Strategic Technology Roadmap in Energy Field — Energy Technology Vision 2100 — http://www.iae.or.jp/2100.html

While energy demand is increasing in the world, we have reconsidered and showed what energy technologies ought to be in order to realize a society based on the truly sustainable structure of energy supply and demand. From a long-term view until 2100, we have described technologies by a "backcasting" method which can overcome resource and environment constraints we are globally anxious about in the future.

We hope that this vision will not only put emphasis on long-range research and development but also help people discuss an international framework for the post-Kyoto protocol. At the same time, we hope this roadmap will have a good effect on the research and development management after several revisions from a viewpoint of a short-and-medium-term vision.

(1) Assumption of constraints in the future

Global resource constraint: *Oil production is assumed to peak in 2050*
Natural gas production is assumed to peak in 2100
Global environmental constraint: *CO_2 emission intensity per GDP (CO_2/GDP) should be reduced to 1/3 in 2050 and less than 1/10 in 2100*
Condition of the future image of technologies in Japan:
- Up to the production peaks, substitution of other energy resource should be realized
- CO_2 intensity should be reduced at the same ratio as above — Japan leads the world into the foreseeable future

(2) Case study under excessive conditions of energy structure

Case A: *Maximum use of fossil resources such as coal combined with CO_2 capture and sequestration*
Case B: *Maximum use of nuclear energy*
Case C: *Maximum use of renewable energy combined with ultimate energy-saving*

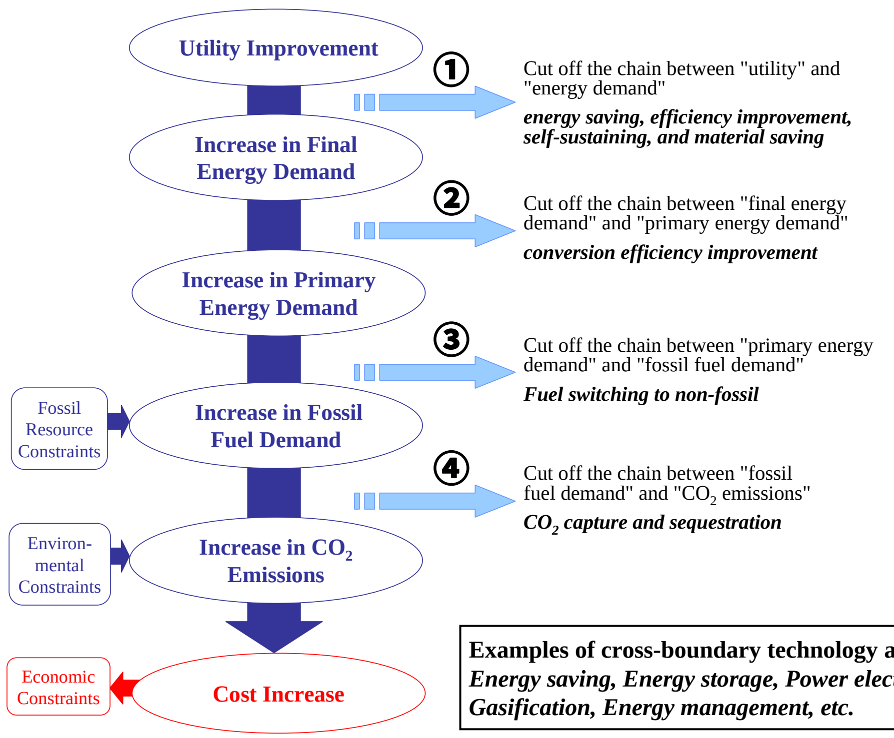
(3) Extraction of technology specification which is required in each sector

Example: *In each section, res/com, transport, and industry, while utility is growing, the necessary energy per unit which should be supplied from the transformation sector is reduced by 70 - 80%.*
Note: On the assumption that the necessary energy increases in proportion to a growth of GDP.

(4) Expanding major technology menu which is needed to realize the technology specification along the time axis

A fundamental concept of measures

Technologies that realize the truly sustainable structure between supply and demand, which can break away from the "increasing chain" at present



Examples of cross-boundary technology among sectors
Energy saving, Energy storage, Power electronics, Gasification, Energy management, etc.

Major technology specification required in each sector and a view of measures

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

Res/Com

Res/Com		2000	2030	2050	2100
Total energy demand		1 time		1.5 times	2.1 times
Energy supplied from transformation sector*	Residential / Commercial		45% / 35% reduction	60% / 55% reduction	80% / 80% reduction
CO_2 intensity	Residential	3.5 t-CO_2/Household (1 time)	1.9 t-CO_2/Household (1/2 times)	1.1 t-CO_2/Household (1/3 times)	0 t-CO_2/Household
	Commercial	118 kg-CO_2/m^2 (1 time)	77 kg-CO_2/m^2 (2/3 times)	40 kg-CO_2/m^2 (1/3 times)	0 kg-CO_2/m^2

Energy saving — *Equipment and building, etc.*
Energy creating — *Photovoltaic etc.*
Energy management — *Energy accommodation etc.*
towards self-sustaining of each appliance, house or office, and community

(1) Energy saving containing new equipment in the future
(2) Energy creation by ubiquitous energy such as solar power (ultimately self-sustainable system independent of transformation sector)
Furthermore, maximum use of energy by accommodation, dispersed storage, etc.

