JSME Technology Roadmaps

August 28th 2009
The Japan Society of Mechanical Engineers

Introduction

Science and technologies showed rapid progress and propagation in the twentieth century, prevented disasters and accidents, overcame diseases, supplied many products and materials, produced industries, and satisfied a variety of needs for society. In the new century, technology and engineering are now turning their focus toward guaranteeing continuity under environmental restrictions and realizing sound, comfortable lives and safe and secure society for people with different values.

With such a background, the Japan Society of Mechanical Engineers must grasp its role in this age and contribute to society as a group of specialists responsible for machine-related technology and science. It established a Machine Day (August 7) and Machine Week (August 1 to 7) in 2006, executed different events for making many people understand the relationship between mechanical technology and human society and the roles of the technology and engineers, and promoted activities for fixing these days together with related organizations. In 2007, the 110th anniversary of its foundation, the Society authorizes twenty-five Mechanical Engineering Heritages of historical importance in Japan. Many people approve the Society's intention of saving the historical heritage of mechanical technologies and leaving them to the next generation as part of our cultural heritage.

On the 110th anniversary of foundation, the Japan Society of Mechanical Engineers decided to prepare the JSME Technical Roadmaps from an original point of view, in addition to authorization of the mechanical engineering heritage, in order to meet the trust and relegation of society to mechanical technology and the needs of the society as well as to lead society.

Ten years ago, i.e., the centennial of its foundation, the Japan Society of Mechanical Engineers reformed the organization for the forthcoming 100 years. The JSME Technical Roadmaps were strongly needed by members in the process of that reformation. For determining the technical roadmaps, it was necessary to grasp the needs of society; understand the legal regulations, principles, mechanisms, and limits of the technologies; and judge the economic efficiency, scale of the industry, consumer tendencies, and many other factors in a comprehensive manner. Quantitative examination has been very difficult until now. Therefore, taking the opportunity of the 110th anniversary, the Japan Society of Mechanical Engineers has been promoting a project for the past two years in order to meet member needs as a society of engineers leading the world, accept the challenge of preparing technical roadmaps; provide technical forecasts related to machines; contribute to the research and development of mechanical engineers and machinery manufacturers, technical development, and enhancement of competition to make Japanese technologies lead the world; and improve the social raison d'etre of the Japan Society of Mechanical Engineers.

The current JSME Technical Roadmaps contain the following matters viewed from the original point of view of the Japan Society of Mechanical Engineers. First, it picks up the general-purpose physical parameters serving as the keys of technologies like the Moore's principle evaluated in the semiconductor field as roadmaps from the academic point of view, forecasts the time-to-time changes of their needs and numeric values and progresses, discusses the possibility of increase in the future and limits from the mechanical point of view, and clarifies the representation of the society that may be realized if these parameters increase in the future. If we analyze the industrial technologies, we understand that they are systematically composed of many physical parameters, and these physical parameters are important in determining product performance common to the industrial technologies in many fields. When we made the JSME Technical Roadmaps, we tried to make many people understand the importance of this point of view.

During the same period, the Ministry of Economy, Trade and Industry made and publicized the Technical Strategy Map 2006 and Technical Strategy Map 2007 that gathered together the industrial, official, and academic best and brightest to lead Japanese technologies. In many discussions with the Ministry, the Japan Society of Mechanical Engineers was proposed to contribute to these Technical Strategy Maps academically and undertook "establishment of academic roadmaps in the mechanical field" in the technical strategy map rolling work of the Ministry of Economy, Trade and Industry. The society members agree that reflection of cooperative industrial-academic discussions upon the technological policy of Japan and contribution to the progress of the industry will meet the purposes of the JSME Technical Roadmaps.

In November 2006, the Japan Society of Mechanical Engineers established a technical roadmap committee in its Industrial-Official-Academic Cooperation Center and asked the technical divisions of this Society to be committee members in order to maintain the consistent activities of the Japan Society of Mechanical Engineers in the JSME Technical Roadmap project, which is expected to contribute to the social, academic, industrial and national processes. Many divisions agreed: the bioengineering, materials and mechanics, the materials and processing, the engine systems, the thermal engineering, the dynamics, measurement and control, the robotics and mechatronics, the environmental engineering, the computational mechanics, information, the intelligence and precision equipment, the transportation and logistics, the design and systems, the technology and society, and the fluids engineering divisions. The working groups (WG) of each division pointed out the technical problems in the element technology represented by each division, carefully selected themes, and set the temporal indicators important for technical innovation. The

Technical Roadmap Committee examines these issues comprehensively. As the first issue, we now publicize the roadmaps from ten divisions.

We conducted a workshop titled "Current Situation and Problems of the Technical Roadmaps—Role of JSME Technical Roadmaps" in the yearly convention at Kumamoto University in September 2006 before this publication. We also sponsored a special project titled "Mechanical Technology Leading Innovations—Prospect of Society in 2025 viewed from Technical Roadmaps" in the yearly convention at Kansai University in September 2007 and exchanged meaningful opinions with many participants. We will sponsor lectures at the ceremony for the 110th anniversary of the foundation of the Japan Society of Mechanical Engineers on October 26, 2007, carry articles in the November and December issues of the JSME Journals, prepare an English version of the JSME Technical Roadmaps, and distribute them overseas.

Principle of Preparation

The Japan Society of Mechanical Engineers focused on the following basic principles when preparing the JSME Technical Roadmaps.

- Selecting problems from the technical and industrial point of view. Investigating the contents from the academic point of view.
- Writing different opinions expressed during preparation in the roadmaps without unifying them forcedly.
- Writing and adding expected environmental changes and necessary breakthrough.
- Assuming that the roadmaps will be utilized by engineers and scholars in related fields as well as nonprofessionals engaged in policymaking, managerial judgment, planning of industrial technology development, mass communication, education and so forth.
- Periodic reviews to update successive roadmaps with the latest information.

It was decided to prepare the JSME Technical Roadmaps in unified forms, since a system where engineers from different technical fields may discuss from common viewpoints is desirable to fulfill these purposes, create new inter-element technologies, and for a bird's-eye view of the mechanical technology systems.

[First Form]: Describing the following matters.

(1) Aims of selecting the technical problems and themes
(2) Social and technical needs for the technical problems
(3) Possibility of mechanisms for achieving advanced key parameters
(4) Prospects for the future

Social & Technical Needs

[Second Form]: Providing time-series illustrations for an overview of the contents in the first form.

- Describing the social and technical needs that require selected technical problems and themes in a simple manner.

Physical Indicators & Units

Year-by-year changes in the general-purpose key parameters related to the technical problems

- Explaining the social and technical needs, based on which the key parameters changed, and showing the curves of those changes, including future changes.
- Selecting proper periods after the 1970s as the starting points according to the technical fields. Providing the future prospect in 2030.

Technical Breakthrough

- Possibility of mechanisms for achieving advanced key parameters
- With what mechanisms can the numeric values in the JSME Technical Roadmaps be achieved?
- What technical breakthroughs are needed?

Changes in Society and Markets

・Prospects for the future
・Describing the social impacts when the JSME Technical Roadmaps are put into practice in scenario form.
・Market scales if utilized by society.

Publication of JSME Technical Roadmaps

“They are to be overcome – Expectation for JSME Roadmaps”

Akira Nagashima

Chairperson of Ceremonial Project Committee for 110th Anniversary of Foundation of Japan Society of Mechanical Engineers

The Japan Society of Mechanical Engineers started two new projects for the society in the 110th anniversary of foundation. They are the JSME Technical Roadmaps and Mechanical Engineering Heritages.

The roadmaps are prepared for the challenges to overcome them, though they are important tools for developing the frontiers. If we only follow the guidelines, our images will be fixed, and we will be beaten in international competition. I believe that both enterprisers and scholars have a mission to overcome these roadmaps with their concepts. Someone may say that, if so, no roadmaps are needed. However, if people going toward unknown frontiers begin to walk with no roadmaps, their behavior is simply reckless courage. I hope that enterprisers, scholars, and even scientific technology critics keep these roadmaps at hand as the scales for measuring their thoughts and checking them quietly. Enterprisers who will start new businesses, engineers who are accepting the challenge of new technologies, and anyone who starts the new research cannot stop looking into the JSME Technical Roadmaps once at least. I hope that these roadmaps will grow into such materials.

It is impossible to find all necessaries in the roadmaps. The JSME Technical Roadmaps make academic values as selling points, while industries, in particular, may criticize for being unrealistic with optimistic cost estimations. In addition to academic roadmaps, there are political roadmaps and in-company roadmaps. I think that linking these three roadmaps with each other will be effective. The political roadmaps show new technologies and products needed strongly by the society in a chronic scale toward the near future, though they cannot be actualized or will not pay at present. The in-company roadmaps show the economic bottlenecks of unprofitable problems, which are needed socially and well known scientifically, and the possibility and challenge points of the companies. It is possible to forecast the future logically based on three factors: Scientific and technical prospects, understanding of the social needs, and corporate profitability.

Showing roadmaps is one of the social tasks of the societies of scientists and engineers as specialist groups. I believe that politicians, mass communication, and people in the society will utilize them as safe and reliable prospects. Their role of supporting the social confidence in the scientific technologies is significant.

The JSME Technical Roadmaps should not be stereotyped. They may possibly make interesting trials in the future, since they cover the problems in limited fields. I hope that the departments of the Society will make various trials and users will make use of them in various ways.

“Challenge to Academic Societies”

—Visualization of Research Strategy based on Academic Sense of Value—

Masayoshi Watanabe

Manager of Production Policy Investigation Section, Ministry of Economy, Trade and Industry

Can’t we have “research and technical roadmaps” prepared by academicians? It was an earnest desire of administrators responsible for the scientific and technical policies for the Society. It might be a challenge for academic societies. Technical roadmaps are utilized actively as general research and development management tools by private companies. The Ministry of Economy, Trade and Industry introduced technical roadmaps as research and development management tools of the government in 2005, though a little too late, and has been using them continuously through year-by-year revision (rolling). Does the academism accept such a concept as the research and technical roadmaps? The concept of as the research and technical roadmaps prepared by the academic societies is not familiar and the whole academic society rarely tried to prepare such roadmaps in the past. Why? Scholars have an ample reason why they can hardly accept roadmaps. It is that the essential activity of the society is developing the frontiers in research activities and the society is a group that walks on undeveloped ways and pursues after the truth. Kotaro Takamura, a great poet of Japan, wrote, “No roads in front of me / Roads are made behind me.” Each scholar is proud of creating his/her own original road. Scholars and researchers may be very reluctant to draw a scenario of the future as if it had been made. It is extreme to stop study if representation of the study is known. Taking account of roadmaps of private companies that build up research schedules of element technologies for actualizing commodity plans meeting the needs of the future markets, I understand that academicians can hardly accept them for the above-mentioned reason.

However, the party responsible for the scientific technology policy does not require such product development roadmaps of companies from academicians. I think that academicians prepare their roadmaps based on academic sense of values, while the technical strategy map prepared by the Ministry of Economy, Trade and Industry was prepared based on the industrial technological sense of values. They need not, I believe, fawn upon the sense of values of the Ministry of Economy, Trade and Industry, and it is important that they determine some axes of values as scholars and express (visualize) how the future researches will develop or should develop. Mutual understanding will not grow unless we present our visions. Lack of mutual understanding may be the cause of the industrial-academic-official communication gap. I am afraid that the academic societies have made little discussions, tough it is quite important how to set the basic axes for deciding the values of researches. It is the reason why I used such an expression as challenge to the academic societies at the beginning. I pay my respects to the eagerness of academicians who bravely challenged such a quite heavy homework as "asking the academic values of researches." If subjects may be set as clear indices and scholars share them as a common scenario, we expect accelerated researches in the future. I greatly hope that challenge of the societies will bear rich fruit, industrial-academic-official roadmap communication will shows a progress according to the scenario and the results of researches of the societies are fed back to the society. Parts of the activities of preparing the JSME Technical Roadmaps published here are carried out as a part of the "Technical Strategy Map Rolling Work in 2006: Preparation of Academic Roadmaps for Linkage with Technical Strategy Maps" entrusted by the Ministry of Economy, Trade and Industry.

Air Resistance (Aircraft)

(1) Purpose

To suppress CO_2 emissions from aircraft, reducing fuel consumption is of the utmost importance. From the standpoint of flight operations, this might be achieved by switching to new aircraft models and improving operation methods. From the viewpoint of engineering, this might be achieved by improving engine fuel efficiency, reducing airframe weight, improving the lift-to-drag ratio, and using alternatives to fossil fuels. This section discusses technology that will contribute reductions in CO_2 emissions by reducing air resistance and thereby improving the lift-to-drag ratio.

(2) Social and technological requirements for technical issues

[1] By 2015, the European Union (EU) is scheduled to introduce a new tax on aircraft CO_2 emissions. This will require marked reductions in CO_2 emissions by that time. One aircraft operating company, easyJet Co. Ltd., intends to reduce the CO_2 emissions from its aircraft 50% by 2015, while aircraft manufacturer Boeing Co. has announced the Performance Improvement Package (PIP) for Boeing 777 model aircraft, which is intended to reduce CO_2 emissions by upgrading existing airframes. Furthermore, there are growing needs for technologies that will lead to CO_2 emission reductions from newly built airframes.

