Technology Roadmap for "Transition Finance" in Chemical Sector

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Ministry of Economy, Trade and Industry

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1. Premise｜Necessity of Technology Roadmap for Chemical Sector

- Technology Roadmap for "Transition Finance" (hereinafter, technology roadmap) selects sectors of high importance of transition and those with high emissions with no alternative measures of decarbonization available today (for technological and economic reasons).

- Chemical product is integrated as material for a wide range of products that support daily life and as the chemical industry is in the upstream of the supply chain, it serves as an industrial basis. Japanese chemical industry manufactures and supplies basic chemicals in a well-balanced manner by naphtha cracking and is the source of the competitiveness of all downstream industries such as the automobile and electrical and electronic industries.

- Further, the chemical industry is expected to be an industry that can effectively utilize CO2 as a resource and is an indispensable industry for the realization of a carbon neutral society.

- At the same time, the chemical industry emits large amounts of CO2 worldwide and is the largest CO2 emitting manufacturing industry behind iron and steel industry in Japan. Transition toward net zero in the chemical sector sector is essential. Transition requires effective use of existing facilities and related equipment, R&D/implementation of innovative technologies for low-carbonization and raising significant funds, as well as updating/introduction of energy-saving facilities are needed. In this regard, we examined domestic and overseas technologies and developed a pathway to 2050.

- Technology innovation and structural change of business for decarbonization will become advantages of companies. To attract world's ESG investments which grew to ¥3,500 trillion ($35 trillion : by GSIA) as of 2020, high-emitting industries are required to disclose their strategies with the understanding of investors' perspectives.

- In terms of contributing to increase the international competitiveness of Japanese chemical industry, the Technology Roadmap was developed through the discussion held with technology and finance experts and representatives of operators of chemical sector.

1. Premise | Objectives and Positioning of Technology Roadmap①

- The Technology Roadmap is designed to serve as a reference for the **chemical companies in Japan, when investigating measures against climate change using transition finance (Note)** based on "the Basic Guidelines on Climate Transition Finance" (Financial Services Agency, Ministry of Economy, Trade and Industry, Ministry of the Environment, May 2021).

- **It is intended to help** banks, securities companies and investors **to assess the eligibility of the fundraiser's decarbonization strategies and approaches.**

- **The final goal of the Technology Roadmap is to achieve 2050 carbon neutrality** and the Technology Roadmap provides envisions of low-carbonization/decarbonization technologies that are expected to be deployed by 2050 and when these technologies will be deployed based on information currently available.

- The Technology Roadmap is aligned with Nationally Determined Contribution (NDC) based on Paris Agreement*1, Green Growth Strategy*2, and R&D and Social Implementation Plan using Green Innovation Fund*3.

- Technologies to realize carbon neutrality in the chemical industry has not been established. Towards decarbonization in the chemical industry in Japan, public and private sector will collaborate to develop technologies that are not yet mature and indispensable toward 2050 carbon neutrality.

- On the other hand, the setting of intermediate targets is required in the basic guideline*4 P10, and more attention is being paid to the effectiveness of emission reductions in 2030, at the chemical industry, **without waiting for the establishment of decarbonization technology while referring to the technology roadmap,** meanwhile, looking ahead towards 2030 and 2040, **the transition period, it is essential to further advance efforts on energy saving/transition technologies in addition to R&D.**

*1 : https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Japan%20First/JAPAN_FIRST%20NDC%20(INTERIM-UPDATED%20SUBMISSION).pdf
*2 : https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf
*3 : https://www.meti.go.jp/press/2021/09/20210915001/20210915001-2.pdf
*4 : https://www.meti.go.jp/press/2021/05/20210507001/20210507001.html

(Note)" Transition finance refers to a financing means to promote long-term, strategic GHG emissions reduction initiatives that are taken by a company considering to tackle climate change for the achievement of a decarbonized society" - *Basic Guidelines*

1. Premise | Objectives and Positioning of Technology Roadmap②

- Transition finance includes not only the investment on facilities and R&D toward low-carbonization/decarbonization within the company but also for cost of dismantlement/removal of existing facilities and response to other environment or social impact (such as land contamination associated with withdrawal from business, decommissioning of furnaces etc. and impact on employment), efforts/activities that contribute to the transition of other industries arising from activities to reduce emissions.

- In the chemical sectors, **products contribute to decarbonization (eco products, noted in P7) for other industries can be subject to transition finance.** Moreover, Basic Guidelines on Climate Transition Finance (noted in P8) states "Transition finance is **available for not only entities with strategies and plans for reducing emissions associated with their corporate economic activities, but also entities that plan to take initiatives that enable others to implement transition strategies through their own products and services".**

- These are important elements for the decarbonization of whole society and economy. At the same time, as these efforts/activities are extremely broad, the Technology Roadmap will cover the "technologies" for low-carbonization/decarbonization mainly in the chemical sector.

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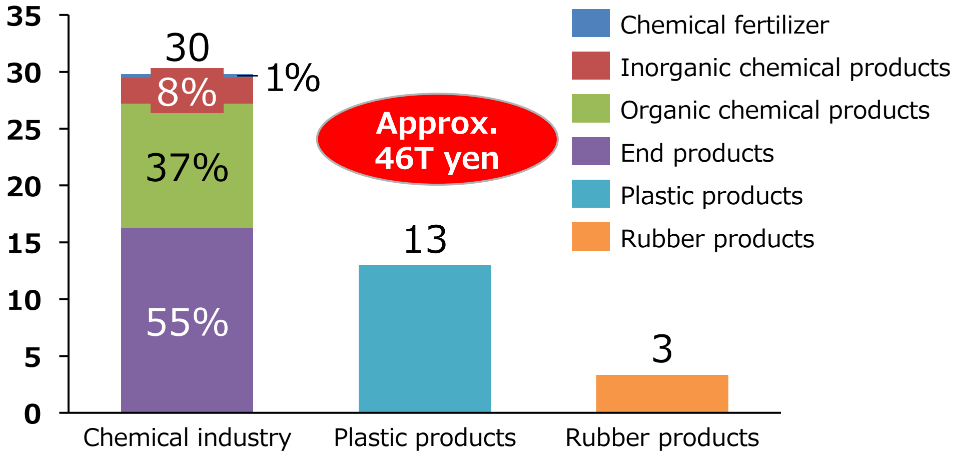
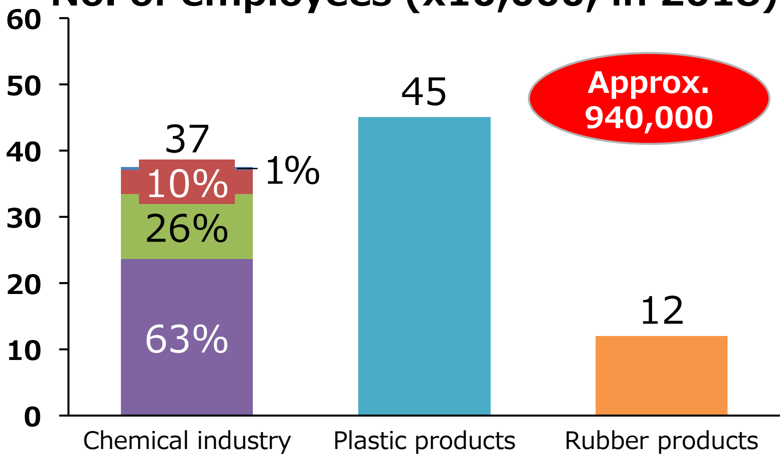
2. Overview of Chemical Industry | Scale of Production of the Chemical Industry

- **Gross domestic shipments total is about 46 trillion yen. There are about 940,000 employees in the industry.**
- Raw materials are used for chemical reactions and other methods **to produce part materials and end products for all sectors**.

Shipment value (¥T, in 2018)



No. of employees (x10,000, in 2018)



Source: Japan Chemical Industry Association website

Chemical industry broadly defined

Upstream: Basic petrochemical products, industrial gases, soda, etc.

Mid-stream: Various intermediate chemicals, derivatives etc.