Transport

Transport	2000	2030	2050	2100
Utility (passenger-km, ton-km)	1 time		1.5 times	2.1 times
Energy supplied from transformation sector* (overall)		20% reduction	50% reduction	70% reduction
Automobile Energy demand*		30% reduction	60% reduction	80% reduction
Share of electricity and/or hydrogen	0%	over 1%	40%	100 %
CO_2 intensity	160 g-CO_2/km (1time)	100 g-CO_2/km (2/3 times)	50 g-CO_2/km (1/3times)	0 g-CO_2/km
Aircraft, Ship, Railroad Energy demand*		10 - 20% reduction	20 - 35% reduction	30 - 50% reduction

Improvement of fuel efficiency — *Hybridization, Weight reduction* → *Fuel cell vehicle (FCV), Electric vehicle (EV) (Hydrogen/electricity storage) (Hydrogen/electricity supply)*
Fuel switching — *Fuel mix (Biomass fuel, Synthetic fuel)* → *Hydrogen/electricity*
towards high fuel efficiency and zero-emission

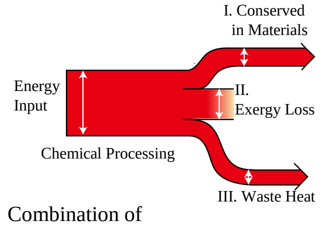
"Energy saving" and "fuel switching" are the main energy saving equipment sector
(1) Improvement of efficiency in engine and drive system
(2) Weight reduction of the vehicle body, ship, and aircraft
- Fuel switching
(i) use of synthetic fuel
(ii) ultimate use of biomass-origin fuel
(iii) switching to hydrogen and/or electricity

Automobile
Conventional internal combustion vehicle engine (ICE)
→ICE-battery hybrid vehicle
→FC-battery hybrid vehicle or EV

Industry

Industry	2000	2030	2050	2100
(Production) × (Value of product)	1 time		1.5 times	2.1 times
Energy supplied from transformation sector*		25% reduction	40% reduction	70% reduction
1) Production energy intensity		20% reduction	30% reduction	50% reduction
2) Material/energy regeneration ratio		50%	60%	80%
3) Improvement of functionality such high-strength etc. (functionality / amount of material)	1 time	2 times	3 times	4 times

Improvement of production process — *Energy saving, Co-production (simultaneous production of material and energy) etc.*
Regeneration of material/energy — *Regeneration and use of material and/or energy in products etc.; Cross-boundary measures beyond sectors*
Improvement of functionality — *Improvement of functionality of material and parts etc.; Material saving of products*
towards maximum use of energy and material and supply high-performance products through the future



Combination of
- Improvement of production process (II and III)
- Regeneration of material/energy from used products (I)
- Improvement of functionality of products

Co-production
Electricity or hydrogen are recovered from exergy loss by use of gasification process, for example, just like simultaneous production of material and energy.
Material/energy regeneration
For example, it is possible to use as raw material or to generate energy by gasification of used chemicals.

Transformation

Transformation	2000	2030	2050	2100
Total energy demand on the demand side (maximum case)	1 time		1.5 times	2.1 times
Share of electricity and/or hydrogen	1 time		2 times	4 times
CO_2 intensity	370 g-CO_2/kWh (1 time)	270 g-CO_2/kWh (2/3 times)	120 g-CO_2/kWh (1/3 times)	0 kg-CO_2/kWh; *110 g-CO_2/kWh (1/3 times) in the case of fossil fuel use with CCS*

Effective use of fossil resources — *High-efficient use of fossil fuels, CO_2 capture and sequestration etc.*
Use of nuclear power — *Nuclear fuel cycle etc. (Large-scale energy storage)*
Use of renewable energy — *Solar, geothermal, wind, biomass, etc.*
towards reliable supply of clean energy

(a) Technology for effective use of fossil resource
(b) Technology for use of nuclear power
(c) Technology for use of renewable energy
Furthermore, as share of renewable energy increases, technologies for large-scale energy storage and energy network system are needed.

***Tentative Translation**, Jan. 4, 2005*

Tentative Translation, Jan. 2006

Energy Technology Vision 2100
Summary

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

2. In the development of the future technology portfolio, we have set excessive conditions for energy structure to identify the most severe technological specifications in sectors of residential/commercial, transport, industry, and transformation. As a result, if all of them are achieved, the constraints will be achieved in excess.

Assumptions of constraint

Global resource constraint: Oil production is assumed to peak in 2050
Natural gas production is assumed to peak in 2100

Global environmental constraint:
CO_2 emission intensity per GDP (CO_2/GDP) should be reduced to 1/3 in 2050 and less than 1/10 in 2100.

Condition of the future image of technologies in Japan:
Up to the production peaks, substitution of other energy resource should be realized and the CO_2 intensity should be reduced at the same ratio as above so that Japan leads the world into the foreseeable future.

Case study under excessive conditions of energy structure

Case A: Maximum use of fossil resources such as coal combined with CO_2 capture and sequestration
Case B: Maximum use of nuclear energy
Case C: Maximum use of renewable energy combined with ultimate energy-saving

Technological specifications which are required in each sector (overview in 2100)

Residential/Commercial

- While “utility” increases in proportion to GDP, 80% of required energy from transformation sector is reduced (per household, floor space).