(3) Potential mechanisms for realizing advanced key parameters

As measures of reducing air resistance and improving lift-to-drag ratios, the following points can be considered:

First, takeoff and landing characteristics will be improved in order to improve fuel efficiency and reduce environmental loading. **[2]** To achieve this improvement, we intend to establish a technology that simultaneously optimizes airframe cruising configuration and high-lift devices for use during takeoff and landing. This optimization will be realized using morphing technology (technology for freely changing an airframe shape).

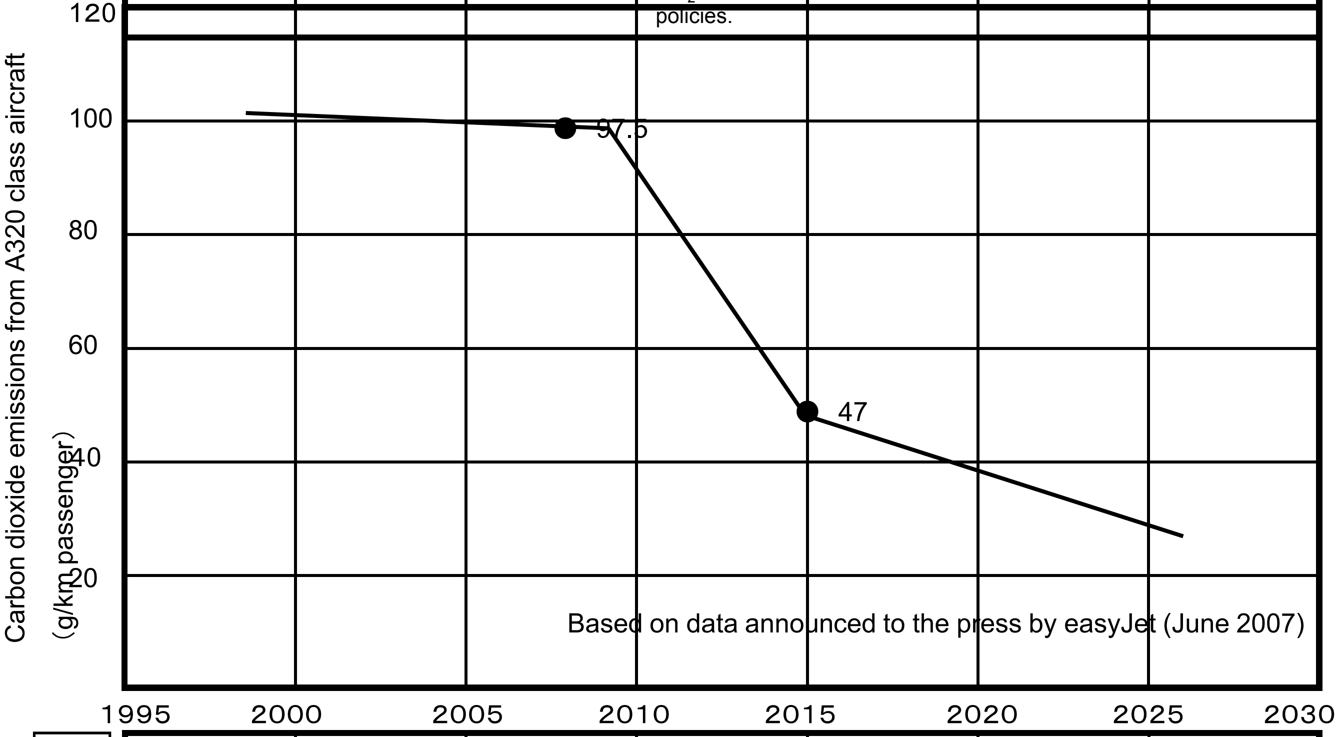
Next, friction resistance will be reduced to improve cruising characteristics and fuel efficiency. To achieve this, we will establish a natural laminar flow wing design technology and develop a technology capable of converting a wing boundary layer into a laminar flow by means of boundary layer control.

Additionally, the induced resistance and interference resistance will be reduced to improve the cruising characteristics, thereby increasing fuel efficiency and reducing CO_2 emissions. To accomplish this, we will establish a technology capable of reducing induced resistance through use of optimum wing end devices and flap scheduling, as well as a technology aimed at reducing aerodynamic interference between fuselage and wings.

(4) Future society outlook

Based primarily on technologies that are already close to practical use, we intend to reduce CO_2 emissions by 50% by 2015. This will be accomplished by promoting technological developments aimed at reducing air resistance and improving the lift-to-drag ratio. Furthermore, we envision further air resistance reductions by the 2030s that will utilize morphing and other breakthrough technologies that have yet to be established.

Social and technological requirements	ICAO gas emission standards applied only to NOx, HC, CO, and Soots. (1981)	ICAO initiated discussions on techniques to reduce CO_2 emissions. (2004)	ICAO discussed techniques to reduce CO_2 emissions.	50% reduction of energy consumption. Introduction of a CO_2 emission right acquisition system for aircraft in and outside EU (2012). ICAO will establish CO_2 reduction policies.			Zero CO_2 emissions by 2050.



Technological breakthroughs		First flight of Honda Jet. (2003)	Successful flight experiment of JAXA small supersonic aircraft. (2005)	Implementation of natural laminar flow wing technology.	Implementation of boundary layer control wing technology.		Implementation of morphing technology.
Social and market changes	Number of jets in service: 10,606 (1997)	CO_2 emissions from private aircraft: 572,000,000 tons (2000)	Number of jets in service: 15,929 (2007) Super-large passenger aircraft (A380) introduced into service RNAV introduced to domestic routes in Japan	CO_2 emissions from private aircraft: 605,000,000 to 776,000,000 tons (2010) Boeing 787 enters service. First flight of environment-friendly small passenger plane MRJ.	Number of jets in service: About 25,200 (2017)	Ultrasonic small passenger plane	Number of jets in service: About 36,600 (2028) CO_2 emissions from private aircraft: 1,228,000,000 to 1,488,000,000 tons (2025)

			Baseline	Climate plan			
			2007		2015	2030	2050
[Name of the technology/solution] Air Resistance (Aircraft)	Savings	Consumption if old technologies are sustained (BAU)	100		100	100	100
		Consumption after implementing new technology and measures			90	80	70
		Net saving			10	20	30
	Cost (Investment, operation & maintenance, fuel)				120	120	110
	Cost Per PJ saved				–	–	–
	GHG reduction potential	Emission if old technologies are sustained and with current trends (BAU)	100		100	100	100
		Emission after implementing new technology and measures			90	80	70
		Total Reduction			10	20	30
	Cost of GHG reduction				120	120	110

Using a value of 100 for the year 2007.

Design Engineering

(1) Aims

The purpose of design engineering is supporting, guaranteeing, and creating product development. We believe that it is one of missions of design engineering to predict the future as correctly as possible based on the past changes of product development in the latter half of the 20th century, though we know that it is difficult to predict products in the future (in 2025, for example).

(2) Social and technical needs

When we consider how product development has changed from the latter half of the 20th century and how it will change in order to predict the design engineering in 2025, needs-oriented innovative portable audio products were produced and propagation of semiconductors since then changed their quality further, for example. Notebook PCs were produced following word processors and have had wide applications in industries and homes. Automobiles aim at low fuel consumption and hybrid systems to reduce influences upon environment. It is possible to develop hybrid systems by utilizing existing motor technology relatively early. Like this, epoch-making products were produced timely in the portable audio and car industries. On the other hand, home electric appliances are lack in remarkable products, though they show continuous progress toward higher performances, higher efficiency, and advanced functions. We must say that elements (technologies) and concept for leading product development is insufficient.

(3) Future directions for determining key mechanisms and parameters

We try to classify designs to clarify the direction in which design should progress by 2025. We correlate designs with the Kano model and classify them into I, II and III as shown below:

I. Must design (corresponding to the “Must-be quality” in the Kano model)
Design must provide a design warranty. Many trouble occur if Must design is ignored. This is the basis of design, though it can hardly be evaluated and coped with properly.

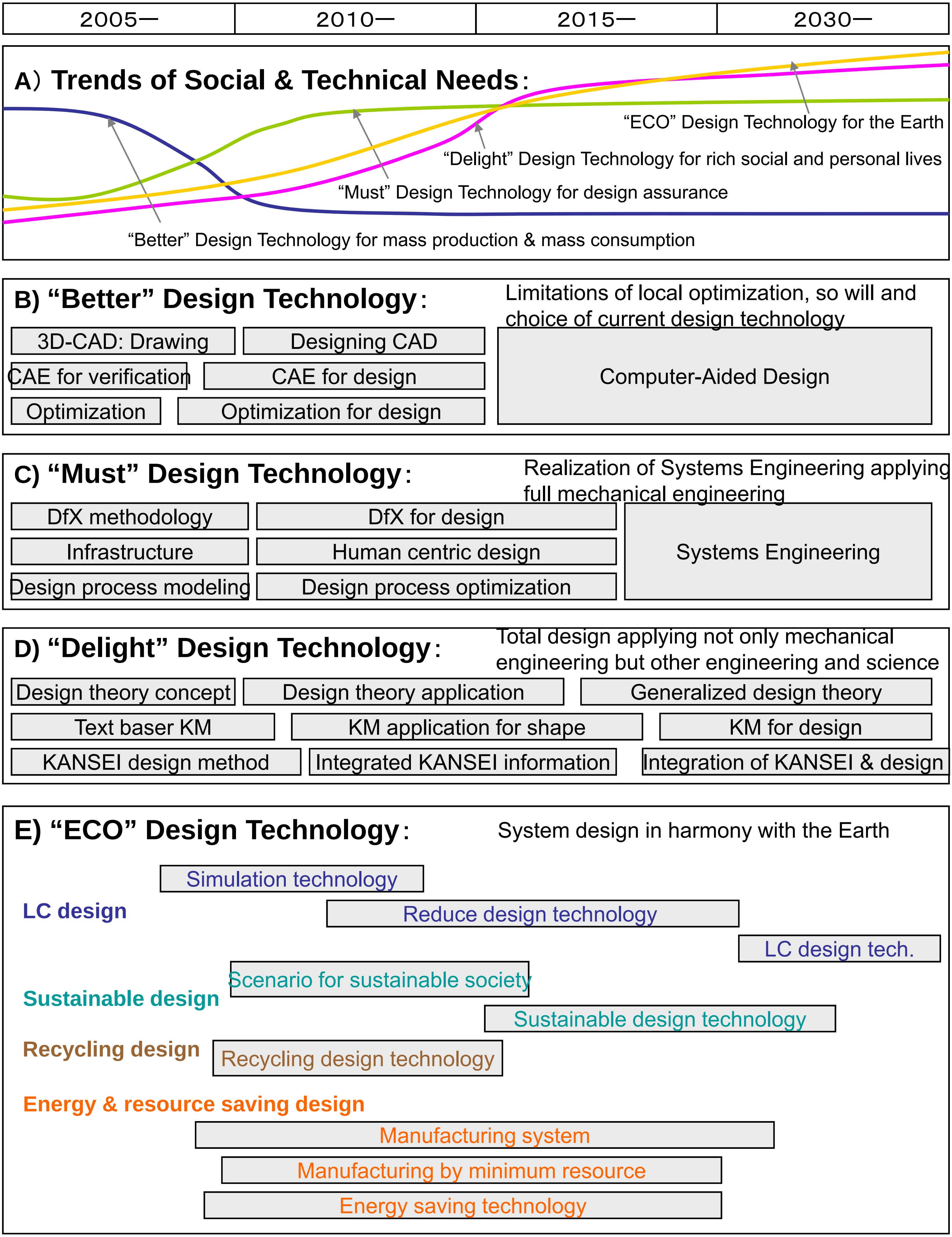
II. Better design (corresponding to the “One-dimensional quality” in the Kano model)
This can be coped with easily, since it may be evaluated clearly. It finally results in cost competition. This is the design for improving efficiency.

III. Delight design (corresponding to the “Attractive quality” in the Kano model)
Design in which design concept is the most important. Many hit products were produced in this field. The point is anticipating the technological and customer needs, though they are likely to consider this as creative design.

(4) Contributions to society

Three products and design technologies correspond to three designs: Better products that support mass production and mass consumption will be sorted, Must products providing a design warranty will be the main stream in the near future, and Delight products that make us happy will be needed in the future. To achieve such development, the design technologies must change from the traditional individual technologies into unification technologies (true computer-aided design and true system engineering).

Roadmap to realize CO_2 reduction by Design Engineering



Thermal Efficiency of Engines

(1) Aims

The roadmap of the engine system department covers gasoline engines used for passenger cars and motorbikes and diesel engines for passenger cars, trucks, buses, and ships. Research on fuel batteries also started recently. Improvement in thermal efficiency is important in the mechanical engineering field. From this point of view, this roadmap predicts the future of fuel efficiency improvement. Refer to the roadmap of the fuel consumption in car.