Downstream: Manufacture of oil and fat processed products, soap, synthetic detergents, pharmaceuticals, plastics, and synthetic rubber; other chemical industries

Supporting end products by supplying materials to the automotive parts industry and electric and electronics industry

- Automobiles
- Aircraft
- Construction & civil engineering
- Electrical & electronics
- Energy
- Cosmetics & pharmaceuticals
- Printing & publishing
- General consumer goods

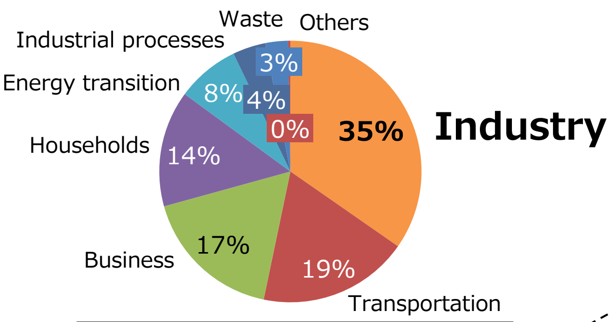
* Materials for solar cells, next-generation automobiles etc. also play a role in contributing to carbon neutrality in other sectors.

2. Overview of Chemical Industry | CO2 Emissions

- The **industrial sector accounted for 35% of CO2 emissions** in Japan in FY2019.
- **About 15% of this is accounted for by the chemical industry**, where **reducing CO2 emissions is an urgent issue**.
- **In the chemical industry, in addition to energy emissions**, **there are also potential emissions from the use of raw materials** such as naphtha.

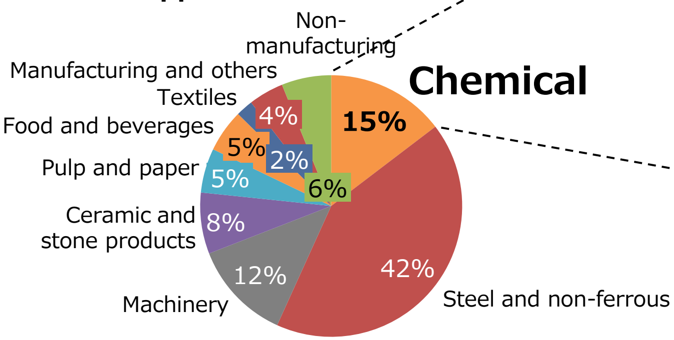
Japan as a whole (FY2019)

approx. 1B tons of CO2



Industrial sector (FY2019)

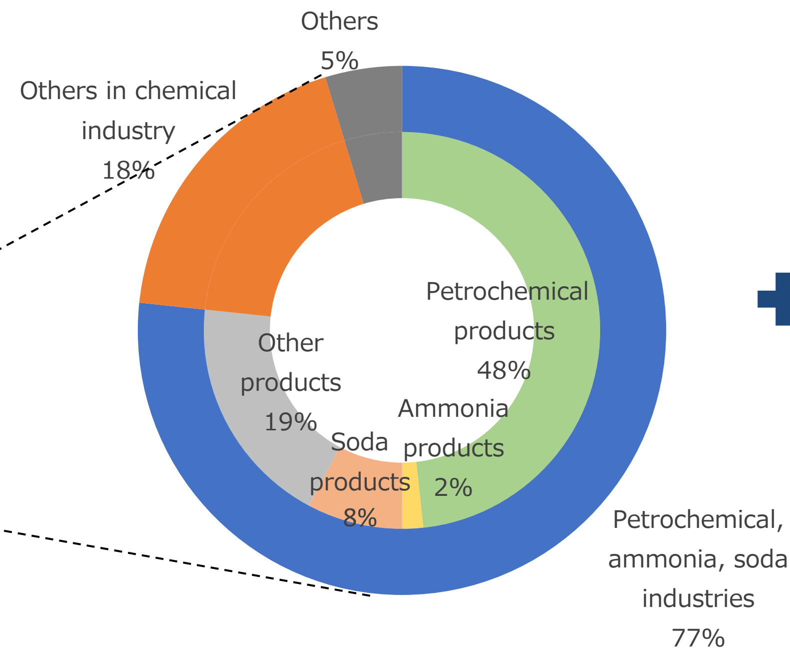
approx. 380M tons of CO2



Source: National Institute for Environmental Studies "Japanese Greenhouse Gas Emissions Data" (FY2019 confirmed figures)

Breakdown of emissions from chemical industry energy sources (FY2019)

approx. 56M tons of CO2



Source: METI, "Comprehensive Energy Statistics" (FY2019 confirmed figures)

Plastic & rubber products, etc.

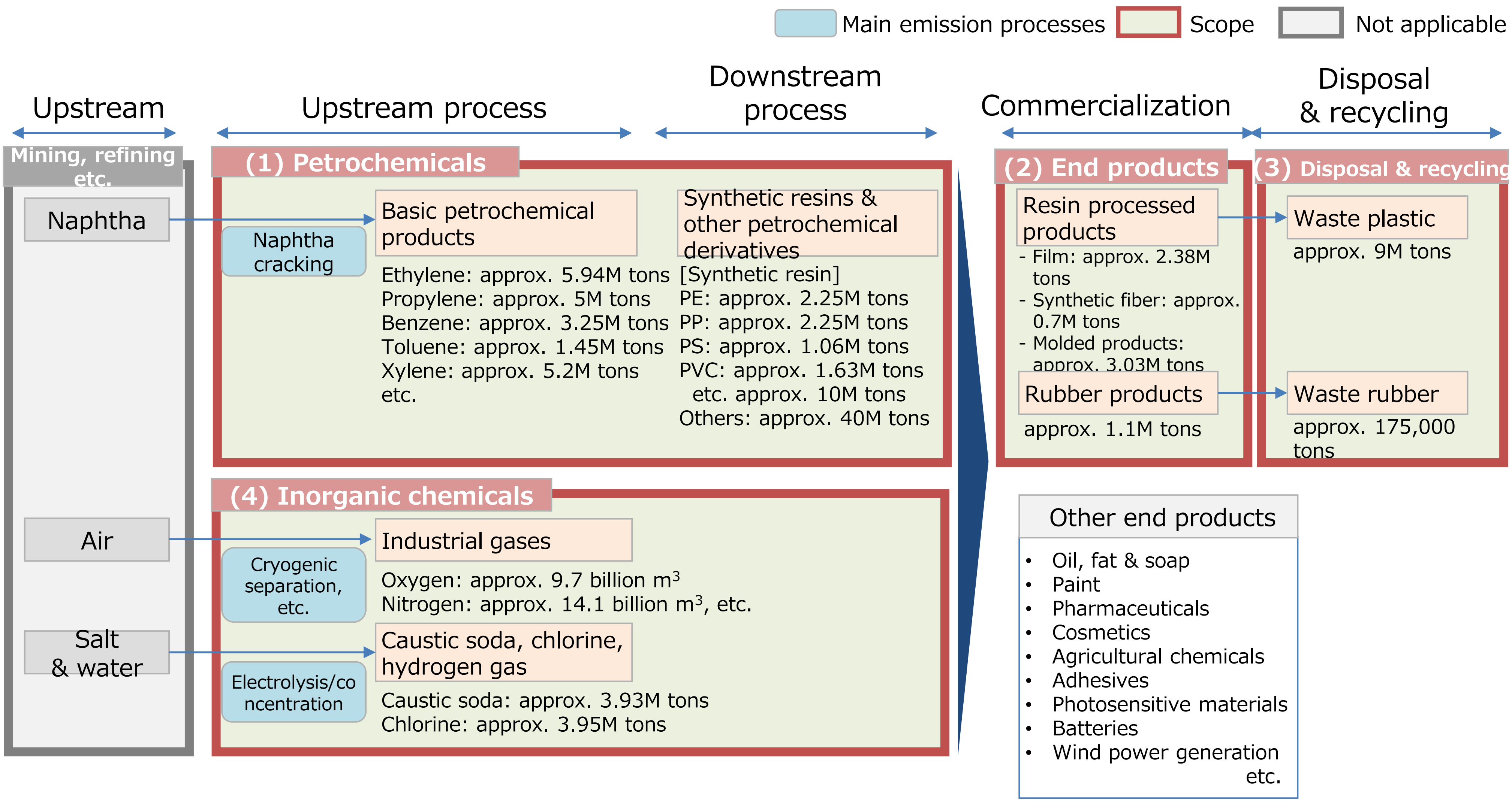
- The manufacture of plastic products and rubber products is not included in the chemical industry according to the standard industrial classification but may be included in a broader sense.
- The plastic and rubber product manufacturing industry emits **about 10 million tons** of CO2 in total.

Non-energy emissions

- **About 43 million kl of naphtha is used annually** as a raw material for petrochemicals.
- This is a **potential emission** because it is only emitted when the used products are incinerated.
- For example, **about 16 million tons** of CO2 are emitted annually from plastic incineration.

