fulfill the vision of the future.

For example, in the "Maps of Technological Strategies in the Energy Field" included in the "Maps of Technological Strategies 2020" as drawn by the METI, five policy goals were established on the basis of the main policies of the "New State Energy Strategies" drafted in 2006: (1) Improvement in total energy efficiencies; (2) Diversification of fuels for the transportation sector; (3) Promotion of development and introduction of new energy sources; (4) Utilization of nuclear power and (5) Stable supply and effective and clean use of fossil fuels. The maps listed the main types of technology in the energy field that would contribute to the attainment of these goals. However, these policy goals will not be achieved by technical development only; they will necessitate a combination of various policy mixes instead, and technical development can be regarded as part of such policy mixes.

In addition, the "Action Plan for Important Scientific and Technological Measures 2011" (drafted by the Council for Science and Technology Policy, Cabinet Office, in June 2010) defined four targets for promoting green innovation, an important subject of the New Growth Strategies, with the aim of creating "Japan as an Environmental Conservation Leader" where people will be able to realize low-carbon and recycling communities symbiotic with nature: (1) Switch to renewable energy; (2) Low-carbon energy supply and use; (3) Energy-saving types of energy use; and (4) Making social infrastructure green. The Action Plan then proposed specific steps to be taken to complete these targets.

The achievement of the final goals of technical development should be measured by the level of contribution to the vision of the future. The matters that can be the goals and quantitative indicators of the vision described in the maps of technological strategies presented here are summarized below:

(1) Contribution to stable energy supply

What falls under this category includes steps to deal with heavy crude oil by developing an advanced technology for cracking heavy oil and development of biofuel production technology and hydrogen production and transportation technology.

Possible quantitative goals are, among others, reduction in crude oil treatment (ratio), amount of heavy crude oil treated (ratio) and amount of renewable energy introduced.

(2) Contribution to the creation of low-carbon communities

The matters to be included in this category are development of innovative energy-saving technologies, such as membrane separation and excergy regeneration, biofuel production technology, super-innovative hydrogen production technology and CCS technology.

Possible quantitative goals include reduction in CO_2 emission, energy-saving level, degree of reduction of specific energy consumption, and level of decrease in the energy intensity index (EII; developed by Solomon, Inc.).

(3) Contribution to increased competitiveness

What falls under this category includes an increase in the value-added of products as a result of the development of technology for converting low-grade distillates into high-quality distillates, cost savings by a reduced amount of crude oil treated and an increased amount of heavy crude oil treated resulting from the development of the advanced technology of cracking heavy oil, cost reduction by the development of advanced energy technology, establishment of the virtual one refinery using advanced ICT and activities for next-generation energy networks.