(2) Social and technical needs

Engines used in cars are closely related to our daily lives and used for inner- and inter-city transportation. It was necessary to clean exhaust gas from engines, so gasoline car emission control started in 1966, and emission control applied to diesel cars in 1974. Emission control is also applied to ship engines and off-road vehicle engines. Stringent exhaust emission regulation will be required in the future. Improvement in the thermal efficiency capable of CO2 reduction is needed and is an important factor. Improvement of the engine thermal efficiency is indispensable for preventing global warming in the future.

(3) Future directions for determining key mechanisms and parameters

Taking an example of large diesel engines for vehicles, development of the direct injection (DI) systems, turbo inter-coolers (TI), 4-valve/cylinder engines, and steel pistons enhanced thermal efficiency improvement. Electronic-controlled pressure accumulating high-pressure fuel injection (common rail type), variable nozzle superchargers (VGT), and variable swirl systems are produced by vehicle needs. Downsizing of vehicle engines was achieved by TI engines in 1980 by utilizing output increase due to superchargers, resulting in remarkable fuel efficiency improvement.

The following may be promising breakthrough technologies for improving the thermal efficiencies of reciprocating engines:

(1) New combustion systems for reducing NOx and PM simultaneously like pre-mixed compression ignition combustion.
(2) Friction-reduced lubricant oil
(3) Synthetic fuel featuring improved thermal efficiency
(4) Mechanical, electrical and chemical technology of generating and recovering thermal and kinetic energies
(5) Transfer from de-fossil fuel to biomass fuel

The fuel cell is an important breakthrough technology currently under examination. It is expected to be put into practical use from 2015 to 2020.

(4) Contributions to society

As global warming shows rapid progress at present, improvement of the engine thermal efficiency directly related to CO2 reduction will possibly be accelerated by stronger external impacts. Thus, researchers and engineers in this field should be ready to take proper means of improving thermal efficiency at any time as society requires.

Taking an example of passenger cars, if the thermal efficiencies of a car at operating-area in the case of fuel economy at 15 km/L is doubled, the car will run at 30 km/L with the same quantity of fuel, and CO2 emission is halved. In 2025, new fuel cell cars and hybrid cars will be used widely, exhaust emissions will become cleaner, and CO2 emissions from cars will be reduced by 20 to 30 %. As global warming shows rapid progress at present, needs for improvement of the engine thermal efficiency directly related to CO2 reduction will become greater. Technical innovation in this field may progress earlier than prediction. We expect that more active discussions will be made based on this roadmap.

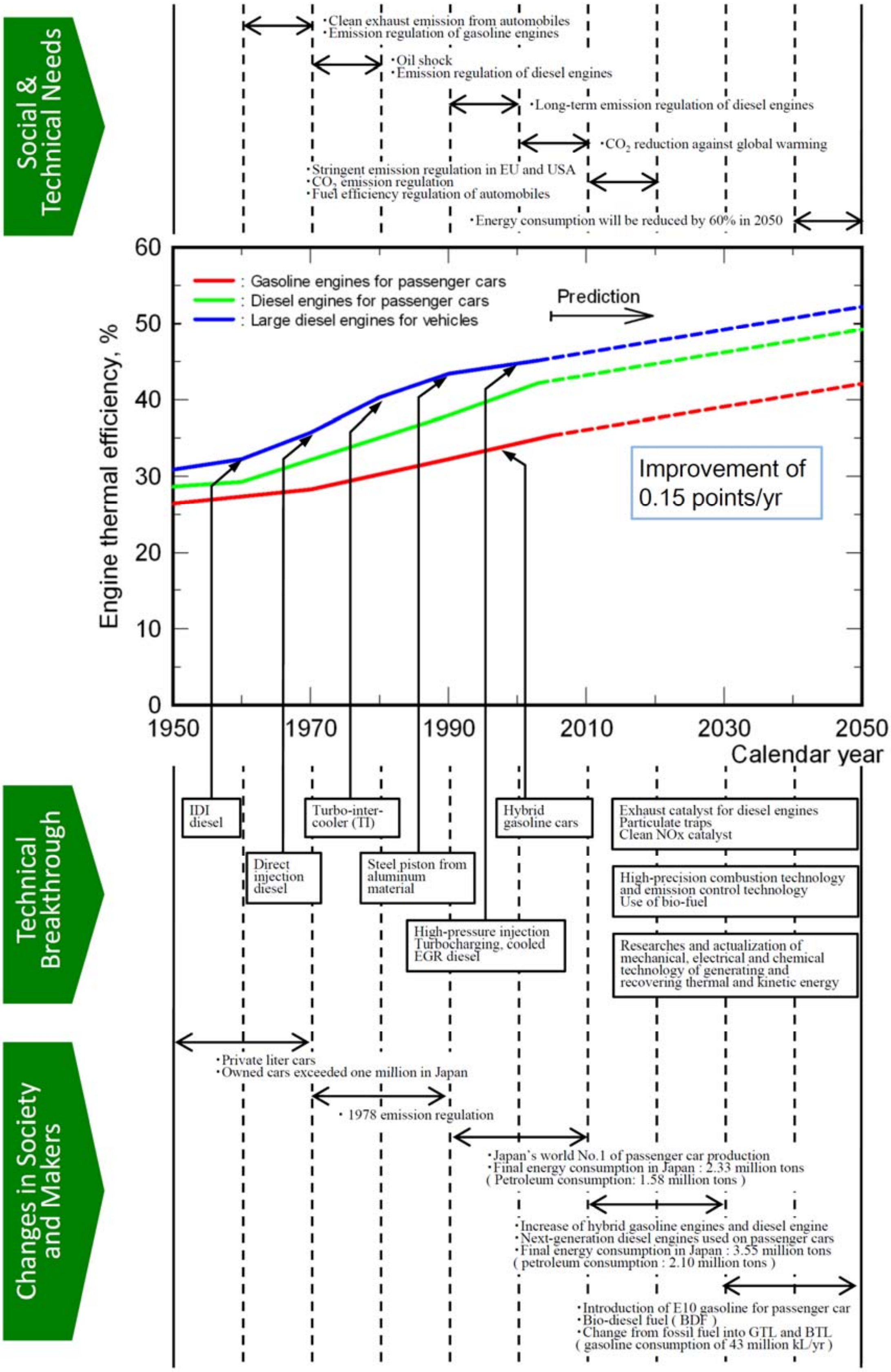
(5) Estimates of carbon dioxide reductions by 2050

CO_2 emission reduction resulting from improving and maintaining the performance of automotive combustion engines, and using diesel engines on passenger cars, was estimated based on the following conditions:

Thermal efficiency of automotive combustion engine (see the figure)
Thermal efficiency increase rate: 0.15 point/year (see the figure)
Number of cars owned: assumed to be stable at 80,000,000
Number of cars replaced: 3,000,000/year (based on Ministry of Land, Infrastructure and Transport (MLIT) Statistics 2000-2006)
Car durability: Assumed to be 20 years
CO_2 emissions from cars in 2006: 222,000,000 tons (based on MLIT Statistics 2006)

The ratio of combustion engine types was assumed to be the same as in 2006, except for passenger cars. In the passenger car sector, the percentage of small diesel car sales was assumed to increase linearly from 10% to the EU level of 60% during the period from 2006 until 2050. The replacement of diesel cars with other diesel cars in this sector was ignored.

Based on the above conditions, car replacement is expected to reduce CO_2 emissions by about 18,000,000 tons (−8.2% from 2006)and by about 35,400,000 tons (−16% from 2006) in 2050.If passenger car sales in Japan were limited to diesel cars, all passenger cars in Japan would be diesel-powered around 2030.Should that happen, CO_2 emissions would be reduced by about27,000,000 tons (−12% from 2006) in 2030 and by about39,000,000 tons (−18% from 2006) in 2050. If all cars were to be replaced with hybrid or fuel cell models and if biofuels were more commonly used, CO_2 emissions would decrease even further.



Social & Technical Needs
・Clean exhaust emission from automobiles
・Emission regulation of gasoline engines
・Oil shock
・Emission regulation of diesel engines
・Long-term emission regulation of diesel engines
・CO2 reduction against global warming
・Stringent emission regulation in EU and USA
・CO2 emission regulation
・Fuel efficiency regulation of automobiles
・Energy consumption will be reduced by 60% in 2050
: Gasoline engines for passenger cars
: Diesel engines for passenger cars
: Large diesel engines for vehicles
Prediction
Improvement of 0.15 points/yr
Engine thermal efficiency, %
Calendar year
Technical Breakthrough
IDI diesel
Direct injection diesel
Turbo-inter-cooler (TI)
Steel piston from aluminum material
High-pressure injection Turbocharging, cooled EGR diesel
Hybrid gasoline cars
Exhaust catalyst for diesel engines Particulate traps Clean NOx catalyst
High-precision combustion technology and emission control technology Use of bio-fuel
Researches and actualization of mechanical, electrical and chemical technology of generating and recovering thermal and kinetic energy
Changes in Society and Makers
・Private liter cars
・Owned cars exceeded one million in Japan
・1978 emission regulation
・Japan's world No.1 of passenger car production
・Final energy consumption in Japan : 2.33 million tons
(Petroleum consumption: 1.58 million tons)
・Increase of hybrid gasoline engines and diesel engine
・Next-generation diesel engines used on passenger cars
・Final energy consumption in Japan : 3.55 million tons
(petroleum consumption : 2.10 million tons)
・Introduction of E10 gasoline for passenger car
・Bio-diesel fuel (BDF)
・Change from fossil fuel into GTL and BTL
(gasoline consumption of 43 million kL/yr)

Demand side

			Base line 2006	Climate plan 2015	2030	2050
Thermal engines of automobiles						
	Savings	Consumption if old technologies are sustained (BAU)(PJ)				
		Consuption (PJ)				
		Net saving (PJ)				
	Cost (Investment, operation & maintenance, fuel)($ per PJ)					
	Cost per PJ saved					
	GHG reduction potential	Emissions of old technologies are sustained and with current trends (BAU)	222,000,000 tons	222,000,000 tons	222,000,000 tons	222,000,000 tons
		Emissions after implementing new technology and measures		216,000,000 tons	204,000,000 tons	187,000,000 tons
		Total reduction potential		6,000,000 tons	18,000,000 tons	35,000,000 tons
	Cost of GHG reduction ($/Tons CO_2-equivalent)					

Heat Pump Hot Water Supply Systems

(1) Aims

A great amount of energy is consumed for supplying hot water in the residential, commercial and industrial sectors. CO_2 emission from residential hot water supply systems only is estimated to be approximately 70 million tons-CO_2/year. Recently, heat pump hot water supply systems that may reduce CO_2 emissions significantly is in the process of propagation. Clarification of the roadmap of this technology will contribute to further progress of the heat pump technology, which is important to suppress global warming.

(2) Social and technical needs

Efficiency improvement and price reduction are common needs. In addition, size reduction, noise reduction, and improvement of performance in cold regions are also required. Multi-function products, including floor heating and central heating, snow melting products, direct hot water supply type products, small local hot water supply systems for lavatories, utilization of waste heat (such as remaining hot water after bathing), heat recovery systems (capable of simultaneous cooling and heating), hybrid products, commercial-use products, industrial-use products and other various products, are needed.

(3) Possibilities of mechanisms for advanced key parameters

There are many technical development elements, including refrigerant, compressors, heat exchangers, motor systems, recovery of refrigerant expansion energy, waste heat recovery technology, hybrid technology, and so forth. Parts of these technologies are described below.

(a) Refrigerant

Refrigerants currently in use are mainly classified as follows: Freon refrigerant and natural refrigerant. Various types of refrigerants were developed according to the uses and characteristics. The high temperature difference heating values at 65 ºC differ with the refrigerant types, while the theoretical COP(Coefficient of Performance) is 12.9. That of CO_2 is 11.5, which is the highest, that of R410 is 9.1, and those of other Freon refrigerants and hydrocarbon refrigerants are about 8. It is expected that efficiency will be improved via circuit designs appropriate to the refrigerant characteristics and advanced refrigerant control.

(b) Hybrid technology

There are two types of main hybrid technologies: utilization of boilers for industrial use and large-scale users, and utilization of solar heat (solar panels) and ground heat. In terms of system configurations, the parallel systems mix heat produced by solar panels and heat pumps in storage tanks or at the outlets, while the integrated systems (installed on roofs, porches or walls) incorporate solar panel evaporators or decompressed-boiling solar panel evaporators in heat pumps. Solar heat hybrid systems are expected to have remarkably improved efficiencies. If they are used decompressed-boiling solar panel evaporators, the efficiency of heat pumps using butane refrigerant may possibly be improved by about 80%.

(c) Noise reduction

Noise reduction technology is important, since hot water storage type heat pump supply systems run at night. The noise level has reduced in the past five years from 45 dB to 38 dB owing to vibration reduction, suppression of noise transmission in solid matter, and noise quality improvement. Higher-speed rotation of compressors and fans is expected to further improve efficiency and reduce the size. Thus, noise reduction technology including noise quality improvement design and inverter technology should be improved.