2. Overview of Chemical Industry | Scope of the Technology Roadmap for Chemical Sector

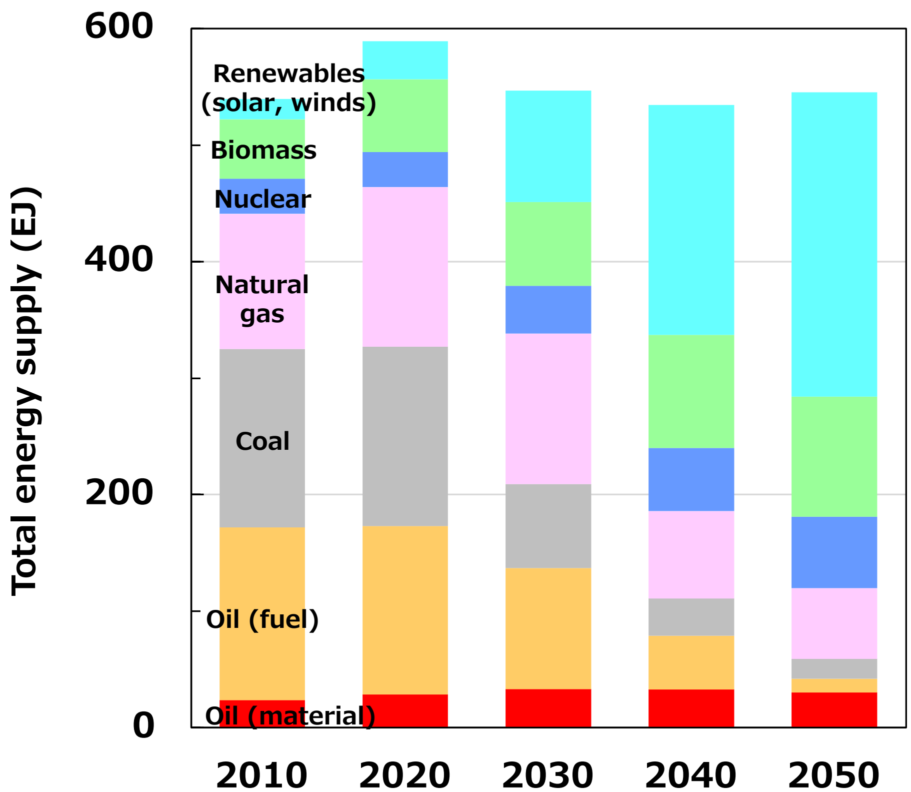
- The Technology Roadmap **covers a range of processes, from upstream processes** such as naphtha cracking **to derivatives, end products, disposal and recycling**.

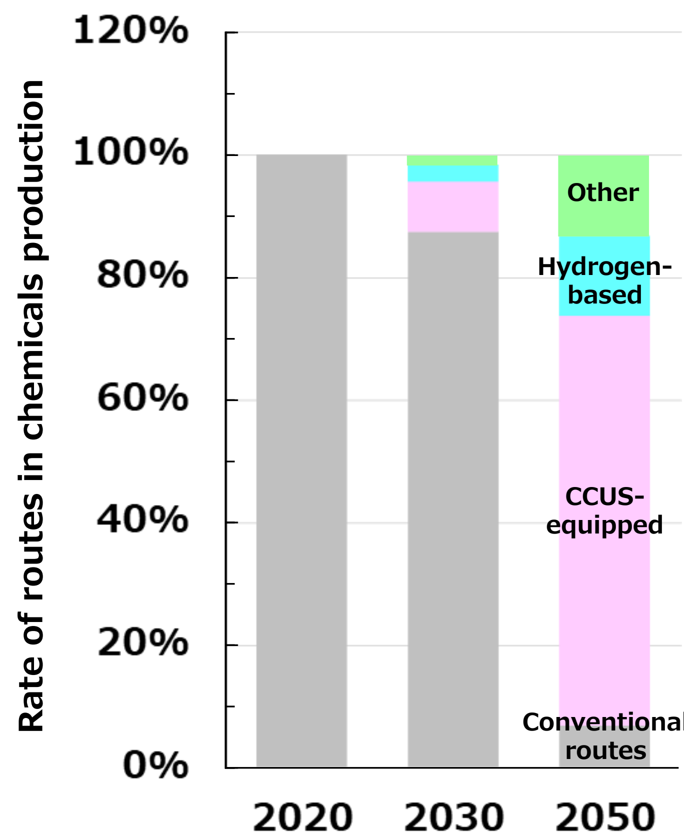


Source: METI, "Current Survey of Production" and various public information

- In petrochemicals, **the use of heat in manufacturing processes such as naphtha cracking is significant, and there are also CO2 emissions from the use of raw materials, so measures are needed to achieve CN in both fuel and raw materials.**
- In **IEA's Net Zero by 2050 scenario**, demand for petroleum, which is a raw material for plastics, will remain constant, and one form the chemical industry's production structure could take toward net zero by 2050 is a **shift of more than 90% to innovative methods** such as CCUS and hydrogen.

Global energy demand forecast





Source: IEA, "Net Zero by 2050"

2. Overview of Chemical Industry | (1) Petrochemicals ②Characteristics of Petrochemical Industry in Japan

- Naphtha cracking in Japan has the **advantage** of being **able to produce a good balance** between C2 and C8.
- Meanwhile, although it does not necessarily have a price advantage over CTO or ethane cracking, it maintains quality advantages in basic chemicals to derivatives due to Japanese technology.

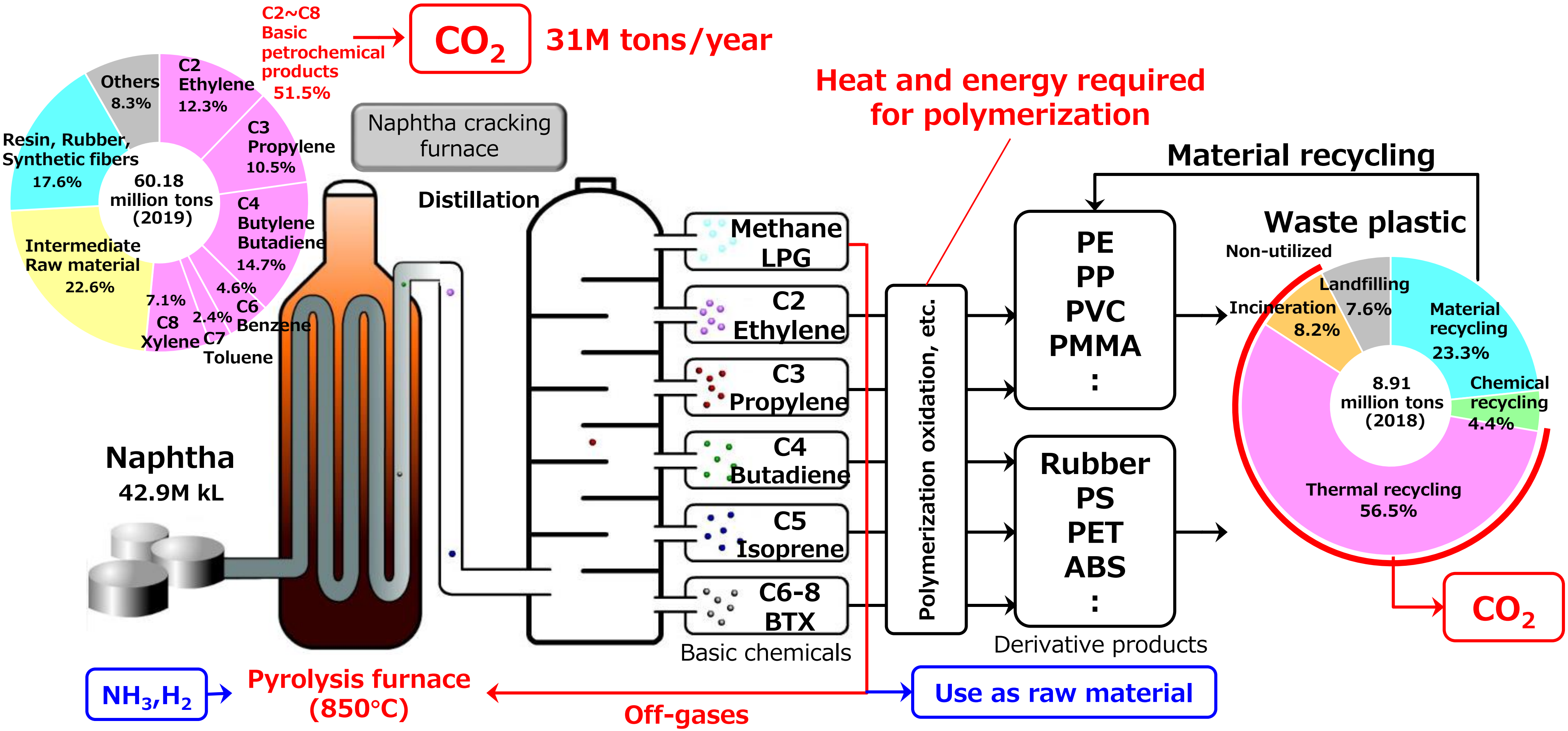
	Naphtha cracking (Japan)	CTO (China)	Ethane cracking (USA)
Manufacturing method	Naphtha → C2 Ethylene Naphtha → C3 Propylene Naphtha → C4 Butadiene Naphtha → C5 Isoprene Naphtha → C6-8 BTX	Coal → Syngas ↓ Methanol Syngas ↓ Methanol → C2 Ethylene Syngas ↓ Methanol → C3 Propylene Syngas ↓ Methanol → C4 Butadiene BTX is manufactured from cracked oil, etc.	Shale gas → Methane 80～90% Shale gas → Ethane 5～15% Ethane 5～15% → C2 Ethylene Ethane 5～15% → C3 Propylene Shortage of C4 or higher: C4 Butadiene, C5 Isoprene, C6-8 BTX
Strength	• **In a naphtha cracking furnace, a good balance of C2-5 olefin and C6-8 BTX can be obtained, enabling a wide range of manufacturing from plastic raw materials to rubber raw materials**	• **Inexpensive and abundant coal can be used as a raw material** • **Technological development of methanol to olefin (MTO) is underway**	• **Ethylene produced from abundant shale gas is inexpensive** • **Advantages for mass production of ethylene and propylene, the raw materials for plastics**
Weakness	• **Naphtha cracking furnaces have operated for many years, and aging countermeasures are an issue**	• **The CO2 emission coefficient of CTO is five times larger than that of the conventional naphtha method** • **Synthetic methanol is expensive**	• **It is difficult to obtain olefins of C4 or higher, which could lead to a shortage of raw materials for rubber, etc.**