- Share of electricity and/or hydrogen is 100%.

Transport

- While "utility (≈ person·km, ton·km)" increases in proportion to GDP, the fuel efficiency is improved equivalent to a 70% reduction of required energy (for automobiles, equivalent to an 80% reduction)
- Share of electricity and/or hydrogen is 100% (except aircraft)
- Fuel switching with appropriate timing to resolve resource constraints

Industry

- While "utility (≈ production volume × production value)" increases in proportion to GDP, 70% of required energy from transformation sector is reduced (per utility)
- Primary fuel switch with appropriate timing to resolve resource constraints

Transformation

- Required energy for each demand sector is supplied sufficiently in each case

3. In order to realize the technological specifications in the future, we sorted out the menu for the key technologies according to the time series, as shown in the energy technology roadmaps.

Important points

Residential/Commercial

In order to realize the technological specifications for the res/com sector, we should (1) carry out energy saving as much as possible including the equipment that will appear in the future, and (2) execute energy creation by using ubiquitous energies such as solar power. Through the advancement of (1) and (2) ultimately, "self-sustenance" which does not depend on the energy supplied from the transformation sector becomes possible. It becomes possible that surplus energy is accommodated through the energy network and moreover, this energy is utilized to the fullest, as the amount of energy created from renewable energy increases.

Transport

The main paths for technological specifications achievement in the transport sector are "energy saving" and "fuel switching." For energy saving in machine units (1) improve efficiency in engines and drive systems (2) weight reduction of bodies (vehicles, ships, aircraft) are important. For fuel switching, (1) synthetic fuel made of natural gas or coal (for reducing oil consumption), (2) biomass fuel that is carbon-neutral, and (3) switching to hydrogen or electricity that generates no CO_2, are required.

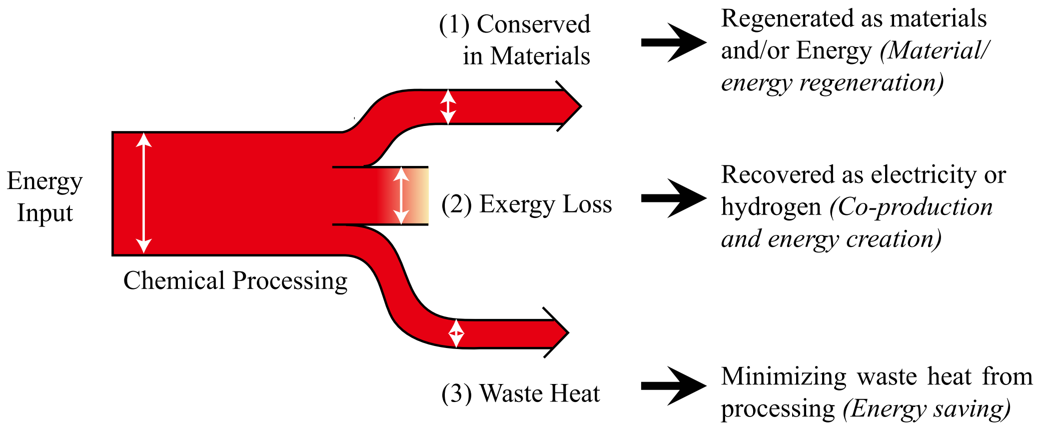
Automobile

The mainstream of automobiles will shift to "conventional ICE → ICE hybrid → FC hybrid", and electric vehicles will be small with a short range. The fuels for ICE will shift from oil to synthetic fuels by 2050. In the process of the shift, petroleum fuels and synthetic fuels are used as a mixture.

Industry

Energy provided in the raw material manufacturing process (material conversion) is categorized in the following three ways:

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



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

The required energy for production processes in (2) and (3) should be reduced.

**Co-production:* For example, we can collect heat, electricity, and hydrogen efficiently from gasification processes even while using fossil fuels. Since we can recover exergy that is lost in the conventional production processes as electricity or hydrogen, this method seems to generate material and energy together when the same raw material is processed.

Regeneration of material/energy "use skillfully"

As can be seen in (1), a product (material) has chemical energy inside. After the life of the product terminates, we can regenerate this (1) as material and/or energy.

**Regeneration of material/energy:* For example, since 60% of used energy is stored as material in the chemical production, it is possible to utilize it as a raw material and to regenerate energy by means of gasification of used products and so on.

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

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

Common technology in the industrial sector

Biomass and wastes become important materials and fuel mainly in industries utilizing carbon (C) as a material. Therefore, management technology of materials including them becomes important in the future.

Transformation

It is necessary to provide the following three technological groups to fulfill energy demand efficiently with reducing CO_2 intensity.

Effective use of fossil resources

In preparation for the oil production peak, we execute a fuel switch to natural gas, and to coal that has comparably a rich volume of resources. Since coal is also a finite resource, it is important to improve the effectiveness of fossil resources use such as power generation (transformation) efficiency. Therefore, gasification power generation (fuel production) technologies and highly effective power generation technologies combined with fuel cells are required. Also, since fossil fuel generates CO_2 emission, CO_2 capture and sequestration (CCS) technologies are essential.