(4) Prospects for the future

Reduction of hot water needs by using high-performance insulating materials, improvements in efficiency of the heat pump hot water supply systems, and power de-carbonization by increasing the renewable energy power generation ratio and CCS (carbon dioxide capture and storage) are three major elements. In the long term, the synergy effect of these three elements will reduce CO_2 emissions in the hot water supply industry. The quantity of residential heat pump hot water supply systems will increase up to 20 million or so by 2030. The expected CO_2 reduction in 2030 including residential, commercial and industrial facilities will be 29 million tons in Japan. Besides, export to overseas countries will increase, since Japanese manufacturers are good at these technologies.

A．Social and Technical Needs

2001-2005

・CO_2 reduction in hot water supply industry
・Improvements in efficiency of hot water storage systems
・Noise reduction
・Performance improvement for cold regions

2005-2010

・Direct hot water supply systems
・Size reduction (Storage tank integrated type)
・Water heaters for snow melting
・Middle-size hot water storage systems for commercial and industrial use
・Hybrid systems (boilers)

2010-2015

・Hybrid systems (solar and ground heat)
・Larger-capacity hot water supply systems
・Waste heat utilization hot water supply systems
・Double-bundle condenser hot water supply systems (heat recovery systems)

2015-2020

・Performance improvement for very cold regions
・Recovery of hot water supply waste heat (remaining hot water and waste hot water)
・Waste heat recovery type small-size local hot water supply systems

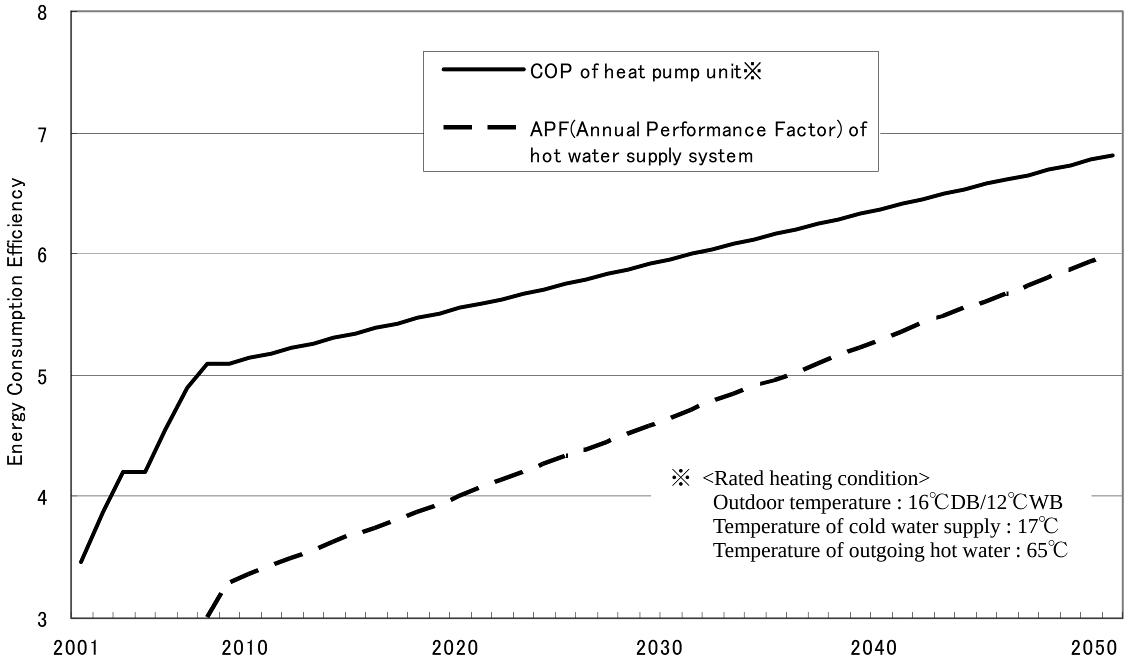
2020-2025

・Small-size direct hot water supply systems using water as heat sources
・Large-size systems for industrial use (heavy use)

2025-2030

・Vapor generation heat pumps
・Very small-size and high-efficiency type products

B．Energy Consumption Efficiency



C．Technical Breakthrough

Technical Breakthrough

2001～2010 ・Development of CO_2 refrigerant Heat Pump Water Heater
④ High-efficiency ejector cycles
⑤ Optimum design of high-efficiency. Small-size DC motors
⑥ SiC power devices
⑨ Vacum heat insulators
⑬ Utilization of underground heat

2010～2020 ① High-efficiency refrigerant circuit design technology
⑥ High-efficiency matrix converter
⑫ Exhaust heat recovery
⑩ Load forecast control
⑬ Using solar heat panels together
① Advanced refrigerant control technology
② Further size reduction using surface tension
③ Micro-channel type heat exchangers
④ Power recovery compressors with integrated expanders
⑬ Decompressed-boiling solar panel evaporators

2020～2030 ① Development of new refrigerant
⑤ Next-generation sensor-less PM motors
⑨ High-density thermal storage and latent thermal storage
① Water refrigerant double-bundle condenser hot water supply systems (heat recovery systems)
⑫ Heat recovery from wastewater

Reference ① ~ ⑬

① Improvement of high-performance refrigerant technology

② Improvement of gas/liquid separator technology

③ Improvement of heat exchanger technology

Reducing air resistance of heat exchangers and improving heat transmission of fins and heat transfer pipes

④ Improvement of expansion valve technology

Improving efficiency and recovering expansion power

⑤ Improvement of motor technology

⑥ Improvement of inverter technology

⑦ Improvement of compressor technology

Reducing mechanical losses and internal leak losses, increasing compression ratio, increasing capacities, and reducing noises

⑧ Improvement of fan technology

Improving efficiency and reducing noises

⑨ Improvement of hot water storage technology

⑩ Improvement of control technology

Quantity control, outlet temperature control, thermal storage and radiation control, and defrosting control

⑪ Improvement of simulation design technology

⑫ Improvement of waste heat utilization technology

⑬ Improvement of hybrid technology

D. Changes of Society and Markets

Changes in Society and Markets

2001～2010
- Number of shipped heat pump hot water supply systems increased by 50% or more every year.
- Subsidy system for CO2 refrigerant Heat Pump Water Heater
- Approx. 20 companies entered heat pump hot water supply system market.
- Number of products reached 1 million (2007)
- Number of products reached 1.5 million (2008).
- First commitment period in the Kyoto Protocol (2008)
- Number of products will reach 5.2 million (2010).

2010～2020
- Second commitment period in the Kyoto Protocol (2013)
- Total number of homes will stop at 50 million.
- Consumption of electric power of new renewable energy: 16 billion kW (2014)
- Average people per family will lower below 2.5
- Japanese influences upon the LNG market will lower (from about 50% down to 19%).

2020～2030
- Average people per family in Tokyo will be below two first in Japan.
- Peak of traditional petroleum production
- Energy consumption in Asian countries will be doubuled in comparison with that in 2004.
- Number of products reached about 20 million. (2030)

			Baseline	Climate plan		
			2007	2015	2030	2050
[Name of the technology/solution] Heat Pump Hot Water Supply Systems	Savings	Consumption if old technologies are sustained (BAU)	100	100	100	100
		Consumption after implementing new technology and measures		(96)	(77)	(28)
		Net saving		(4)	(23)	(72)
	Cost (Investment, operation & maintenance, fuel)			–	–	–
	Cost Per PJ saved			–	–	–
	GHG reduction potential	Emission if old technologies are sustained and with current trends (BAU)	100 2,537Mt-CO_2	100 2,537Mt-CO_2	100 2,537Mt-CO_2	100 2,537Mt-CO_2
		Emission after implementing new technology and measures		96 2,443Mt-CO_2	77 1,956Mt-CO_2	28 719Mt-CO_2
		Total Reduction Potential		4 93Mt-CO_2	23 580Mt-CO_2	72 1,818Mt-CO_2
	Cost of GHG reduction			–	–	–

(1) Purpose

Roughly 20% of all CO_2 emissions are from automobiles. Therefore, improving the fuel efficiency of automobiles is an effective way to reduce CO_2 emissions. Since acceleration loss and rolling resistance increase in proportion to vehicle weight, reducing vehicle weight is an effective means of reducing CO_2 emissions (Fig. 1).

(2) Social and technological requirements for technical issues

To improve such performance issues as collision safety and steering stability, automobile weights have tended to increase in recent years. Materials, structural designs, and production technologies that simultaneously achieve both performance and fuel efficiency are necessary.

(3) Potential mechanisms for achieving key parameters

· Structural design and production technologies are expected to reduce the weight of automobile component materials, curtail the amount of materials used, and to ensure the lightweight materials used possess the necessary rigidity and strength.

· Material technology: Weight reduction by substituting iron and steel components with aluminum, plastic, and other materials that possess small specific gravities or by reducing component thickness by using high-tension steel.

· Structural design: Use of **[1]** Computer Aided Engineering (CAE) for multi-purpose performance optimization in areas such as collision safety, vibration and noise reduction, strength and steering stability, and improved productivity.

· Production technology: Continuous welds with improved rigidity achieved using lasers or structure bonding agents and the formation of high strength materials of various shapes.

(4) Future society outlook

For electric vehicles and hybrid electric vehicles (HEV) that have increased weight due to their batteries, advances in structural design technologies using CAE and materials technologies, including processing technology, are expected to simultaneously achieve safety, operational performance, comfort, and low fuel consumption.

[References]
Society of Automotive Engineers of Japan: Automobiles in 2030 - Scenario of Automotive Technology Developments by Specialists in the Second Field of Technology
Automotive Technology Vol. 62, No. 3 (2008) Feature: Challenge for Higher Fuel Efficiency

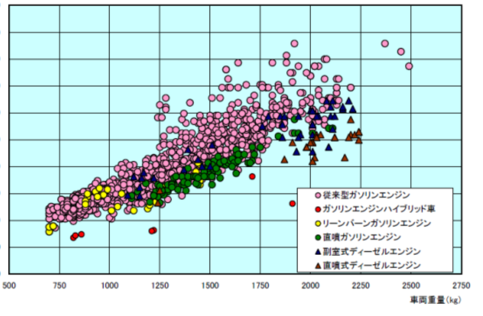


Fig.1. CO_2 emissions by passenger vehicles
MLIT: http://www.mlit.go.jp/jidosha/nenpi/nenpilist/05.pdf
(Quotation not yet approved)

			Baseline	Climate plan		
			2007	2015	2030	2050
[Name of the technology/solution] Creation of lightweight automobiles	Savings	Consumption if old technologies are sustained (BAU)	100	130	150	200
		Consumption after implementing new technology and measures		90	90	100
		Net saving		40	60	100
	Cost (Investment, operation & maintenance, fuel)			110	130	150
	Cost Per PJ saved			–	–	–
	GHG reduction potential	Emission if old technologies are sustained and with current trends (BAU)	100	130	150	200
		Emission after implementing new technology and measures		90	90	100
		Total Reduction		40	60	100
	Cost of GHG reduction			110	130	150

Automobile Traffic Flow Control

(1) Purpose

To reduce vehicle CO_2 emission totals, it is essential to improve average traveling speeds by realizing smooth traffic flows, as well as to improve the fuel efficiency of each vehicle. The utilization of [1] Electronic Toll Collection System (ETC) and other communication technologies is expected to significantly improve future traffic flows. Showing approaches for specific measures will contribute greatly to the early implementation of a ideal future traffic system.

(2) Social and technological requirements for technical issues

It is said that global CO_2 emissions must be halved by 2050 to prevent global warming. The transportation sector is responsible for about 20% of the CO_2 emissions in Japan and automobiles account for 90% of that total. According to a trial calculation, economic losses resulting from time wasted due to traffic congestion amounts to 12 trillion yen a year, which is equivalent to about 15% of the national budget. To achieve the formation of a sustainable traffic society in the future, it is very important to improve traffic flows as well as raise transportation-related energy and time efficiencies.

(3) Potential mechanisms for achieving advanced key parameters

The keys to realizing smooth traffic flows are the prediction of traffic conditions and the implementation of traffic flow control based on those predictions. Traffic flow predictions can be simulated in real-time based on traffic information collected from vehicle sensors on roads and from probe cars as well as past traffic data. Based on the simulation, optimum route information can be provided to drivers and traffic signals can be optimally controlled to prevent traffic congestion and prevent traffic jams at bottlenecks. Further future advances in high-speed and large-capacity communication technologies will enable more smooth interactions between vehicles and traffic signals, and among vehicles. This will reduce vehicle stops at intersections as well as speed decreases that occur when vehicles encounter each other during merging and lane changes, and subsequently improve the average traveling speed. **[2]** To achieve the early implementation of these new traffic systems, it is necessary not only to improve technologies but also to establish a strong cooperation of the numerous stakeholders that includes system standardization, establish of a social consensus etc.