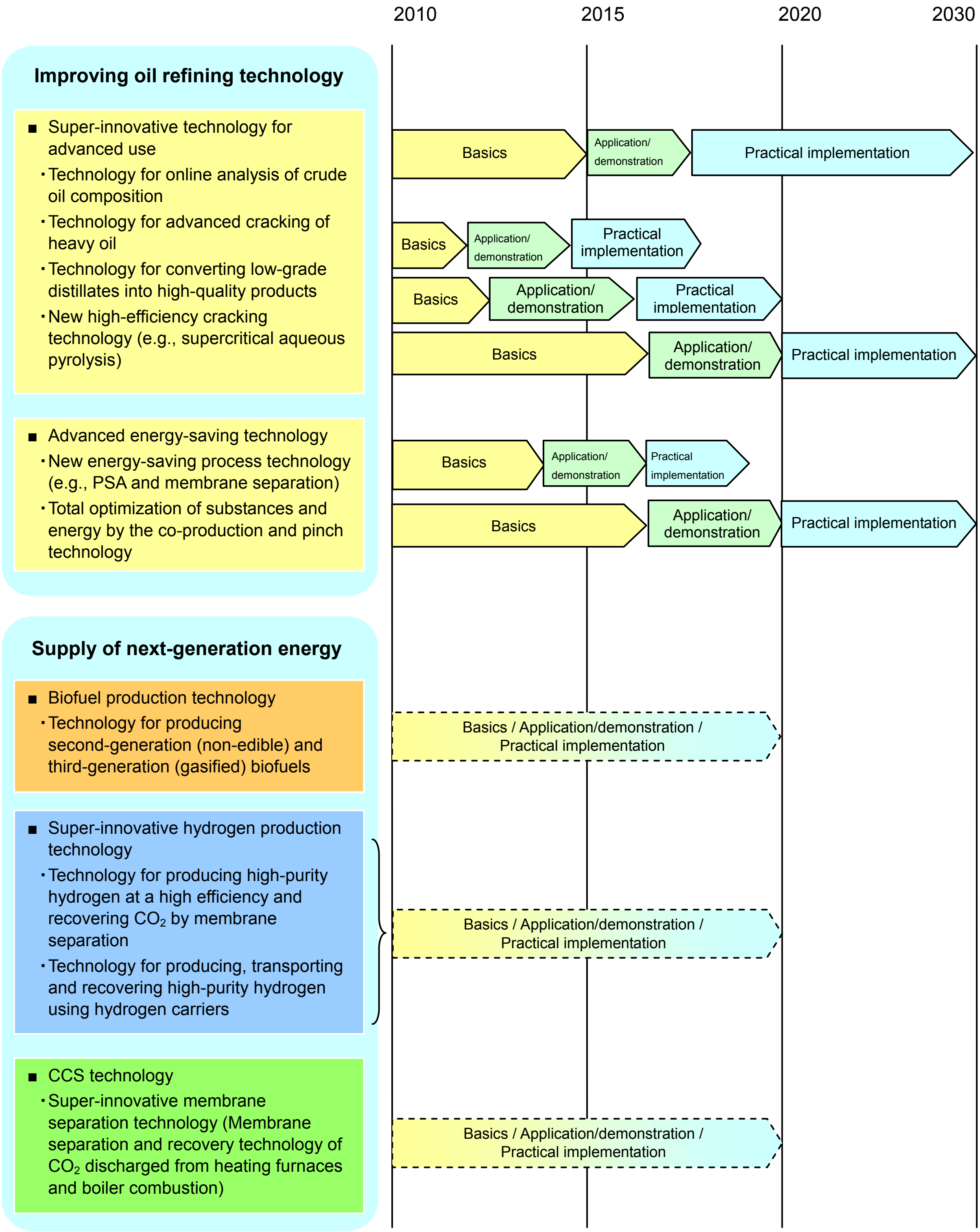
Possible quantitative goals are, for example, the amount of cost reduction and amount of value added.

The quantitative goal used will be one of those mentioned above or a combination of them, and the values for judging the achievement of the goal should be determined properly considering the prospects and cost of the development of each technical element required for attaining the goal and the benefits to be derived. To do this, a detailed examination of each technical element is needed, and we will make this problem one of our future tasks.

6. Conclusion

In the foregoing, the important problems that are considered for the petroleum energy resource field to tackle in the medium to long term have been summarized fairly comprehensively. But, for technological strategy maps like these, there exist no perfect maps originally, and we have drawn them just as part of the references to ideas. Technology is progressing rapidly, and breakthroughs will be beyond the expectations of those concerned in some cases. Moreover, some sudden changes in the management environment of the petroleum industry actually fell short of the expectations of the parties concerned. Therefore, in circumstances where changes take place at a very fast speed both in technical development and in the management environment, it is important to take an attitude of always viewing the related phenomena as a whole. We will use these technological strategy maps as tools for sharing strategic ideas among the petroleum industry and will revise them every several years in light of the changing environment.

Road map of technological strategies for the petroleum energy resource field (1)



Road map of technological strategies for the petroleum energy resource field (2)