Nuclear power utilization technologies

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

Renewable energy utilization technologies

It is important to improve effectiveness of power generation (transformation) by renewable energy such as solar power, geothermal, wind power, and biomass. Since the capacity factor of solar or wind power generation is low, and these facilities need a large installed capacity, technologies for easy installation are also required. Since natural energy depends on weather conditions etc., it is essential to establish a large scale of storage technologies and network system technologies including system control (energy management).

Cross-boundary technologies

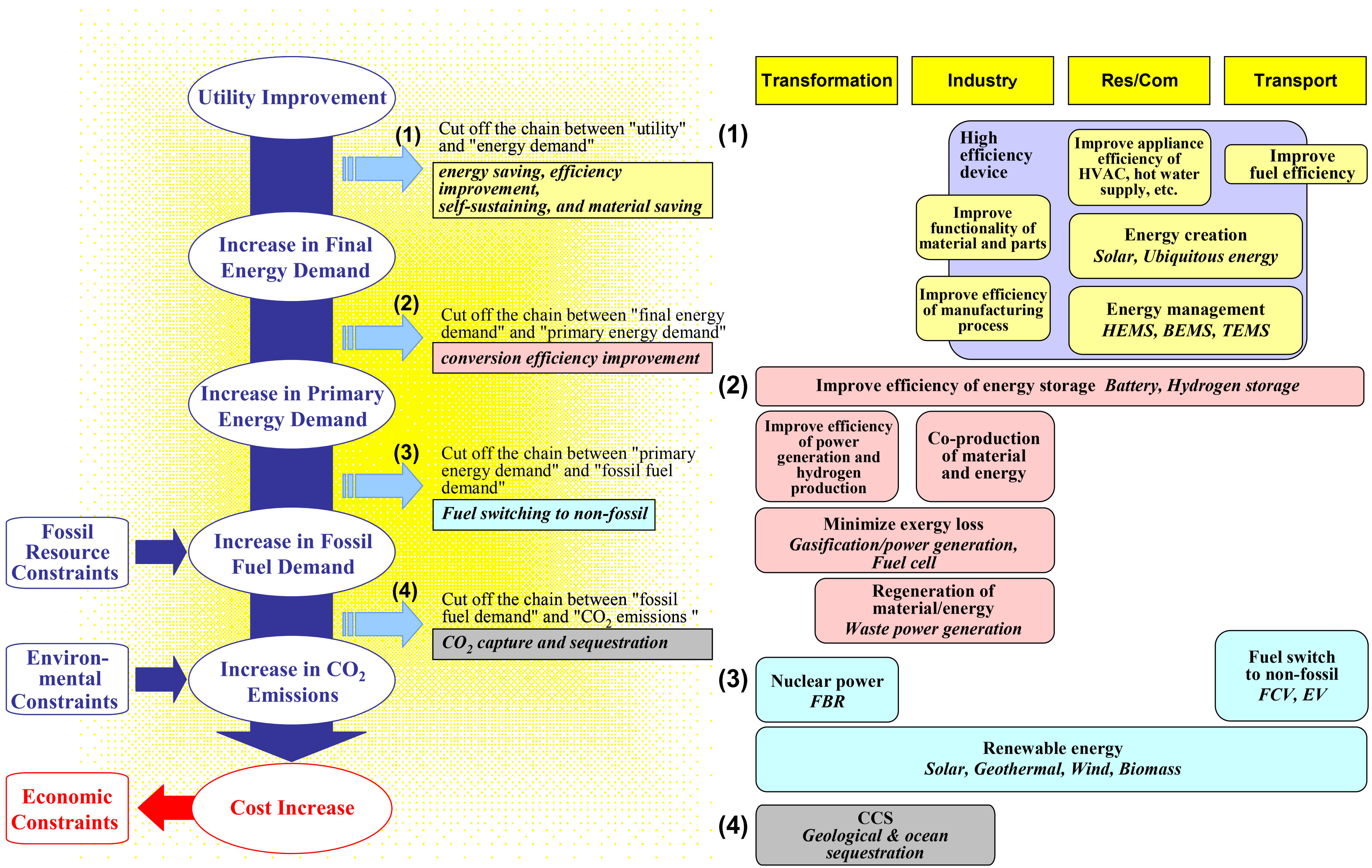
Once a cross-boundary technology is established, it can work effectively in a wide range of applications. Therefore, it can be an important technology.

Example: Energy-saving technology, energy storage technology, power electronics technology, gasification technology, energy management technology, etc.

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

In Japan, current capacity for geological CO_2 sequestration is considered to have limitations. We have to consider ocean sequestration to satisfy required capacity, but there are necessary tasks for ocean sequestration that need to be undertaken, such as an environmental assessment and a social consensus. Case A cannot be a long-term solution when we consider finite fossil resources. Therefore, we think the combination of case C (utilizing renewable energy and ultimate energy-saving technologies) and case B (operating nuclear power reliably) is desirable for society on long-term basis, by avoiding climate change by CO_2 capture and sequestration as required on a mid-term basis. However, evaluation and combination of these cases can vary according to situations in the future. It is important to prepare technologies through R&D for change in the social and economic situations at various occasions in the future.