(4) Future society outlook

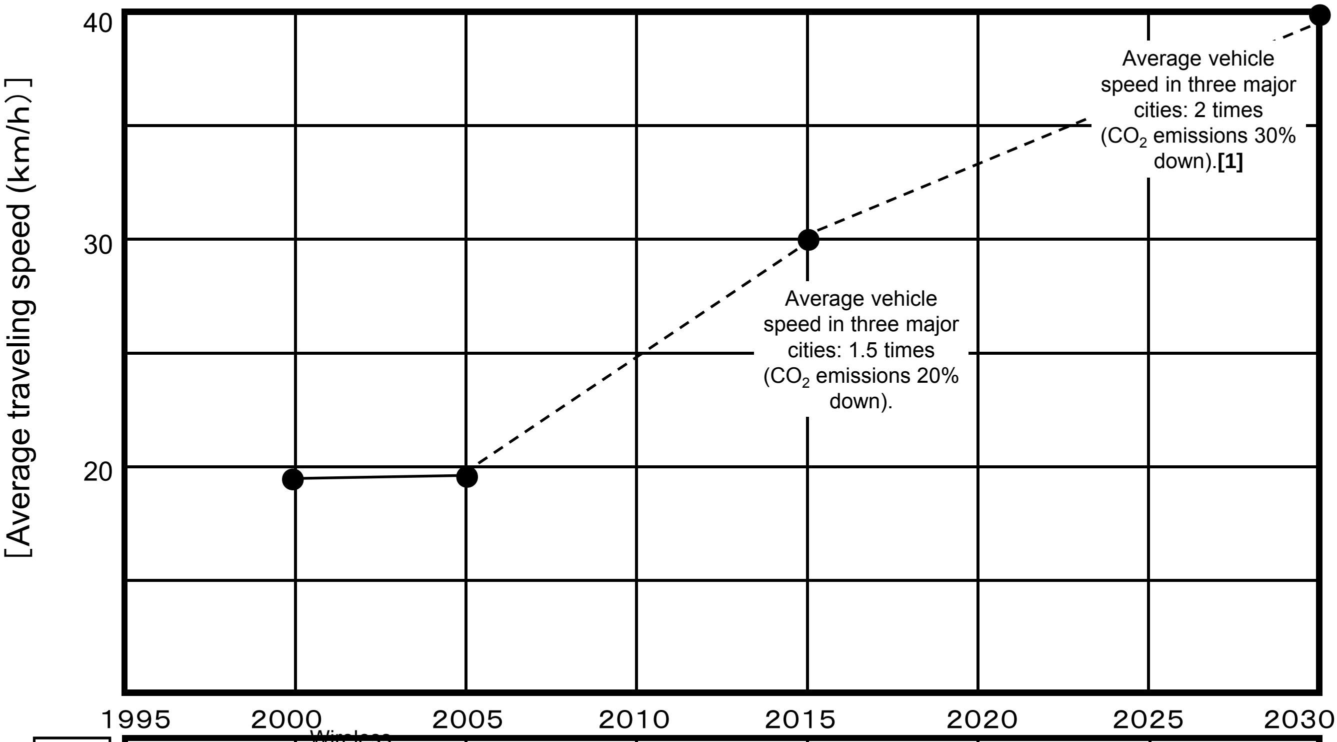
At the present time, [3] Intelligent Transportation System（ITS）related efforts will aim at promoting the practical use of the Dynamic Route Guidance System (DRGS) and GreenWave in order to improve traffic flows. Around 2050, it is expected that a high-grade infrastructure coordination system will exist that enables easy monitoring of surrounding traffic situations and communication between drivers and which will realize well-controlled traffic flows that are free of sudden accelerations or decelerations. In addition, a system that collects detailed **[4]** Origin-Destination (OD) information in advance will prevent congestion by providing optimum route guidance. By 2100, automatic driving will be possible. Particularly in cities, where perfected centralized traffic control systems will optimize traffic flows for all vehicles, railways, and new modes of transportation.

References:

1. Society of Automotive Engineers of Japan: November 2008 Vol. 62Feature: Measures For Realizing Cool Earth 50; Project by The Institute of Applied Energy
2. Feature: Next-generation Automobile and Fuel Initiative (METI)
3. NEDO Energy Conservation Technology Forum 2008
4. Other: AHS Roadmap, ITS Roadmap of Second Tomei Expressway, and references from the Radio Regulatory Council of the Ministry of Internal Affairs and Communications (MIC)

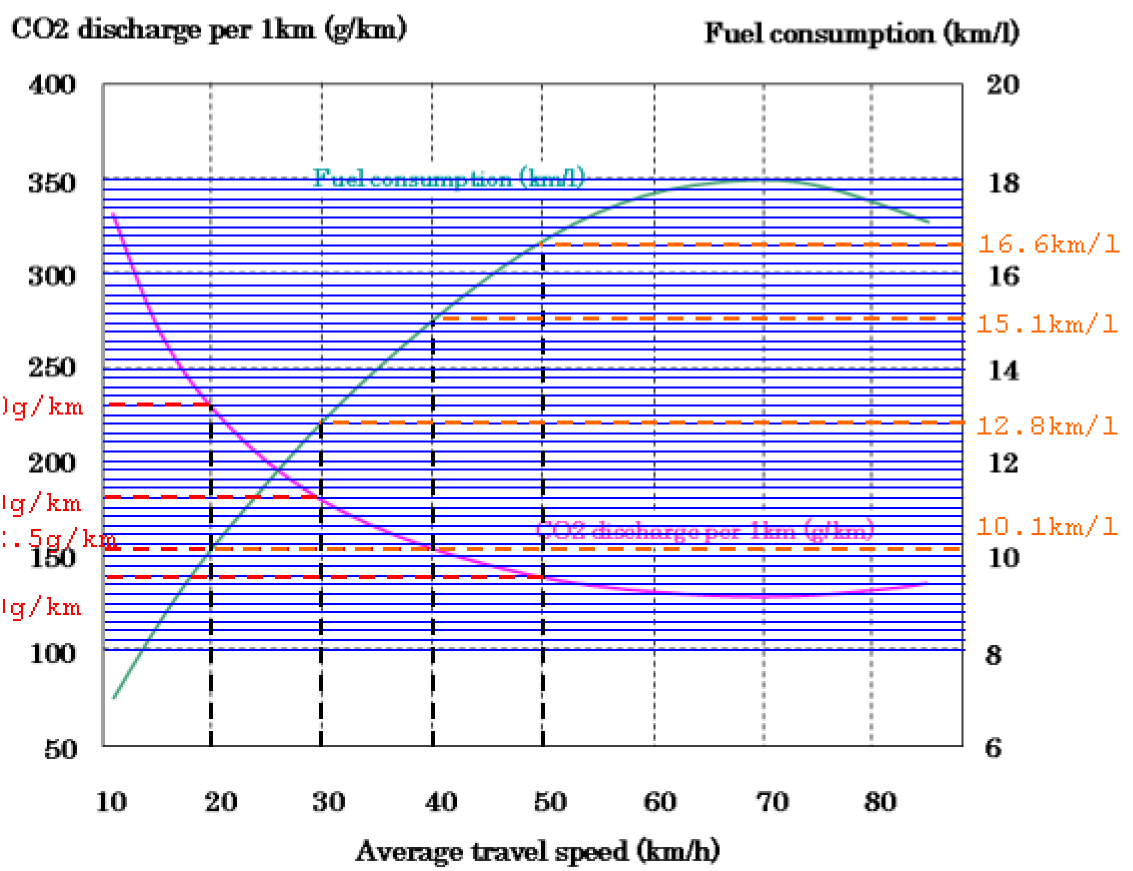
Automobile Traffic Flow Control

	1995–2000	2000–2005	2005–2010	2010–2015	2015–2020	2020–2025	2025–2030
Social and technological requirements				Kyoto Protocol (1997) Reducing CO_2 emissions 6% from 1990 levels by 2012.			New National Energy Strategy (2006) Improving energy efficiency 30% from 2003 levels by 2030. Cool Earth50 (2008) Reducing CO_2 emissions by 50% from 2008 levels by 2050.



	1995–2000	2000–2005	2005–2010	2010–2015	2015–2020	2020–2025	2025–2030
Technological breakthroughs		Wireless communication technology Traffic flow measurement (image-type vehicle detector, etc.) Environmental recognition	Cleansing of probe information and other large data volumes	Practical use of Mobile WiMax (10Mbps) Prediction of vehicle behavior Data compression	Standardization of inter-vehicle communication Protocol. Vehicle group control Personal mobility	Improved GPS position accuracy (1 m or less) Automatic driving	
Social and market changes	Start of VICS service Practical use of signal control system (MODERATO) Change of expressway speed limit for light vehicles and motorbikes (80→100km/h)	Congestion information service by Probe Car Initiation of experiments for new signal control (Profile, etc.) Practical use of Electronic Toll Collection (ETC) Large-scale Retail Store Building Law	Practical use of DRGS by Probe Car Initiation of Driving Safety Support Systems (DSSS) experiment Spread of real-time fuel gauge Eco-driving route information systems Strengthened parking regulations	Experiment for advanced signal control using probe information Optimum departure time prediction system (using probe information) Traffic demand management (Road pricing) Sag congestion prevention system Production started for EV	Smooth merging and lane change Signal linkage Eco-driving Intelligent logistics system Sharing system of Electric personal mobility vehicle[2]	Merging support system Expressway automatic driving and file run Second Tomei Expressway to be completed	Signal linkage Green Wave

			Baseline		Climate plan		
			2007		2015	2030	2050
[Name of the technology/solution] Automobile Traffic Flow Control	Savings	Consumption if old technologies are sustained (BAU)	100		120	130	150
		Consumption after implementing new technology and measures			95	85	90
		Net saving			25	45	60
	Cost (Investment, operation & maintenance, fuel)				–	–	–
	Cost Per PJ saved				–	–	–
	GHG reduction potential	Emission if old technologies are sustained and with current trends (BAU)	100		130	150	200
		Emission after implementing new technology and measures			100	100	120
		Total Reduction			30	50	80
	Cost of GHG reduction				–	–	–



Reference materials:【伊東大厚のトラフィック計量学】 http://response.jp/issue/2006/1030/article87808_1.html

Fuel Cell Vehicle

(1)Purpose

It is anticipated that in the 21st century, today's fossil-based energy society will change to a hydrogen-based energy society, which will utilize the ultimate clean energy source. Fuel cell vehicles are expected to play a very important role in this change. Therefore, establishing this technological field is a matter of great social and academic significance and is expected contribute to the development of mechanical engineering.

(2) Social and technological requirements for technical issues

Currently, automotive manufacturers are leading the development of fuel cell vehicles. Some vehicles capable of operating on public roads already exist, although their supplies are limited. Additionally, various companies are working in a number of engineering fields to generate power from fixed and installed fuel cells, and to supply hydrogen.

(3) Potential mechanisms for achieving advanced key parameters

The primary issues related to fuel cell vehicles include the **[1]** durability of fuel cell stack and costs. However, improvements to hydrogen storage methods are also important from safety perspectives and suppliers must establish an infrastructure for producing, transporting, and stocking hydrogen.

Reductions to the amount of precious metals required for fuel cell stack is especially important in terms of costs and stable supply and its achievement will require a major technological breakthrough. As sources of driving force, motors for hybrid vehicles must be made as efficient and compact as possible. Therefore, new technologies, including those related to structural mechanics and materials, must be comprehensively improved.

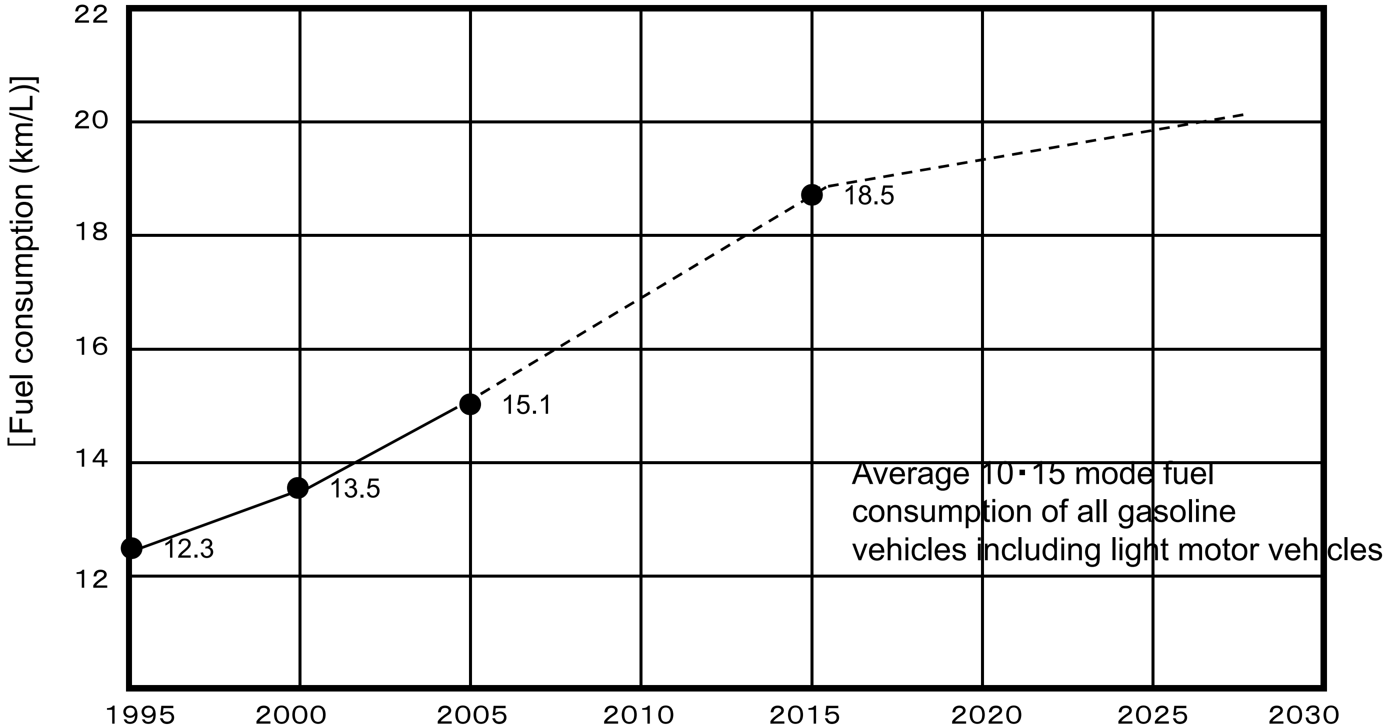
(4) Future society outlook

Currently energy conservation and reducing exhaust emissions are the most important issues. **[2]** During the transition from internal combustion vehicles to hybrid and electric vehicles, various changeover technologies will be needed, including new technologies related to internal combustion.