* China is also engaged in production of basic chemicals from aromatics through COTC (Crude Oil To Chemicals).

Source: Prepared by the Materials Section using the Green Innovation Fund Social Implementation Plan, etc.

2. Overview of Chemical Industry | (1) Petrochemicals ③Manufacturing Process Details

- In naphtha cracking furnaces, **off-gases such as methane are obtained** in addition to basic chemicals and **used as a heat source to raise the temperature to 850°C**. Since these **off-gases are a source of CO2 emissions**, **it is necessary to make the heat source carbon neutral** and **to use the off-gases as raw materials**.

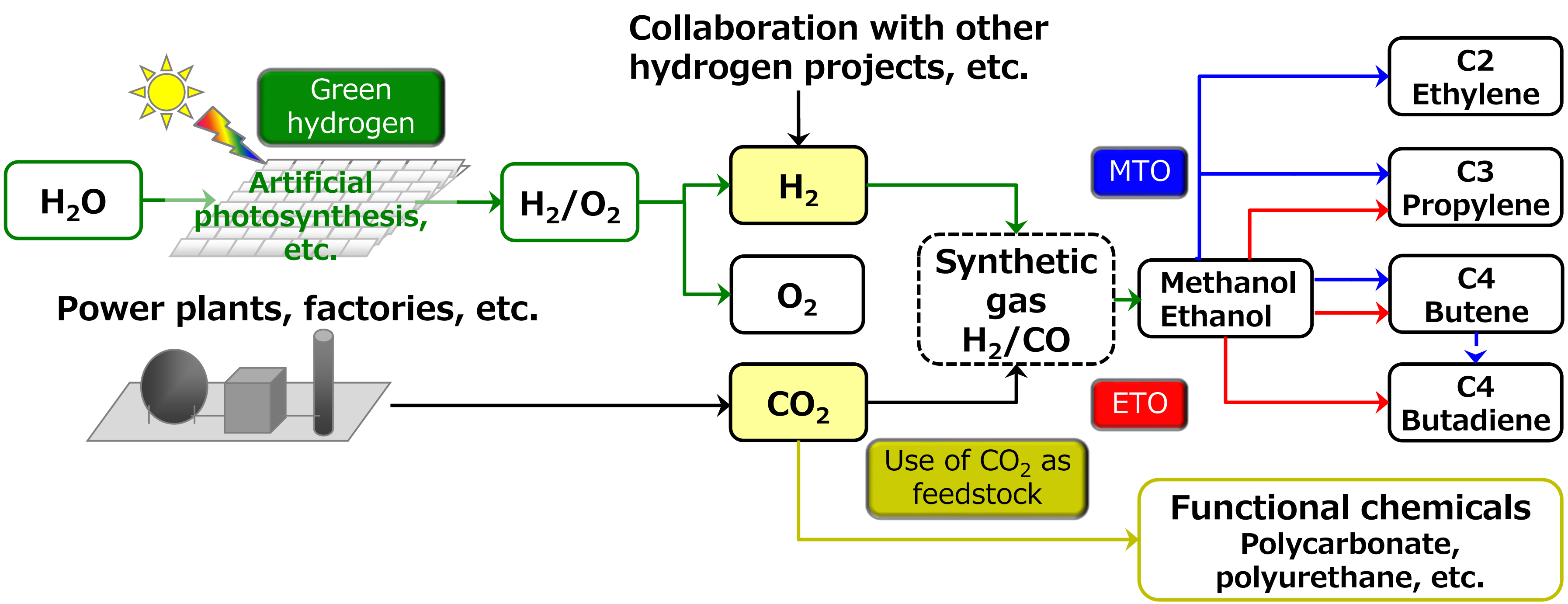


Source: (Left) Calculated by multiplying the domestic production volume in the "Chemical Handbook 2020" by the CO_2 emission intensity in "IDEA v.2.3" and subtracting the CO_2 emissions from oil refining
(Right) Japan Plastics Recycling Association, "Basic Knowledge of Plastic Recycling 2020." Calculated from general waste plastic emissions factor 2.77 kg-CO2/kg-waste plastic

④Movement Toward Raw Material Switching

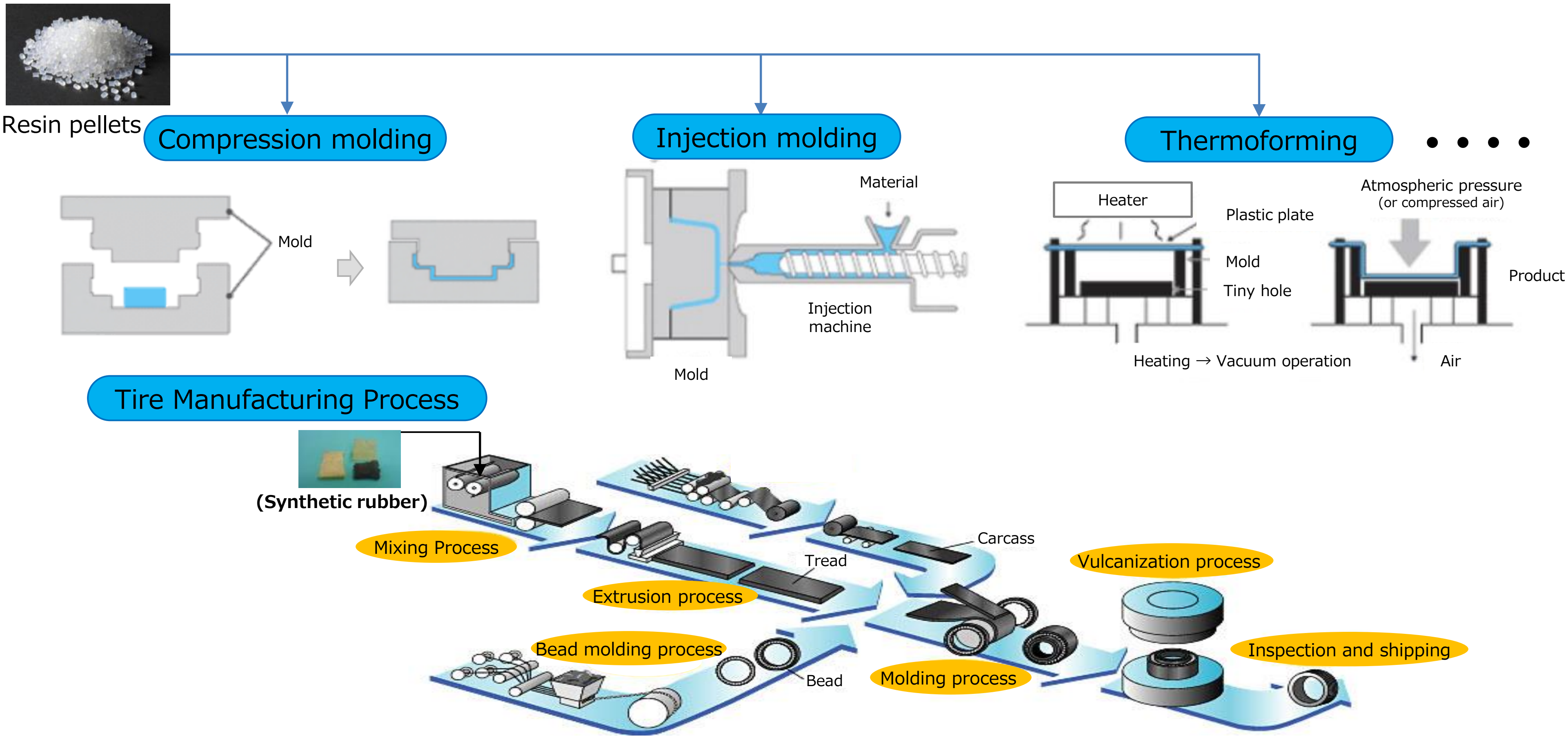
- While upgrading naphtha cracking furnaces in this way, **it is also necessary to consider CO2 as a resource and work on switching raw materials** for CN by 2050.
- Promote raw material switching by improving the yield of **processes (MTO, ETO) that produce ethylene and propylene through chemical raw materials such as methanol and ethanol** from **hydrogen production by artificial photosynthesis**, a technology being developed only by Japanese companies.