4. Issues in the future
   - Examination on the basis of short and medium term
   - Detailed studies on key technologies



Utility Improvement
Increase in Final Energy Demand
Increase in Primary Energy Demand
Increase in Fossil Fuel Demand
Increase in CO_2 Emissions
Cost Increase
Fossil Resource Constraints
Environ-mental Constraints
Economic Constraints
(1)
Cut off the chain between "utility" and "energy demand"
energy saving, efficiency improvement, self-sustaining, and material saving
(2)
Cut off the chain between "final energy demand" and "primary energy demand"
conversion efficiency improvement
(3)
Cut off the chain between "primary energy demand" and "fossil fuel demand"
Fuel switching to non-fossil
(4)
Cut off the chain between "fossil fuel demand" and "CO_2 emissions "
CO_2 capture and sequestration
Transformation
Industry
Res/Com
Transport
(1)
High efficiency device
Improve appliance efficiency of HVAC, hot water supply, etc.
Improve fuel efficiency
Improve functionality of material and parts
Energy creation
Solar, Ubiquitous energy
Improve efficiency of manufacturing process
Energy management
HEMS, BEMS, TEMS
(2)
Improve efficiency of energy storage Battery, Hydrogen storage
Improve efficiency of power generation and hydrogen production
Co-production of material and energy
Minimize exergy loss
Gasification/power generation, Fuel cell
Regeneration of material/energy
Waste power generation
(3)
Nuclear power
FBR
Fuel switch to non-fossil
FCV, EV
Renewable energy
Solar, Geothermal, Wind, Biomass
(4)
CCS
Geological & ocean sequestration

Major technology specifications required in each sector and a view of measures

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- **Energy saving** — *Equipment and building, etc.*
- **Energy creating** — *Photovoltaic etc.*
- **Energy management** — *Energy accommodation etc.*

towards self-sustaining of each appliance, house or office, and community

Transport

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Utility (passenger-km, ton-km)	1 time		1.5 times	2.1 times
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Aircraft, Ship, Railroad Energy demand*		10 - 20% reduction	20 - 35% reduction	30 - 50% reduction

- **Improvement of fuel efficiency** — *Hybridization, Weight reduction* → *Fuel cell vehicle (FCV), Electric vehicle (EV)*
- *(Hydrogen/electricity storage)*
- *(Hydrogen/electricity supply)*
- **Fuel switching** — *Fuel mix* (*Biomass fuel, Synthetic fuel*) → *Hydrogen/electricity*

towards high fuel efficiency and zero-emission

Industry

	2000	2030	2050	2100
(Production) × (Value of product)	1 time		1.5 times	2.1 times
Energy supplied from transformation sector*		25% reduction	40% reduction	70% reduction
1) Production energy intensity		20% reduction	30% reduction	50% reduction
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- **Improvement of functionality** — *Improvement of functionality of material and parts etc. Material saving of products*

towards maximum utilization of energy and material and supply high-performance products through the future

Transformation

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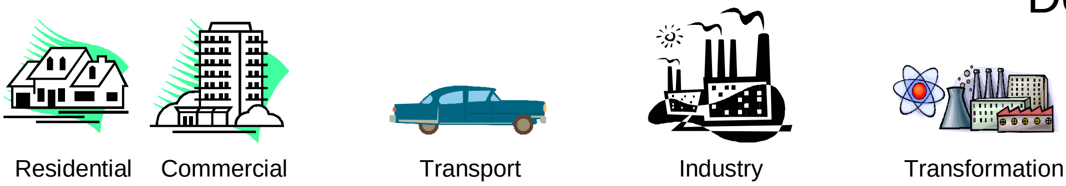
- **Effective use of fossil resources** — *High-efficient use of fossil fuels, CO_2 capture and sequestration etc.*
- **Use of nuclear power** — *Nuclear fuel cycle etc.*
- *(Large-scale energy storage)*
- **Use of renewable energy** — *Solar, geothermal, wind, biomass, etc.*

towards reliable supply of clean energy

Document 1



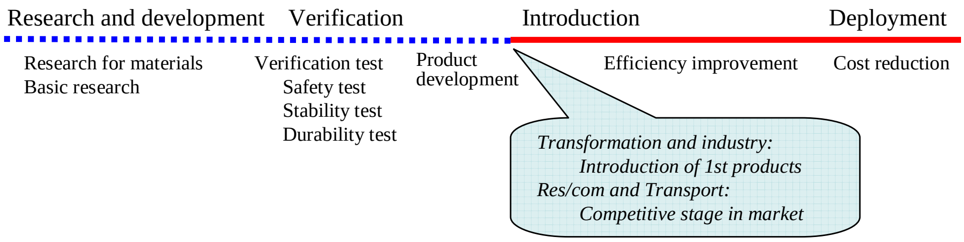
Energy Technology Roadmap 2100 Summary

Tentative Translation, Jan. 2006

This summarized sectoral roadmaps includes Res/Com, Transport, Industry, and Transformation sectors, and each sectoral roadmap consists of 2 sheets as follows.

1: Main technological targets and a basic concept of technological specifications

2: Main technologies for achievement of technological specifications



Basic concept in each sector

Common

The common assumption in demand sectors is that "utility (economic activity, quality of life, etc.)" increases in proportion to GDP. In order to breakaway from the "linkage" of risk enlargement between economic growth and the resource/environmental constraints, we should prepare the technologies for the future to minimize the intensity of required energy which is supplied from the transformation sector.