There are issues to solve in each technological field. Without dramatic breakthroughs, **[3]** the system for transportation and logistics will be formed on the basis of the advantage of each field.

Fuel cell vehicles are considered ideal because of their efficiency and zero CO_2 emissions. Resolving the above issues will enable the rapid propagation of these vehicles.

Social and technological requirements	Reduction of exhaust emissions	Reduction of exhaust emissions	Reduction of exhaust emissions Regulations for exhaust emissions and fuel consumption in Japan, USA and Europe will be greatly strengthened (problem for automobile industry in 2009) Euro 5 (new EU automobile emission regulation)	Reduction of energy consumption to half New tax to reduce CO_2 emission from aircraft in EU	Achievement of new fuel consumption standard by government (passenger vehicle: 16.8 km/L, small bus: 8.9 km/L, small truck 15.2 km/L)		(Reducing energy demand 60% by 2050)



Technological breakthrough		Hybridization (gasoline and diesel)		Integration of DPF and urea SCR methods for emission gas purification		Practical use of NO_X direct decompositio n technology	Practical use of gasoline H CCI combustion Practical use of HFCV
Social and market changes	Automobile NOX Law (1992) Tokyo's campaign for no diesel vehicles (since 1999) Revised Energy Conservation Law (1999)	Automobile NOX･PM Law Domestic automobile production: 10.5 mil., sales: 5.87 mil.	Commercialization of next-generation electric vehicles that suppress operating costs to 1/8 that of gasoline vehicle. "Urea SCR system" (reducing NOx into nitrogen and water) becomes the primary device in measures for reducing gas emissions Bioethanol for use as automobile fuel to reach an oil equivalent of 500,000 kiloliters (2010)	Domestic automobile production: 10.52 mil., sales: 5.6 mil. Spread of electric vehicles with fuel cells. (Number of such vehicles registered in Japan: 50,000) Market scale of rechargeable batteries for hybrid vehicles reaches 300 bill. yen Number of hybrid vehicles in Japan, USA, and Europe markets: 2.19 mil.	Domestic automobile production: 10.65 mil., sales: 5.43 mil. Spread of fuel cells for environment-friendly and efficient use Portable power cell (for electric vehicle, etc.) Global market scale of diesel vehicles to grow to 29 mil. cars/year Global market of hybrid vehicles: 5.37 million cars	Spread of in-area transportation by very lightweight compact vehicles Total traffic volume in 2020 to 2030 up 16% from the present, reaching a peak Number of fuel cell vehicles registered in Japan: 5 mil. Infrastructure network for hydrogen supply to fuel cell vehicles	Total share of fuel cell, hybrid, and electric vehicles to account for about 40% (2050) Cell performance improves; plug-in electric vehicles spread Total traffic volume in around 2030 up 20% from the present, reaching a peak Number of fuel cell vehicles registered in Japan: 15 mil.

			Baseline	Climate plan			
			2007		2015	2030	2050
[Name of the technology/solution] Fuel cell vehicle	Savings	Consumption if old technologies are sustained (BAU)	100		120	130	150
		Consumption after implementing new technology and measures			120	125	135
		Net saving			0	5	15
	Cost (Investment, operation & maintenance, fuel)				5	0.5	0.2
	Cost Per PJ saved				–	–	–
	GHG reduction potential	Emission if old technologies are sustained and with current trends (BAU)	100		130	150	200
		Emission after implementing new technology and measures			130	147	180
		Total Reduction			0	3	20
	Cost of GHG reduction				5	0.5	0.2

Using a value of 100 for the year 2007.

[2] The above listed effects are limited to the fuel cell vehicles and the extent to which fuel cell vehicles spread is not considered. The costs provided are relative to a value of 100 for the prototype in 2007, including manufacturing and other infrastructure expenses.

Materials & Mechanics for Higher Efficiency/Output Energy Systems

(1)Aim

Because of increasing demand on energy around the current world, it is indispensable to improve the efficiency of power plants mainly for reducing the emission of CO_2 as well as savings of resources. For fossil power plants, fluid temperature and pressure conditions should be upgraded drastically for attaining higher efficiency within the minimum the total life cycle cost. For nuclear power plants, higher output and higher reliability should be achieved.

It is the aim of this roadmap to show how the technologies related to materials and strength section lead to new power systems with minimum environmental impact and energy consumption.

(2)Social and technical needs for technical problems

The technical problems for materials and strength are the difficulties for attaining high temperature strength of materials used in the energy systems. From the economical and strategic point of view, strengthening elements in the materials should be carefully selected. Rare elements should not be used easily and should be fully recycled using pollution free methods. The key requirements are to optimize the material selection and application to structural components. As no serious accident should be allowed even for very high efficiency machines, the use of suitable materials and the optimization of total life cycle cost of power plants are the most important requirements.

(3)Key parameters

Key parameters affecting the efficiency and output are the fluid temperature and pressure for thermal power plants and MW output power for nuclear power plants. The measures in materials and mechanics field to attain the target values of those parameters are as follows. One is the scale of structural analysis applicable to actual large scale components and the other is the applicability of long term life assessment method for components under complex service or damaging conditions. For new materials developed for new types of plants, new structural evaluation methods will be developed in this field and this process will be continued for the future energy systems.

(4)Possibilities of mechanisms for advanced key parameters

・Developing the structural strength and life evaluation technology for a variety of heat-resistant and robust materials to enable design for improving the steam temperature and pressures of steam power plants.

・Developing the structural strength evaluation and life extension technology for heat-resistant and thermal barrier materials for improving the gas temperature of gas turbine plants.

・Developing the environmental strength evaluation technology to ensure the reliability of higher output nuclear power plants.

(5)Prospects for the future society

・Developing various types of high-efficiency machines using diversified energy resources designed by new strength evaluation technology for environmental, energy security and economical reason.

・Developing the maintenance and retrofit technologies for utilizing the existing facilities more efficiently to attain the environmental and economical target for stable supply of electric power in the world.

(1)Purpose

Humans have always yearned for strong materials and have worked diligently throughout history to create new materials. Currently, people are not just seeking strong materials, they also desire materials that possess the added value of light weight. **[1]**In the case of transportation, constructing transportation equipment using materials that possess great specific strength is the most effective method to reduce transportation costs and enhance safety. This also satisfies the national-level requirement of reducing CO_2 emissions as part of overall energy conservation efforts. Therefore, by noting the specific strength of metallic and nonmetallic materials, while taking in consideration the technology needed for combining materials, **[2]** the machine materials and materials processing division has reviewed past results and predicted future potentials. Since material development takes longer than other research fields, we will describe the transition of demand for materials that possess great specific strength beginning with the first half of the 20th century.

(2) Social and technological requirements for technical issues

Materials of great specific strength are used in various fields, including transportation equipment, architecture, medical care and social welfare. The social and technological requirements and purposes include the following:

•Demand from the fiercely competitive aircraft industry for large airframes in order to achieve low fuel consumption, and reduced noise

•Reduction of fuel consumption by automobiles for environmental protection and fuel cost curtailment

•Development of high-speed railway networks and lightweight, energy-saving train cars

• **[3]**Governmental guidance related to anti-seismic building structures and increasingly tall high-rise buildings

• Reduction of the burden on care workers by providing improved welfare and care equipment to the aged society

•Demand for improved sports equipment

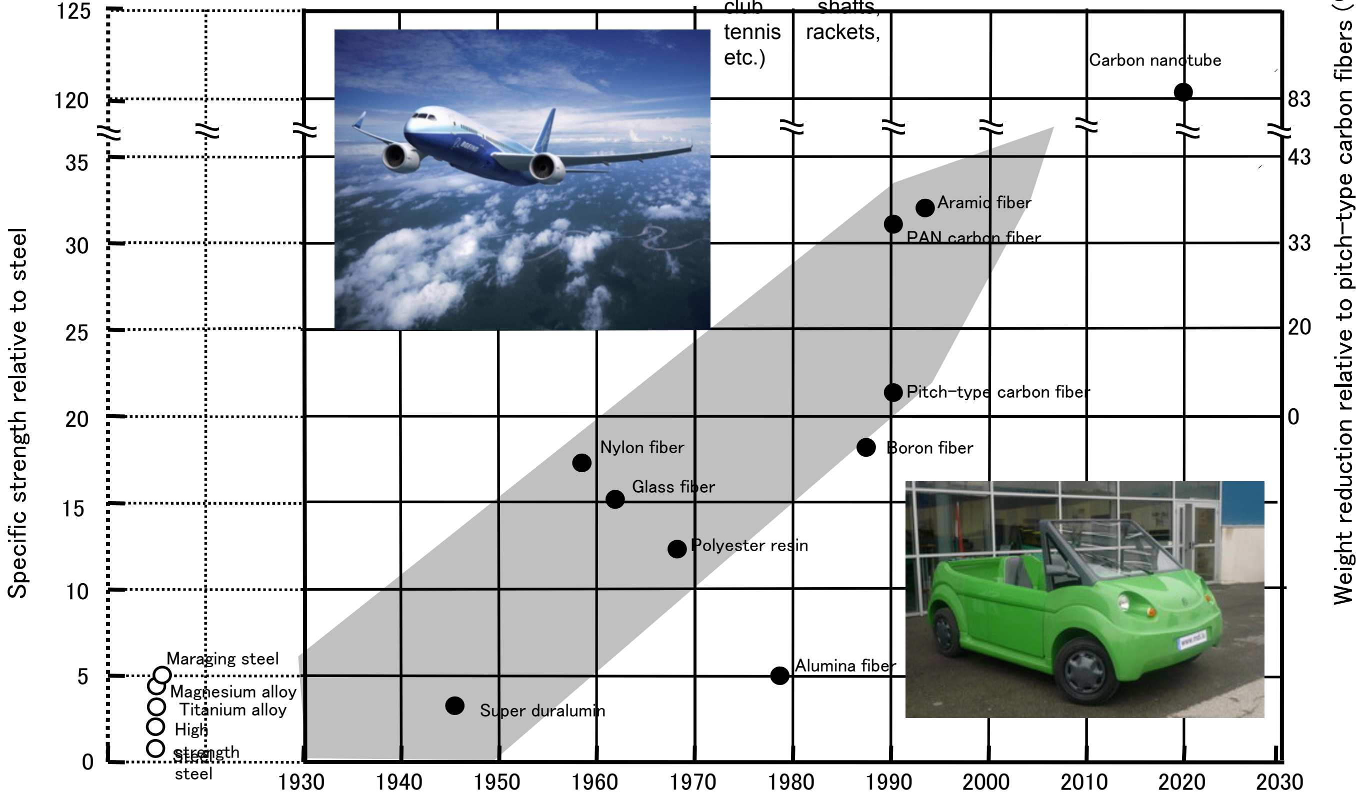
(3) Potential mechanisms that achieve high-grade key parameters

Materials that possess great specific strength were first applied to national aerospace development, medical care and sports projects, which are areas where the financial aspect is a secondary consideration. The materials then spread into general society use. To ensure the full diffusion of such materials throughout society, cost reduction is a decisive factor. If manufacturing costs can be reduced, the consumption of these materials will increase and with increased use, manufacturing costs will decline even further. In the future, further improvements to materials with specific levels of strength will be essential as a matter of course. Additionally, it will be important to improve the technology needed to combine such materials, and to develop materials that have strong thermal and environmental resistance. as well as great specific strength. Ensuring the ease of workability of these materials and eliminating any harmful effects on human involved in the manufacturing processes will also be important.