Image of raw material switching



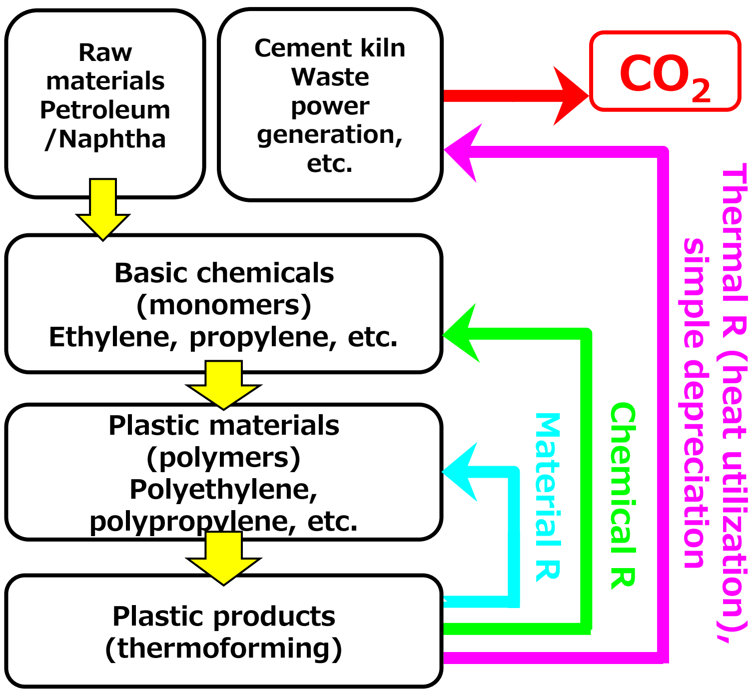
Source: Prepared from the Green Innovation Fund Social Implementation Plan

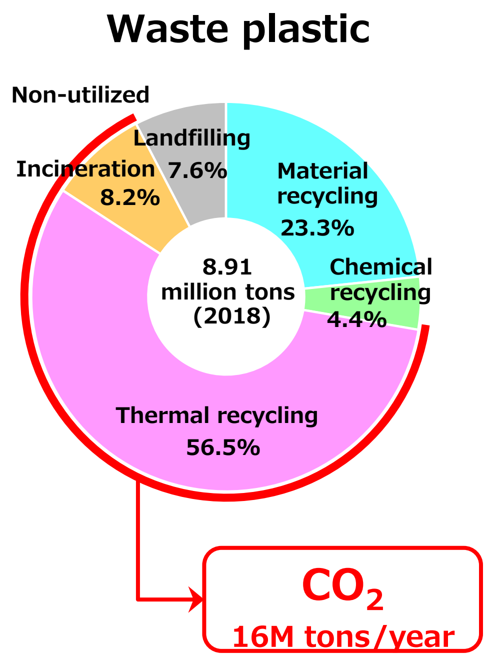
- Using resins, etc. produced in the industrial complex, **end products such as plastic and rubber products are manufactured by heating and other processes using various molding machines**.
- **Energy is used mainly in the form of electricity and steam during processing**. For CN by 2050, we need to decarbonize by ①**improving efficiency thorough energy saving** and ② **procuring renewable energy**.

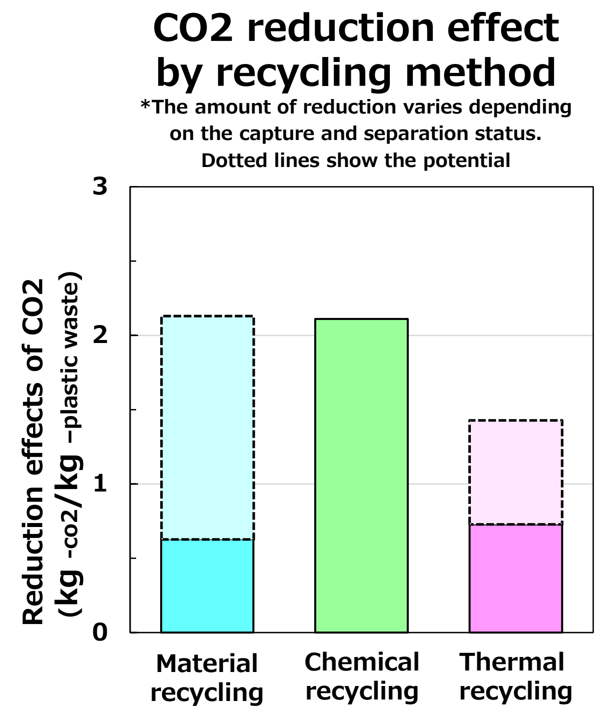


Source: Prepared from the website of the Japan Plastics Industry Federation, etc.

- Of the 8.91 million tons of **waste plastic** generated annually, **about 84% is recycled,** of which **about 60%** is used as a heat source for power generation through waste incineration (**thermal recycling**).
- **In the end, however, 16 million tons of CO_2 are emitted per year, including simple incineration**, so it is **important to recycle resources** through chemical recycling etc. Production of raw materials derived from crude oil will decrease due to the establishment of chemical recycling technologies, which will also help to reduce emissions in the chemical industry as a whole.