The growth of GDP in Japan assumes to be about 1.5 times in 2050 and 2 times in 2100.

Residential/Commercial sector

"Utility" per household in the residential sector and per floor space in the commercial sector increases in proportion to GDP. In order to improve the energy intensity, we should (i) carry out energy saving as much as possible including the equipment that will appear in the future, and (ii) execute energy creation by using ubiquitous energies such as solar power. Through the advancement of (i) and (ii) ultimately, "self-sustenance" which does not depend on the energy supplied from the transformation sector becomes possible. If the quantity of energy creation by renewable energy becomes large, we can distribute excessive energy through network, or store energy to utilize maximally.

Transport sector

"Utility (≈ person·km, ton·km)" of automobile use increases in proportion to GDP. In order to improve the energy intensity, we should (i) promote the energy saving by the improvement of engine efficiency and the reduction of vehicle weight, however, fuel cell hybrid cars or electric cars which are driven by carbon engines should be mainstream in the future in order to improve the energy intensity and CO2 intensity drastically. (ii) As for fuels, the share of biomass fuels and mixed fuels of petroleum and synfuels will increase and then the share of hydrogen or electricity will increase after the oil production peak in the middle of this century

Industry sector

"Utility (≈ functionality)" of products increases in proportion to GDP. In order to improve the energy intensity, we should (i) improve quality and functionality of materials and products, (ii) improve production processes and develop an innovative production process (energy saving, effective energy use, co-production of materials and energy in the process), and (iii) regenerate materials and/or energy which is held in products. Moreover, the action of cross-boundary (collaboration between industries, industrial - residential/commercial, and industrial - transformation, and so on) by optimum integration of production processes improves efficiency in the entire society.

Transformation sector

In order to satisfy the energy demand efficiently and to reduce CO2 emission intensity, we should (i) use fossil resources effectively, (ii) execute a fuel switching to non-fossil resources such as renewable and/or nuclear energies, and (iii) establish an energy network including a large-scale energy storage, because of the increased requirement of the energy management to control the fluctuation of energy supply.

Res/Com

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

Energy saving

Efficiency improvement of equipment

Lighting with less heat loss *Equipment with less heat loss*

Improving thermal performance of housing and building → *Active control of sun shading and thermal insulation*

Efficient heating → *Efficient heat transfer, preheating by unused energy*

Improving electric power conversion efficiency → *Electric power conversion with least loss*

Food storage at room temperature

Self-sustaining

Use of ubiquitous energy (minute pressure, temperature difference, vibration, radiowaves, etc.)

Energy saving enables equipment using little energy

Energy creation from ubiquitous energy

0 t-CO_2/household

0 kg-CO_2/m^2

Photovoltaic generation

Installation in all places such as PV paint

Installation in windows

Installation in curved surfaces

Installation facilitation

Energy creation *Efficiency improvement and increase of durability*

Energy management

BEMS•HEMS

Self-sustainable housing and building

Demand management → *Management of demand and energy creation* → *Energy accommodation in community*

(Energy supply in community) → *Supply and storage management in community* → *Supply and demand management in community*

TEMS **Self-sustainable community**

Res/Com

2000 | 2030 | 2050 | 2100

Energy saving

Lighting

- High efficiency lighting: High efficiency LED; Organic EL lighting; Low heat loss & high efficiency lighting
- Use of natural light: Advanced use of solar light (high efficiency light focusing and transmission); Light storage, bio-chemical light emission

HVAC & hot water supply

- High performance construction material for housing and buildings: High thermal insulation, improvement of indoor air environment, improvement of wellness; Active controllable construction material
- High efficiency HVAC system: High efficiency heat pump, thermal storage air-conditioning, use of solar heat or unused exhausted heat
- Distributed power generation using fossil fuels: Fuel cell cogeneration; FC/GT hybrid system (commercial use); (Ultra-high efficiency FC using hydrogen)
- High efficiency hot water supply: High efficiency heat pump; Vacuum insulation storage

Kitchens

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

Power and others

- Information appliances (Big screen display etc.): Low power consumption PDP/LCD, high-capacity optical networking/storage; LED/EL display (High definition large screen, low power consumption)

Common technology

- High efficiency devices (electric power conversion etc.): 45nm process; SiC; GaN, AlN, etc.; CNT transistor/diamond semiconductor; Single electron transistor

Energy creation

- Unused energy conversion to electricity etc.: Thermoelectric conversion; Piezoelectric/magnetostrictive/bio-photovoltaic conversion
- Photovoltaic generation: Thin film type; Dye-sensitized type, organic thin film type, etc.; Super-high efficiency new type; Cost reduction, high efficiency, installation facilitation

Energy management

- HEMS/BEMS: Monitoring; Cooperation with the grid; Demand forecasting; (Control including lifestyle and amenity)
- TEMS (Energy management system in community): Energy accommodation; Cooperation with energy storage system; Cooperation with power and energy grid
- Energy storage and network (Electricity, heat, and hydrogen): Lithium battery; New rechargeable battery, thermal storage; Local energy network (LEN); Hydrogen fuel cell; Distributed energy storing