(4) Future society outlook

As part of future research and development efforts into materials that have great specific strengths, we will need to plan for their social influences by assuming they will be distributed widely among the public. In other words, we will need to develop these materials while taking into consideration what influence they will have on the global environment as well as the need to recycle such materials after they reach the end of their service life.

Social and technological requirements		・Development of military aircraft	・U.S. Apollo Project ・Development of civilian aircraft	・Advance of aircraft steel ・Advance of high-speed railway networks ・Space Shuttle Project ・Expectations toward highly functional sports equipment (golf club shafts, tennis rackets, etc.)	・Reduction of automobile fuel consumption ・Expectations toward care-related medical equipment ・Anti-seismic structures ・Increasing heights of high-rise buildings	・CO_2 reduction



Technological breakthroughs	・Development of duralumin by Wilm	・Successful synthesis of 66-Nylon by Wallace Carothers		・Invention of PAN carbon fiber by Dr. Akio Shindo ・Development of C/C carbon	・Discovery of carbon nanotubes	
Social and market changes		Restoration after the Second World War	High economic growth Mass consumption Private automobile ownership boom Automobile exhaust gas problem	First Oil Crisis Second Oil Crisis	Global warming Development of large aircraft Aged society Anti-seismic measures	Appearance of emerging countries

Energy-saving Carriages for Tokaido Shinkansen Trains

(1) Purpose

Compared with other means of transportation, railways offer a number of excellent characteristics such as high-energy efficiency and reduced impact on the global environment. Therefore, clarifying the excellent characteristics of the Tokaido Shinkansen and other railways will contribute to global environmental conservation. With such conservation in mind, we are aggressively working on ways to reduce energy consumption by Shinkansen train carriages.

(2) Social and technological requirements for technical issues

About 40 million people travel between the Tokyo and Osaka areas each year. A close examination of this economic and social artery shows that the transportation volume provided by the Tokaido Shinkansen during fiscal 2006 was approximately equal to that provided in fiscal 1990, but that CO_2 emissions declined substantially due to energy conservation efforts. **[1]** In contrast, while the transportation volume provided by aircraft grew due to an increase in the number of flights, the volume of CO_2 emissions from aircraft almost doubled**.** In fact, the transportation data for fiscal year 2006 indicates that a transportation shift from aircraft to the Tokaido Shinkansen could reduce the total amount of CO_2 emitted from 900,000 tons to 390,000 tons annually,

This indicates that even though the time required for an aircraft and a Tokaido Shinkansen to travel between the two cities is roughly the same, depending on the transportation selected, **[2]** CO_2 emissions could be curtailed by as much as 510,000 tons yearly. This equals the annual CO_2 emissions from about 98,000 general households.

If this shift had been assumed from fiscal 1990, the reference year of the Kyoto Protocol, total emissions could have been curtailed about 30%, from approximately 580,000 tons to approximately 390,000 tons.

(3) Potential mechanisms for achieving key parameters

JR Tokai has worked diligently to improve energy conservation by upgrading the train carriages and making other qualitative and quantitative improvements. An example of these efforts is reflected in the upgrades to Tokaido Shinkansen carriages. While the maximum speed of the Tokaido Shinkansen was 220 km/h at its 1987 inauguration, due to carriage speed improvements, it was raised 50 km/h to a top speed of 270 km/h in 1992 with the introduction of the Series 300 model trains. This increase was the result of aggressive efforts to improve power electronics and other technologies. Since that time, at relatively short cycles of seven to eight years, the train carriages have been further upgraded to Series 700 and Series N700.

Furthermore, simulations conducted on the Tokyo and Shin-Osaka run showed a remarkable decrease in energy consumption by the Series N700, which is just half of that consumed by Series 0 trains, despite the fact that the maximum speed of Series 0 trains was 32% slower. These improvements are the results of stringent carriage weight reduction, aerodynamic streamlining, power regenerative braking that recycles consumed energy, the carriage-body tilting system, and other new technologies.

■ Reduction of carriage weight

Carriage weight reduction greatly improves energy conservation performance. After the Series 300, we adapted bolsterless trucks to Series 700 and N700 models because of their simpler structures. The Series 700 and N700 also adopted bodies made of lightweight aluminum alloy instead of the steel bodies used in the Series 0 and 100 trains. Furthermore, the Series 0 and 100 trains used DC motors, while the Series 300 and later trains adopted extremely efficient and compact AC motors that epitomized the advances in semiconductor technologies.

These and other efforts have made Series 300 or later carriages over 250 tons each lighter Series 0 carriages.

■ Reduction of running resistance

To reduce running resistance, a new nose shape that provides excellent aerodynamic characteristics was developed for Series N700. The nose shape was the result of approximately 5000 computer simulations and wind tunnel experiments. The shape was named "Aero double wing" because it resembles a bird flying with outstretched wings. For cabin windows, the window glass was integrated with the metal exterior of the carriage to create a smooth surface with no level differences. Furthermore, the joints between each carriage are covered with hoods designed to provide a smooth exterior to the entire train.

These efforts have reduced the running resistance of Series N700 trains by about 20% in comparison compared with the Series 700.

■ Extension of power regenerative brake

A power regenerative brake system converts kinetic energy into electric energy (power generation) by using electric motors as generators during braking, and then channeling the generated power to the overhead line for use by other trains, has been adopted. JR Tokai put power regenerative braking to practical Shinkansen use, for the first time, with the Series 300 and has continued to use it with Series 700 and N700 trains.

For Series 700 trains, 12 of the normal 16 carriages were equipped with the brake system, but with the Series N700, the brake systems was extended to 14 carriages in order to acquire all the braking force usually required for a train equipped with the power regenerative brake system. This has further raised the energy efficiency and contributed to reductions in Shinkansen energy consumption.

■ Implementation of carriage-body tilting system

To increase operating speeds on speed-limited curves, the Series N700 adopted a carriage-body tilting system. This system enables the train to negotiate curves at increased speed while maintaining a comfortable ride. The system has resulted in time savings not just for negotiating the curves, but by reducing the need for acceleration and deceleration as well as its frequency. This has made further contributions to energy conservation.

When the Shinagawa Tokaido Shinkansen station was opened in October 2003, we replaced all carriages with the high-speed, energy-efficient Series 700 and 300 models.

In July 2007, The Series N700, which offers improved service and environmental performance entered service. Use of this model had reduced energy consumption (*) by about 19% at the end of fiscal 2007. (*Based on the amount of energy require to operate run one carriage for 1 km).

By fiscal 2011, 80 trains consisting solely of Series N700 carriages will be in operation and thus strengthen the environmental superiority of the Tokaido Shinkansen. By improving our service and encouraging more users to select and use Tokaido Shinkansen, we will contribute to reducing the environmental load of the entire transportation sector.

(4) Future society outlook

Various means of transportation have different characteristics. For long-distance transport to overseas destinations, aircraft may be the most suitable means available. However, for rather short distances and areas of great demand, such as the route between the Tokyo and Osaka areas, it is clear that the Shinkansen is a rapid and suitable mass transportation system.

By shifting passenger demand to the environmentally superior Shinkansen, CO_2 emissions can be curtailed. As one of the solutions to the global warming problem in the 21st Century, we think that role sharing by utilizing the optimum characteristics of each means of transportation is necessary to reduce the environmental burden caused by the entire sector.

			Baseline	Climate plan		
			2007	2015	2030	2050
[Name of the technology/solution]	Savings	Consumption if old technologies are sustained (BAU)	100	90	85	80
		Consumption after implementing new technology and measures		80	60	40
		Net saving		10	25	40
	Cost (Investment, operation & maintenance, fuel)			100	110	120
	Cost Per PJ saved			-	-	-
	GHG reduction potential	Emission if old technologies are sustained and with current trends (BAU)	100	90	85	80
		Emission after implementing new technology and measures		80	60	40
		Total Reduction		10	25	40
	Cost of GHG reduction			100	110	120

Advanced Nuclear Power Generation

● Outline of technology

Nuclear power has excellent supply stability, and it emits no carbon dioxide in its generation process. It is currently the only clean base load energy sources in Japan. It is a source of energy that can address both carbon dioxide emissions reductions and economic development since it is capable of stably supplying electrical power necessary for economic development at a relatively low cost.

It is necessary to improve domestic and international mainstream light-water reactor application technologies and to develop advanced nuclear power generation technologies such as the innovative fast reactors through 2050. More specifically, the matters to be addressed include technology development for the next-generation of light-water reactors to improve safety, economic efficiency, and reliability drastically; fast reactor cycle technology to improve the efficiency of the uranium resource utilization considerably; and the development of small and medium reactors in compact sizes to address power demands in developing nations and islands states.

● Technology development roadmap

Japan has successively constructed light-water reactors, and it currently has 55 light-water reactor units with nuclear power providing about 30% of Japan's total generation. The light-water reactions have a considerably lower frequency of unplanned stops compared to those reactors in other nations. We thus have the world's top-level technology, human resources, and industry size in all aspects, from technology development to design, production, construction and operation. On the other hand, our nuclear reactor manufacturers have been slow to enter the international market, and international recognition of the nuclear reactors we have developed is low. In addition, there is little standardization of rectors because nuclear power plants have been individually designed and constructed fro each site to address the individual demands of the domestic utility companies.

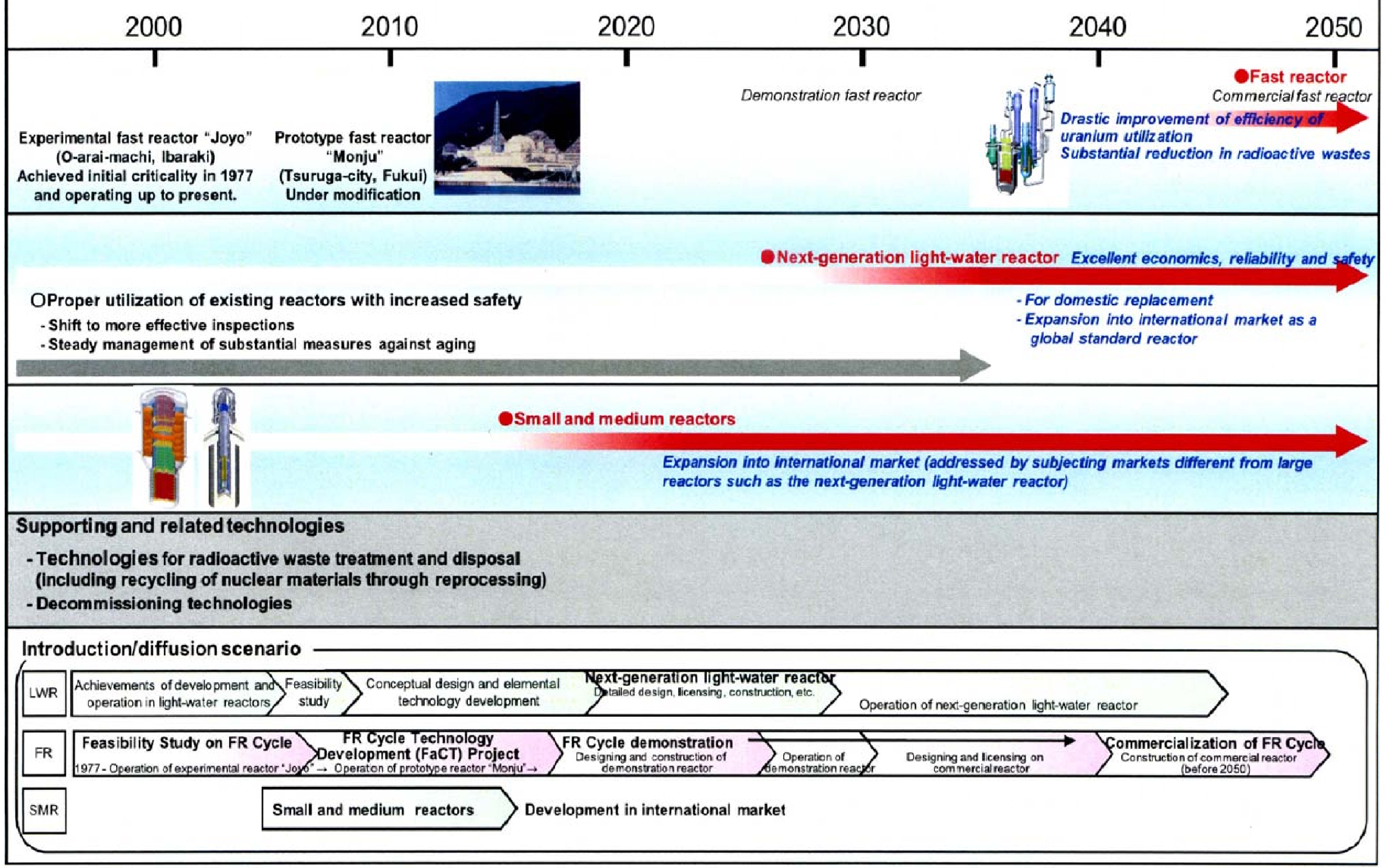
While drastic expansion in the international market is expected, the nuclear reactor manufacturers in the U.S., France and Russia have been actively expanding their business so that they can participate in new construction markets over the world with support from their respective governments. The nuclear reactor manufacturer in Korea is competitive with certain components. China is also developing its own reactors based on technologies introduced from other countries. In such circumstances, Japan needs to maintain and improve its level of technological development with the government's assistance through its investment in research fields with high investment risks and large ripple effects.