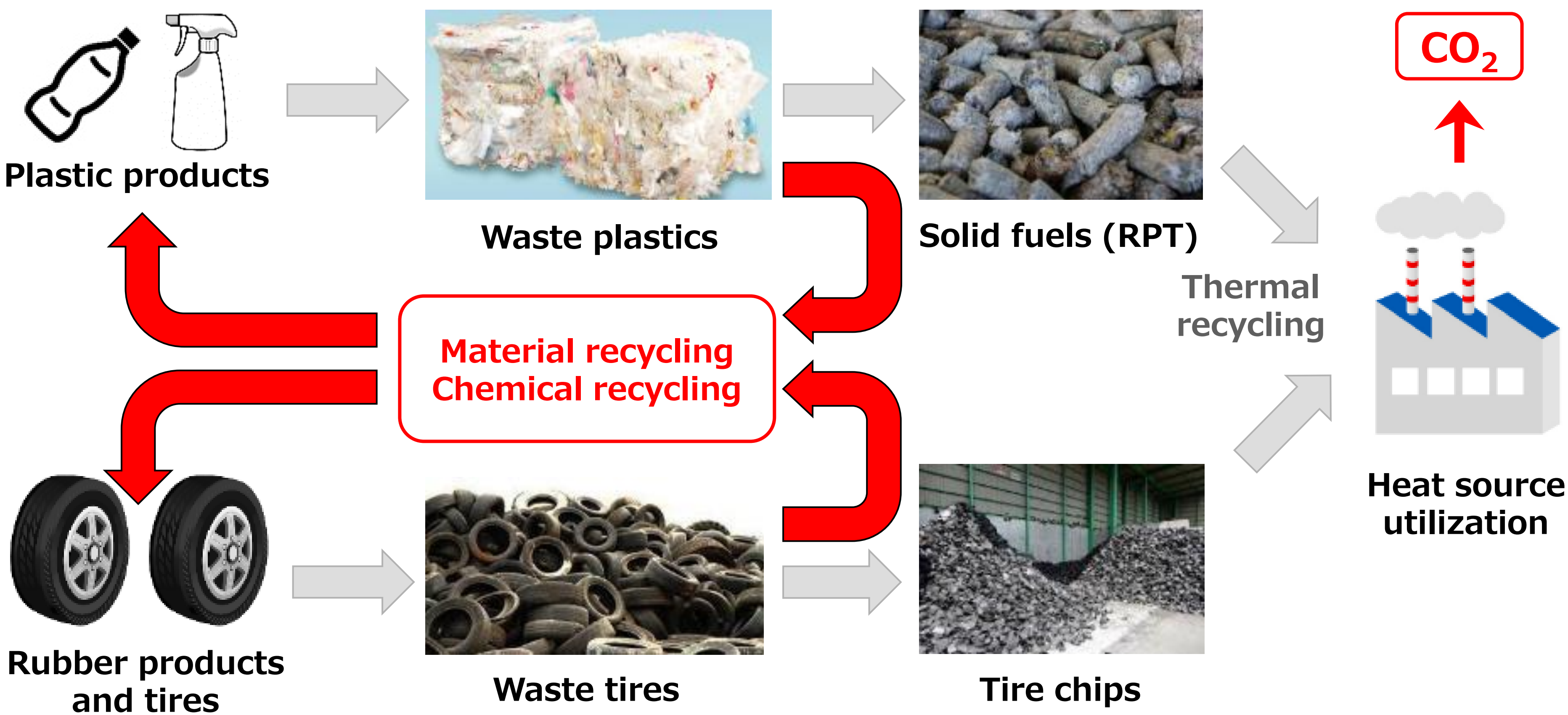
Source: Excerpt from Green Innovation Fund Social Implementation Plan materials and Plastic Resource Utilization Association materials

Source: Environmental Impact Assessment of Plastic Packaging Recycling Methods and Energy Recovery (LCA) https://www.nikkakyo.org/system/files/Summary_JaIME LCA report.pdf

 ②Direction for Decarbonization

- Reduce the use of energy to incinerate waste plastics and **expand circulation-type chemical recycling (CR) and material recycling (MR)** to recirculate them as resources. In doing so, **we need to work on low carbonization**, such as by developing high-yield catalysts to reduce CO2 emissions during production to about half those of conventional methods.

Transition image for waste plastic and waste rubber recycling



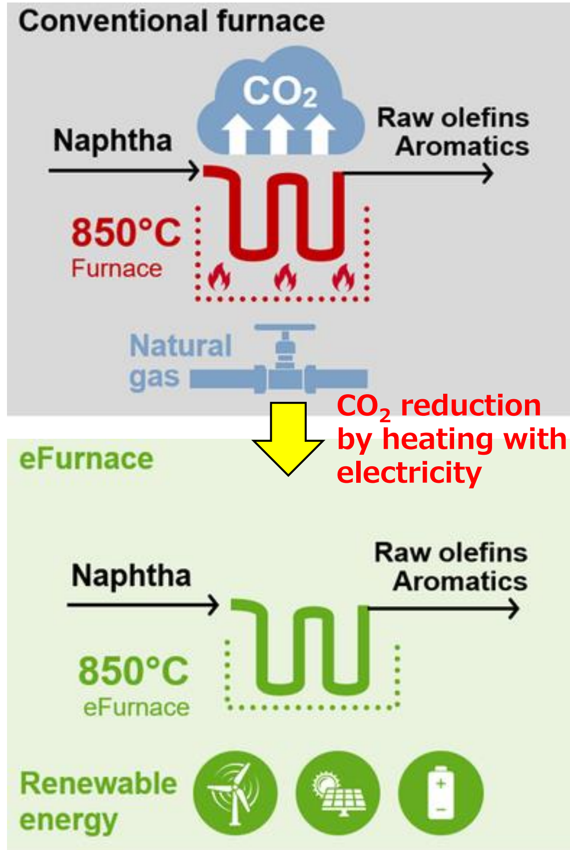
Source: Prepared from various public information, etc.

Reference: Trend of World's Major Chemical Manufacturers

- The world's major chemical manufacturers are also making progress toward achieving CN.
- In Europe and the USA, there are studies into reducing CO_2 **by realizing electric heating through the use of inexpensive renewable electricity as a heat source for naphtha cracking furnaces and by using catalysts, etc**.

Company name	Examples of Initiatives to Achieve CN
BASF (Germany)	➢ Production of basic chemicals using electrically heated steam cracker ➢ CO_2 free hydrogen production by water electrolysis method and methane pyrolysis method ➢ Investment in wind power projects ➢ CCS
DOW Chemical (USA)	➢ Production of basic chemicals using fluidized catalytic dehydrogenation cracker ➢ Promoting the use of renewable energy
LG Chemical (Korea)	➢ Introduction of 100% renewable energy ➢ CCUS
INEOS (UK)	➢ Development of clean hydrogen fuel ➢ Switching of hydrocarbon raw materials to bio raw materials
SINOPEC (China)	➢ Clean energy development (Natural gas, biomass, etc.) ➢ CCUS (methane gas capture)