Transport

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Utility (person-km, ton-km)	1 time		1.5 times	2.1 times
Energy supplied from transformation sector* (overall)		20% reduction	50% reduction	70% reduction
Automobiles — Energy demand		30% reduction	60% reduction	80% reduction
Share of electricity and/or hydrogen	0%	1% or more	40%	100%
CO_2 intensity	160 g-CO_2/km (1 time)	100 g-CO_2/km (2/3 times)	50 g-CO_2/km (1/3 times)	0 g-CO_2/km → Consequentially, 1/10 or less is achieved.
Aircraft, ships, and trains — Energy demand		10-20% reduction	20-35% reduction	30-50% reduction

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

Energy Conservation

Automobiles

(Engine) → *Engine/Electric motor (hybrid system)* → *Electric motor Fuel cell/Battery*

Energy saving by vehicle weight reduction — *Super-light compact cars for regional use*

0 g-CO_2/km (Automobiles)

Liquid fuel

(Oil) → *Synthetic fuel (mixture)*; *Biomass fuel (mixture)*

Hydrogen storage — *Compressed hydrogen → liquid hydrogen, hydrogen storage material*

Hydrogen supply — *Batch transportation → Effective on-site production → pipeline transportation (limited region)*

Electric energy storage — *Battery and capacitor, etc.*

Electricity supply — *Cable-connected charge → Cable-less non-contact charge*

Aircraft / Ships / Trains — *Engine efficiency improvement*; *Energy saving by body weight reduction*; *Hybrid drive*; *Hydrogen drive, Superconducting motor drive*; *Ship enlargement, Low-speed operation*

Transport systems — *Energy saving by transport system cooperation*

Fuel switch

Transport

2000 — 2030 — 2050 — 2100

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

Automobile

ICE hybrid vehicle: Vehicle weight reduction, engine efficiency improvement, motor and electric power conversion efficiency improvement, system control improvement — (Shift to FC hybrid vehicles)
Fuel efficiency 1.5 times (2000) — *2 times* (2050)

Synthetic fuel: GTL — CTL

Biomass fuel: Ethanol or ETBE, BDF — BTL

FC hybrid vehicle: FC efficiency improvement, lightening hydrogen and body, and motor and electric power conversion efficiency improvements — Supplementary power supply with solar cells
Fuel efficiency 3 times — *4 times* — *5 times*

Hydrogen storage: Compression, liquefaction, and storage materials (inorganic, alloy, carbon, and organic)

Hydrogen supply: Batch transportation of by-product hydrogen — On-site fuel reforming — On-site water electrolysis — Pipeline transportation

Electric vehicle (for short distance): Weight reduction in batteries and vehicles, motor and electric power conversion efficiency improvement — Supplementary power supply with solar cells
Fuel efficiency 4 times — *5 times* — *6 times*

Electricity storage: Lithium battery — New lithium battery or other type batteries

Electric supply: (Manual cable-connected charging) — Cable-less automatic non-contact charging

Common technology

Weight reduction: Super-high-tension steel, high-tension aluminum, magnesium, titanium, compound material

Air-conditioning energy saving: Heat pump efficiency improvement, insulation, shading

Aircraft: Efficient airframe, jet engine efficiency improvement — *Fuel efficiency 2times*

Ships: Domestic: Weight reduction, electric drive, optimal arrangement of small propellers, superconducting motor. — Hydrogen fuel cell ship
Ocean: Ship enlargement, optimization of navigation speed, superconducting motor

Trains: Weight reduction, motor and electric power conversion efficiency improvement, aerial conductor/battery hybrid system
(non-electrification section) Diesel/battery hybrid train — Hydrogen FC/battery hybrid train

Industry

	2000	2030	2050	2100
(Production) X (Value of product)	1 time		1.5 times	2.1 times
Energy supplied from transformation sector*		25% reduction	40% reduction	70% reduction
1) Production energy intensity		20% reduction	30% reduction	50% reduction
2) Material/energy regeneration ratio		50%	60%	80%
3) Improvement of functionality such high-strength etc. (functionality / amount of material)	1 time	2 times	3 times	4 times

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

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

(Energy saving in process)

Development of innovative production process
Use of bio/nano catalyst etc

Zero-emission process

Cogeneration & cascade use of heat

Integration and cooperation of material and energy

Co-production (simultaneous production of material and energy)

(Fossil resource use) → *Biomass/hydrogen use*

Regeneration of material/energy *"use skillfully"*

Efficiency improvement of material regeneration process

Regeneration and utilization of material/energy in products

Regeneration & utilization of material/energy beyond sectors

Cross-boundary measures beyond sectors

Design technique for easy separation & sorting
Durability improvement

Improvement of functionality of material and parts

Material saving of products

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

Industry

2000 2030 2050 2100

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

Energy saving

- Iron & steel: Energy saving of conventional process, development of next-generation rolling mill technology; SCOPE-21, introduction of innovative sintering technology; Innovative steel production process
- Chemical: Energy saving production technology of petrochemical feedstock; System of sustainable carbon cycle chemistry (SC3)
- Cement: Energy conservation of conventional cement and eco-cement process; Zero emission cement process
- Common: Highly efficient technology for heat transfer, heat insulation and heat storage, high efficient industrial combined heat and power, cascade use of heat, power recovery system
- Production and utilization technologies of biomass (use of biotechnology etc.)
- Innovative production process (use of bio/nano-catalysts etc.)