To address the domestic needs for the replacement of reactors expected around 2030, we will promote the development of next-generation light-reactor application technology to drastically improve safety, economic efficiency, reliability while utilizing the achievements that our light-water reactor development programs and operations have yielded so far. Specifically, technologies to reduce the generation of spent nuclear fuel and to address seismic isolation will be developed. Meanwhile, cooperation between the government and the private sector will be necessary to address the development of innovative technologies that may become the domestic and global standard with international standardization while there is a global trend of re-recognition of the use of nuclear power and an increase in international cooperation on the issue.

Furthermore, we will promote the development of fast reactor cycle technology to improve the efficiency of uranium utilization drastically and reduce radioactive waste substantially, with an objective to build a demonstration reactor and a related cycle facility by 2025 and commercialization of the technology before 2050. It is important to seek to obtain a position as a global standard reactor through multilateral or bilateral forums for cooperation such as GNEP (Global Nuclear Energy Partnership and GIF (Generation IV International Forum) with this research and development.

Moreover, the development of small and medium reactors to address the needs of developing nations and island states will be promoted in order to expand our technology into an international market different from that of our large next-generation light-water reactors. Specifically, we will promote the development of innovative basic technologies while advancing both the international expansion of our nuclear industry and international cooperation under the framework of GNEP and other organizations. This will utilize our experience and skills to improve the economics of reactors with drastic size reductions and maintenance cost reductions.

⑤ Advanced Nuclear Power Generation



Energy Saving through Emulation of Low-friction Biological Joints

Bioengineering Division

1. Overview-

The fields covered by the Bioengineering Division are extremely broad-ranging, and it would currently be difficult to provide a general overview of its technologies development effort or to present and discuss their key parameters. Therefore, we shall focus on biomimetics as a development field that shows the overall effort. Biomimetics is devoted to achieving an understanding of biological principles and mechanisms and then applying them to the development of technological processes, materials, and designs. This report focuses on the "Lubrication Problem" and in particular, the achievement of energy savings through emulation of the low-friction joints prevalent in natural life forms.

In 1966, H.P.Jost who had made a significant contribution to the edifice of knowledge of "Tribology"; the science and technology of interacting surfaces in relative motion and of related subject and practices, reported the broad economic effect of the Lubrication Problem (Jost report). The economic impact of the Lubrication Problem in Japan has been also estimated by the Technical Research Institute (TRI) of the Japan Society for Promotion of Machine Industry (JSPMI) to account for 3% of the Japanese Gross Domestic Product (GDP), or approximately 15.5 trillion yen in fiscal 2007. (The TRI report described the effect in terms of Gross National Product (GNP), but it has been converted to a GDP base here in view of the trend toward increasing globalization.)

2. Social and technological needs and technological tasks

There are more than 500 million cars on the road worldwide, and losses due to friction and heat account for two-thirds of their fuel consumption. Estimates indicate that if the annual fuel consumption of these cars could be reduced by 10% by reducing friction, the conserved energy would be sufficient to provide electric power for all households in Japan for a year or more.

The automotive industry has made progress in reducing fuel consumption through improvements in engine, transmission, and clutch efficiency. However, breakthroughs that go well beyond present technologies will be necessary for any approach to the ultimate goal of “zero (motive) friction/zero wear” in their sliding components.

Reduction of energy consumption through reduction of friction does not represent the full economic effect of improvements in lubrication technology. As reported by Jost, it accounts for only about 14% of the total economic effect. The largest gain, representing some 50% of the total economic effect, is the result of reduced component wear and related maintenance and replacement costs. This is followed by the reduction of consequential losses due to malfunction, which represent about 25% of the total.

3. Possible mechanisms for enhancement of key parameters

Bearings are one of the mechanical components most intimately related to the Lubrication Problem. They may be broadly classified as either plain (slide) bearings or rolling (ball or roller) bearings. Unless accompanied by a pressurized lubricant supply system, plain bearings are prone to lubricant film rupture during low speed operation, which inevitably leads to high friction and high wear. Their performance improves during high speed operation, but shear resistance of lubricant increases and the energy loss becomes a matter of concern. For rolling bearings, on the other hand, the level of standardization and mass production is one of the most advanced among mechanical components, and their performance at low operating speeds is excellent. During high-speed operation, however, limitations arise due to centrifugal forces on their rotating bodies and their retainer lubrication.

Biological joints in the human body are constantly exposed to severe fluctuations in load, sliding speed and direction, and motive friction. Despite this, they exhibit low friction ($f < 0.001$) and low wear (service life: more than 70 years) due to the superior complex of effective interactive lubrication systems throughout the range from boundary to fluid lubrication regions. Joint cartilage, composed of collagen fibers, forms bearings with a porous structure that is low in elastic modulus (<10 MPa) and contains lubricants composed of proteoglycans (sugar-protein complex). When bearings come into direct mutual contact in the boundary lubrication regions, the bearing surfaces deform and simultaneously exude these lubricants, thus moderating the state of lubrication. In the mixed lubrication regions, the low elastic modulus bearing surfaces promotes the rapid generation of a lubricating film. In the full-fluid lubrication region, the synovial fluid (natural joint lubricating fluid), with its non-Newtonian nature, behaves as a low-viscosity fluid under high shear, minimizing the shear resistance of the lubricant film and thus reducing energy loss.

The development and introduction of lubricating systems with a performance matching that of biological joints will require the development of new materials and other advances, and practical implementation is not expected before 2020 at the earliest. Furthermore, if the replacement of conventional lubricating systems is limited to service environments similar to those of biological joints, they may be expected to account for about 2% of the Lubrication Problem. Improvements to conventional lubricating systems by incorporating the possibilities suggested by biological joints and for which investigations can already be initiated, such as mechanisms for exudation of lubricating fluids from bearing surfaces and the use of non-Newtonian flow mechanisms in lubricating oils, may be expected to account for a further 2%. Derivative technologies may account for another 3%. In total, then, energy-saving technology resulting from emulation of low-friction biological joints may ultimately represent a contribution of 7% to resolution of the Lubrication Problem. This equates to about one trillion yen when calculated on the basis of the Japanese GDP in fiscal 2007.

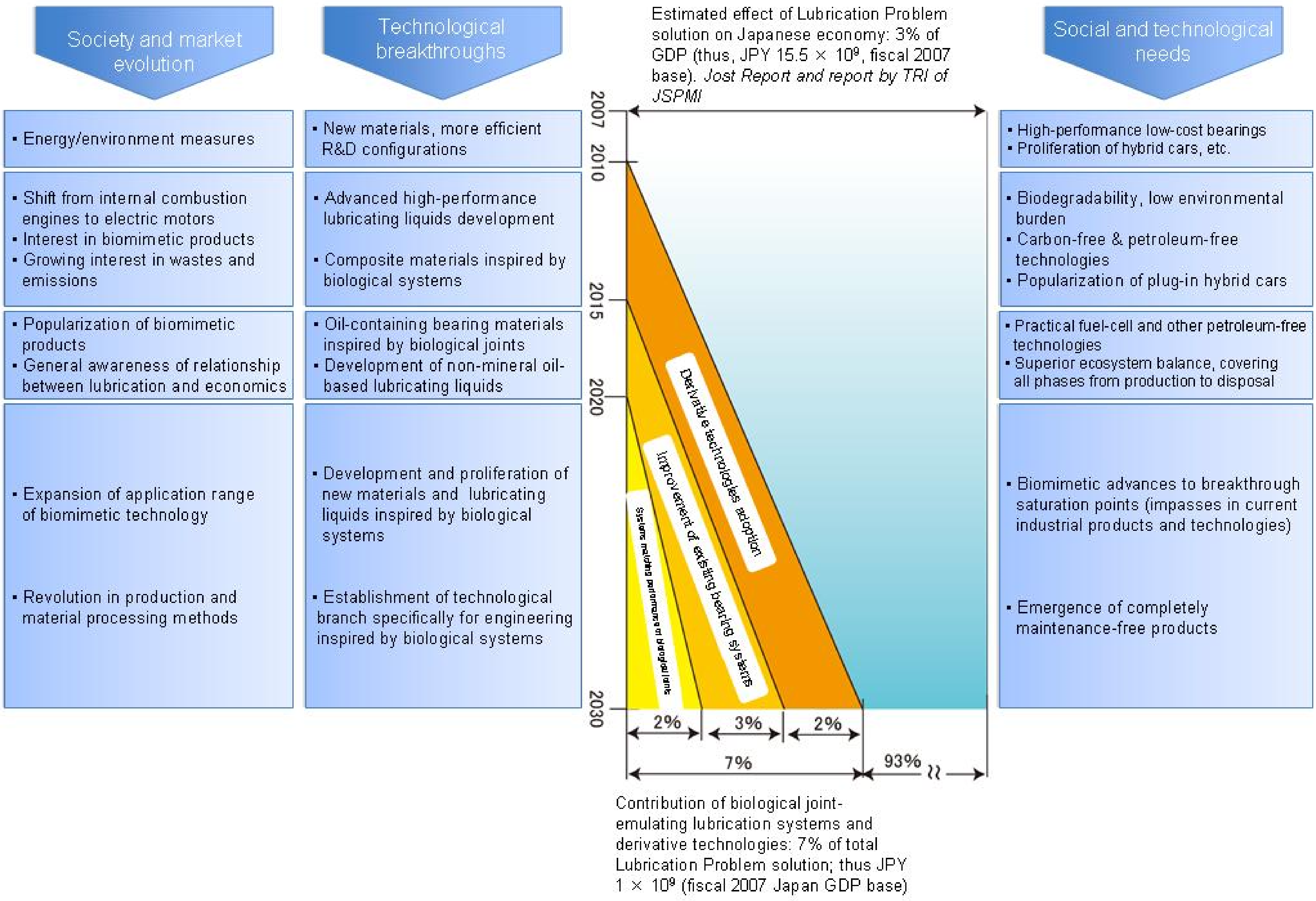
4. Outlook on future social aspects

Living bodies are constructed primarily from organic compounds containing large amounts of water. If it becomes possible to mimic their material composition, it will eliminate the requirement for mineral lubricating liquids and it will also mimic their promotion of the decomposition of product components and thus emulate their low environmental burden.

Internal combustion engines, the traditional power source for automobiles, inherently require careful consideration of heat resistance in the development of their lubrication components. With the adoption of fuel cells or other power sources, areas that are free from heat resistance problems will expand, and the number of areas in which lubrication systems emulating living bodies can be utilized can be expected to increase.

Adoption of electrical drive systems may also be expected to lead to simplification of mechanical components, elimination of cams, tappets, crankshafts, gear pumps, and other components requiring oil-based lubricating liquids, as well as an expansion of the areas amenable to the utilization of water-based lubricating liquids. All of this will present new opportunities for taking advantage of the secondary effects of lubricating systems that emulate those of living bodies, such as their biodegradability and their low environmental burden in disposal and other phases.

In the manufacture of parts and components, the cutting, milling, pressing, rolling, and other processes are all affected by the Lubrication Problem. This is another field in which favorable conditions are emerging for development of lubrication systems emulating those of living bodies, and the development of the seeds for derivative technologies.



Society and market evolution
Technological breakthroughs
Social and technological needs
Estimated effect of Lubrication Problem solution on Japanese economy: 3% of GDP (thus, JPY 15.5 × 10⁹, fiscal 2007 base). Jost Report and report by TRI of JSPMI
2007
2010
2015
2020
2030
• Energy/environment measures
• New materials, more efficient R&D configurations
• High-performance low-cost bearings
• Proliferation of hybrid cars, etc.
• Shift from internal combustion engines to electric motors
• Interest in biomimetic products
• Growing interest in wastes and emissions
• Advanced high-performance lubricating liquids development
• Composite materials inspired by biological systems
• Biodegradability, low environmental burden
• Carbon-free & petroleum-free technologies
• Popularization of plug-in hybrid cars
• Popularization of biomimetic products
• General awareness of relationship between lubrication and economics
• Oil-containing bearing materials inspired by biological joints
• Development of non-mineral oil-based lubricating liquids
• Practical fuel-cell and other petroleum-free technologies
• Superior ecosystem balance, covering all phases from production to disposal
• Expansion of application range of biomimetic technology
• Revolution in production and material processing methods
• Development and proliferation of new materials and lubricating liquids inspired by biological systems
• Establishment of technological branch specifically for engineering inspired by biological systems
• Biomimetic advances to breakthrough saturation points (impasses in current industrial products and technologies)
• Emergence of completely maintenance-free products
Derivative technologies adoption
Improvement of existing bearing systems
Systems matching performance of biological joints
2%
3%
2%
7%
93%
Contribution of biological joint-emulating lubrication systems and derivative technologies: 7% of total Lubrication Problem solution; thus JPY 1 × 10⁹ (fiscal 2007 Japan GDP base)