Naphtha cracking furnace at BASF, Germany

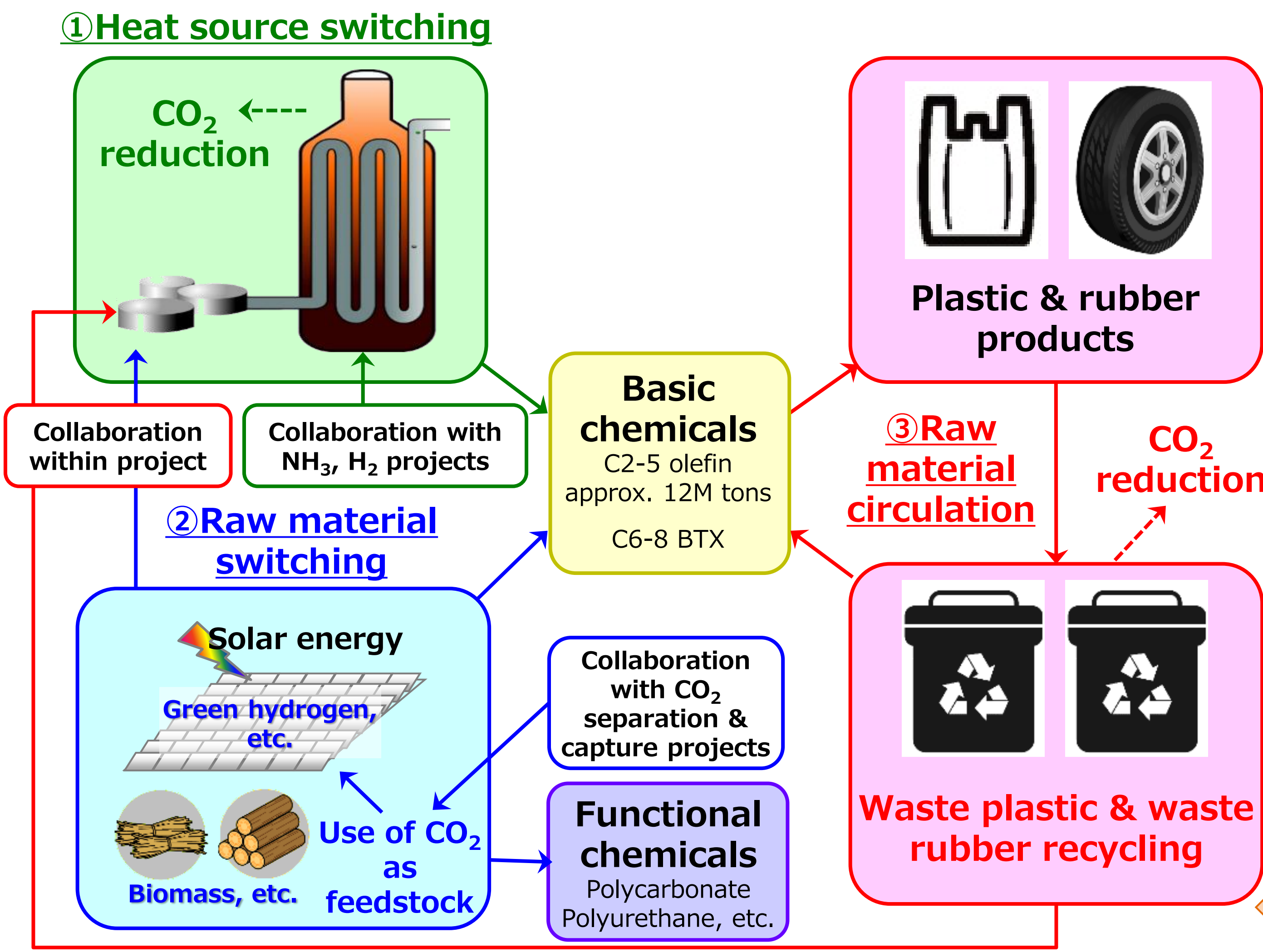


From BASF website

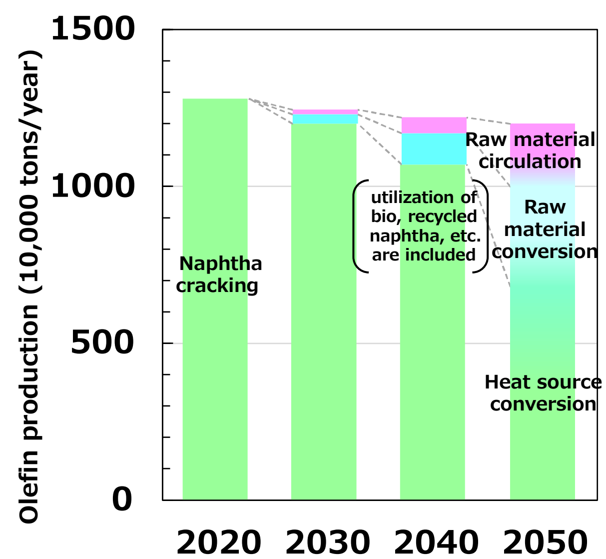
Source: Prepared by the Materials Section from press releases, etc. issued by various companies

Direction for Decarbonization in Japan

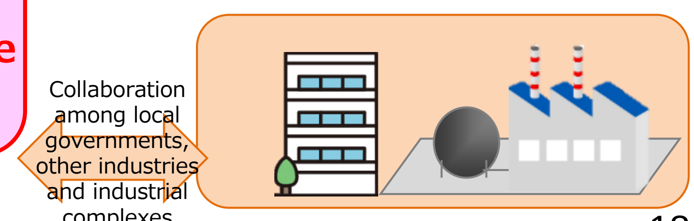
- The petrochemical industry aims to become carbon neutral in Japan by ①**switching heat sources**, ②**switching raw materials**, and ③**circulating raw materials**. In doing so, **cooperation with local governments and other industries is essential from the viewpoint of promoting a circular economy**, and utilization of CCUS for the collection of exhaust gas, etc. is also necessary.



Basic chemicals production Transition image in Japan



* Although the rates in the above chart will vary depending on things such as the production status of petroleum products and technological progress, our goal is to create a system that can respond to multiple factors, including balancing the production of basic chemicals with carbon neutrality, and overseas expansion.



Source: Prepared from the Green Innovation Fund Social Implementation Plan

2. Overview of Chemical Industry | (4-1) Caustic Soda ①Manufacturing Process

- Using salt as a raw material, **chemicals for raw and auxiliary materials and reactants for a wide range of industry sectors are manufactured**. Electricity is added to salt water to produce caustic soda, chlorine and hydrogen by electrolysis.

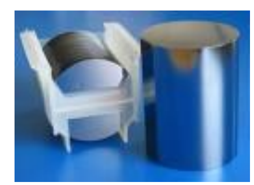
- The products have an extremely high energy cost as a percentage of their added value **(about 50% of manufacturing costs are for electricity). For this reason, the business model is highly susceptible to energy taxation.**

- Caustic soda is used as a neutralizer in the production of cathode materials (material precursors) for lithium-ion batteries such as those in EV vehicles. **In future, we expect increased demand for caustic soda as a neutralizer for cathode material manufacturers during the phase of global EV market activation and full-scale penetration**.

Industrial salt > Dissolution > Electrolysis > Various manufacturing processes > End products

2NaCl (Salt) + **$2H_2O$ (Water)** ⇨ **2NaOH (Caustic soda)** / **Cl2 (chlorine)** / **H2 (hydrogen)** ⇨

In-vehicle lithium-ion batteries, EVs



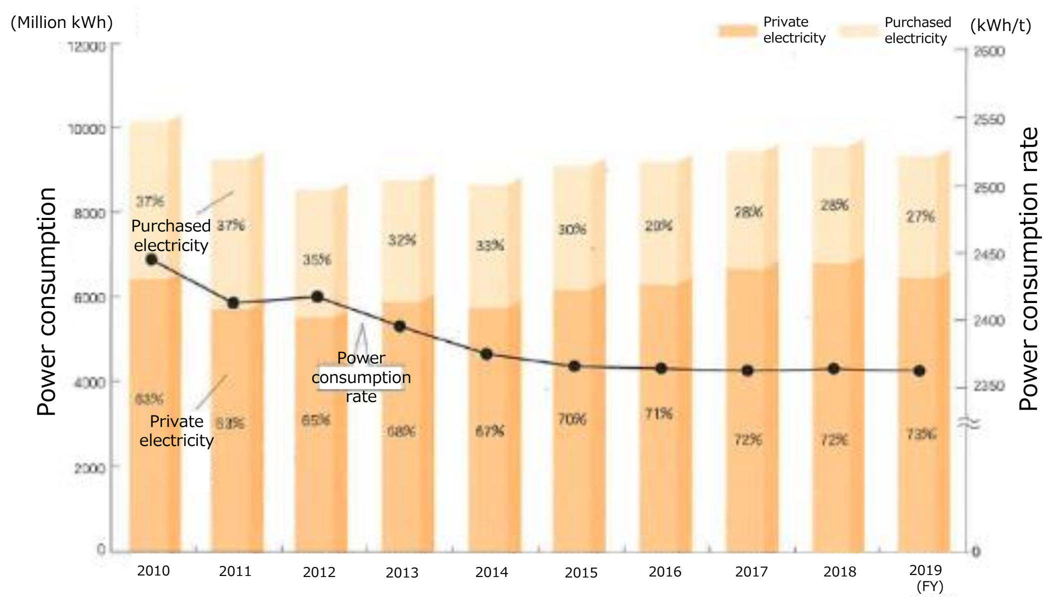
Polysilicon (For solar cells, semiconductors, etc.)

etc.

 ②**Characteristics of Soda Industry in Japan**

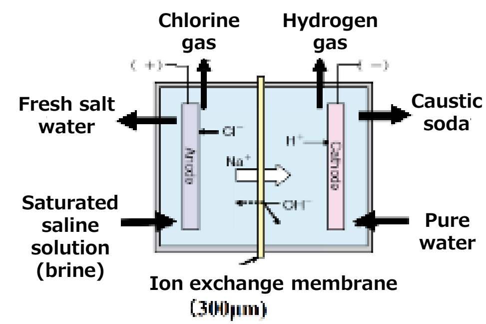
- In the soda industry, **energy costs are directly linked to corporate competitiveness**, and so **the consumption of electricity from in-house power generation accounts for more than 70% of the total electricity used, far exceeding the 20% average for the whole manufacturing industry**.
- In order to reduce this power consumption, **an ion-exchange membrane method have been introduced** which consumes less energy, and **by promoting research and development, we have improved our unit energy consumption year by year** to a world-class level. Licensing has also contributed to the reduction of CO_2 emissions in Japan and overseas.
- We are also **100% dependent on imports of raw salt (from Mexico, Australia, and India)**.