Coproduction (Material & Energy)

- Common: Gasification technology, integration with GT; Industrial furnace combined with FC
- Chemical: Co-production of electricity, hydrogen, and chemicals
- Innovative heat storage technology (industrial heat transformer, chemical heat storage, etc.)
- Cement: Co-production of electricity and heat through gasification of wastes
- Paper & pulp: Use of biomass; IGCC using biomass as fuel; IGFC using biomass as fuel

Regeneration of material/energy *"use skillfully"*

Regeneration of material/energy

- Coupling operation among industries for efficient energy use; Material cascade management
- Use of non-conventional fossil fuels and low quality materials, gasification of industrial wastes and biomass
- Regenerative technologies of materials, byproducts, and energy
- Removal, separation and recovery, and recycling technology of trace elements

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

High performance materials/parts

- Iron & steel: Electrical steel; High-strength steel, innovative structural material, welding rod, etc.; Next-generation functional materials

Material saving of products

- Others: High functional and high tension plastics, ultra high strength and lightweight cement, highly functional and high quality paper
- Integration, modularizing, and downsizing of products

Transformation

	2000	2030	2050	2100
Total energy demand on the demand side (maximum case)	1 time		1.5 times	2.1 times
Share of electricity and/or hydrogen in final energy	1 time		2 times (Case A and C) 3 times (Case B)	4 times (Case A and B) 3 times (Case C)
CO_2 Intensity	370 g-CO_2/kWh (1 time)	270 g-CO_2/kWh (2/3 times)	120 g-CO_2/kWh (1/3 times)	0 g-CO_2/kWh *110 g-CO_2/kWh (1/3 times)* *In the case of fossil fuel use with CCS*

Reduction in fossil use

Efficiency improvement of fossil fuel use

Fuel switching and efficiency improvement

(oil) → *Natural gas*

(coal) → *Coal (clean coal technology + CO_2 capture and sequestration (CCS))*

0 t-CO_2/kWh

Nuclear energy use

Nuclear fuel cycle

Load following operation

Efficiency improvement

Renewable energy use

Solar — *Technology that can be set up in all places such as roads and dams*

Geothermal

Wind power — *Onshore* → *Offshore*

Biomass — *Wood and biomass (waste and unused biomass)* → *Fuel crops production*

Efficiency improvement

Installation simplification

Energy storage

Introduction of non-fossil energy

Transformation

2000 — 2030 — 2050 — 2100

Fossil fuel use + CO2 capture and sequestration technology

Gasification power generation and fuel processing technology
- IGCC 1700 ºC class GT
- IGCC 1500 ºC class GT
- Integrated coal gasification combined cycle power generation (IGCC)
- Chemical reproduction type IGFC
- Integrated coal gasification fuel cell combined cycle power generation (IGFC)
- Co-production technology with electric power and fuel
- Hydrogen production technology by integrated coal gasification
- *In the case of fossil fuel maximum use*
- *Power generation (conversion) efficiency*: *41% 46% 50% 55% 65%*

CO_2 capture and sequestration technology
- CO_2 capture technology from high-pressure gas

Nuclear energy technology

Efficiency improvement of light-water reactors
- Japanese next generation type light-water reactor
- The fourth generation light-water reactor (supercritical pressure reactor)
- *Power generation efficiency*: *34% 36% 43% 45%*

Fast Breeder Reactor, FBR (Nuclear fuel cycle)
- Miner-actinide nucleus conversion
- Nucleus conversion of long-life FP
- Upgrade (gas cooling FBR)
- Nuclear power hydrogen (high temperature steam electrolysis)
- *Power generation efficiency*: *42% 44% 48%*
- *In the case of nuclear energy maximum use (the nuclear fuel constraint)*

Renewable energy technology

Photovoltaic generation
- Crystal type, Thin film type, Dye-sensitized type etc., Super-highly effective new model
- *Power generation efficiency*: *13% 22% 30% 40%*
- Small scale distributed power generation → large area
- MW class large scale power generation
- Hydrogen production by solar light and heat use

Geothermal power generation
- Shallow geothermal system (Steam, binary power generation)
- Deep geothermal system
- Power generation utilizing hot dry rock

Wind power generation
- (Onshore) Scale-up and cost reduction
- (Offshore) Coast inshore (bottom supported type), Sea neighboring, Open ocean (floating body type)

Biomass use
- Direct combustion, Gasification reforming, Fuel crops production
- Methane/ethanol fermentation
- Biomass gasification fuel and hydrogen production
- Hydrogen production by large-scale biomass fermentation

Energy storage and transmission technology

Electricity and fuel storage (hydrogen and synthetic fuel, etc.)
- Lithium battery
- New rechargeable battery, SMES, flywheel
- Electrolytic hydrogen and hydrogen storage technology
- Mass energy storage
- Load leveling at moment, Load leveling every few days, Adjustment between seasons

Network technology
- Technology for distributed generation networking
- Short-term, best operation technology including electric power storage
- Pipeline transmission of hydrogen