<Trends in electricity consumption, purchased/private electricity, and the power consumption rate>



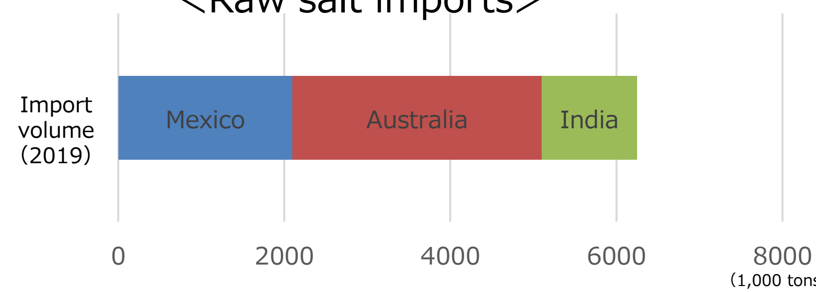
Source: Soda Industry Guidebook 2020 (Japan Soda Industry Association)

<Electrolyzer (ion exchange membrane process)>



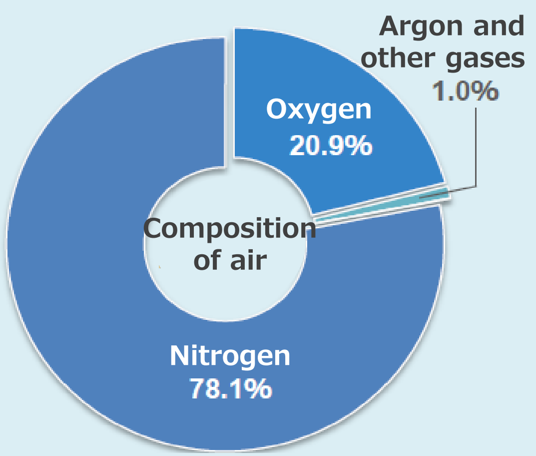
New electrolytic cell for caustic soda

<Raw salt imports>



Source: Prepared from Soda Industry Guidebook 2020 (Japan Soda Industry Association)

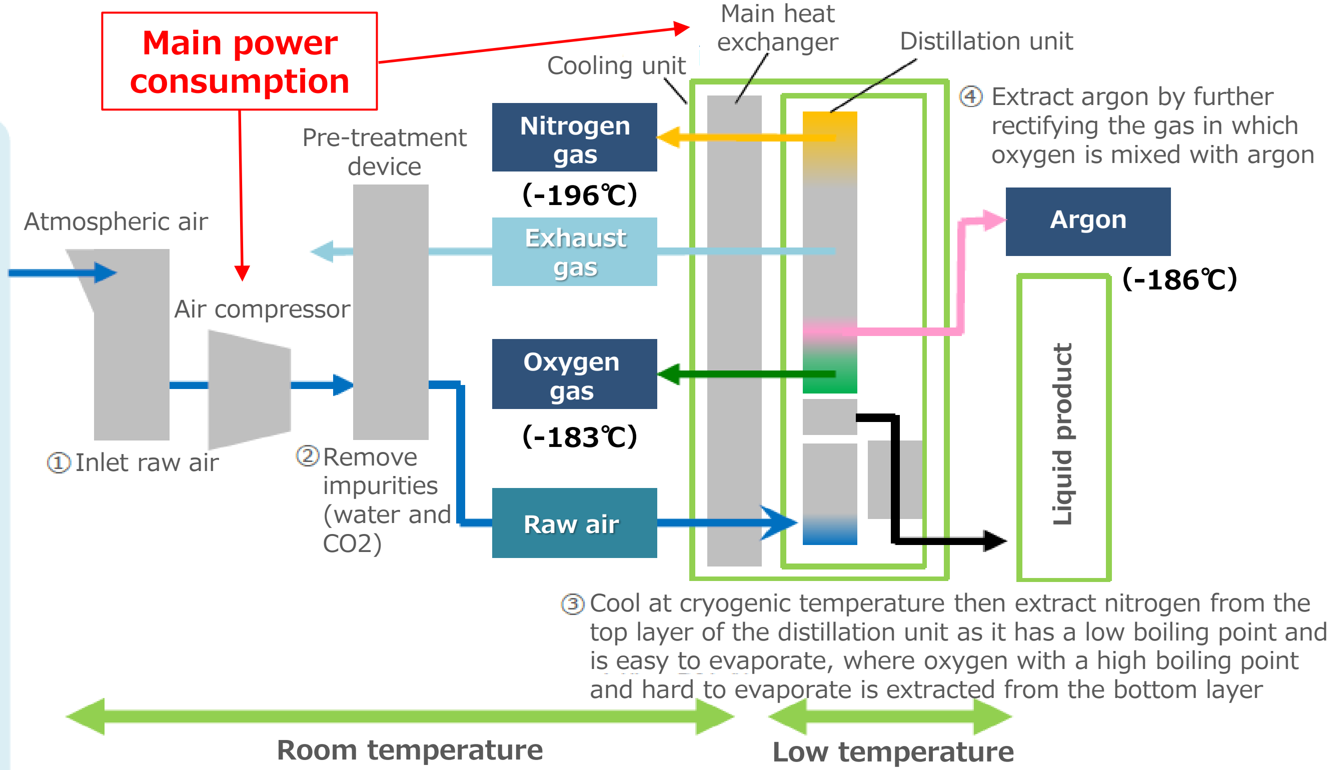
- Industrial gases are **manufacturing infrastructure** supporting iron and steel, chemicals, electronics, etc.
- The main industrial gases are ①oxygen, nitrogen, and argon obtained by separating air, ②hydrogen and carbon dioxide obtained as byproducts of petroleum and chemical plants, ③helium obtained as a byproduct of natural gas, etc.
- The mainstream method of producing oxygen, nitrogen, and argon is cryogenic separation, which uses the different boiling points of the components of air to separate and extract them. **Compression and heat exchange consume electricity, which therefore accounts for the majority of the production cost.**



<The boiling points of gases>

Oxygen	-183℃
Nitrogen	-196℃
Argon	-186℃

<Production of oxygen, nitrogen, and argon by cryogenic separation>



Source: Prepared from materials published on the website of Nippon Sanso Holdings Corp. and others

2. Overview of Chemical Industry | (4-2) Industrial Gases ②Characteristics of Industrial Gases in Japan

- Industrial gases are produced by various manufacturing methods, and are **supplied on-site, in bulk, or in packages depending on the supply volume**, to support people's lives and manufacturing in Japan.
- In order to reduce CO2 emissions from the supply of these gases, we control CO2 emissions along the entire supply chain **by introducing planned deliveries and other means of shortening the distance traveled during delivery**.

Raw materials	Manufacturing method	Type
Air Composition of air in atmosphere - Nitrogen 78% - Oxygen 21% - Argon and others 1%	Air separation	Nitrogen Oxygen Argon
By-product gases from petroleum & chemical plants	Refined	Carbonic acid Hydrogen
Natural gas	Refined → Imported	Helium

Supplied by pipeline (on-site supply)

Nitrogen, Oxygen

Major suppliers: Steel, petrochemicals, oil refining

Supplied by tanker truck (bulk supply)

Nitrogen, Oxygen, Argon, Carbonic acid, Hydrogen, Helium

Major suppliers: Automobiles, ships, glass, paper, construction machinery, food, semiconductors

Streamlining during transportation by planned deliveries, etc.

Supplied by cylinder (packaged supply)

Nitrogen, Oxygen, Argon, Carbonic acid, Hydrogen, Helium

Major suppliers: At-home medical care, construction, advanced medical care, R&D

2. Overview of Chemical Industry | (4) Industrial Gases and Caustic Soda
Direction for Decarbonization

- Both are **power-hungry industries**, consuming large amounts of electricity in their manufacturing processes. Therefore, in order to achieve carbon neutrality by 2050, we need ① **thorough energy conservation**, ②**non-fossil fuels for procured power sources and fuel switching for in-house power generation**, and ③**reduced CO2 emissions throughout the supply chain, including logistics**.

<Direction for Decarbonization>

① **Full-scale introduction of energy-saving technologies**

② **De- or low-carbonization through non-fossil fuels for procured power sources and fuel switching for in-house power generation**

③ **Reduction of CO2 emissions throughout supply chain, including logistics**

<Trend toward CN among major Japanese manufacturers>

- **Caustic soda**
  - Reduction of CO2 through the development and licensing of further energy-saving technologies for electrolytic cells.
  - Reduction of energy-derived CO2 emissions by switching from coal to biomass, etc. for in-house power generation facilities.

- **Industrial gases**
  - Reduction of electricity consumption through introduction of energy-saving air separation equipment, etc.
  - Realization of “stable supply,” “energy saving,” and “reduced CO2 emissions” through regional liquefied gas plants
  - Reduction of CO2 emissions along the entire supply chain by streamlining logistics

Source: Prepared by the Materials Section from various public information

2. Overview of Chemical Industry | (5) Summary of Major Emission Sources and Methods for Decarbonization

Sector		Main emission sources	Methods for decarbonization
Petrochemicals	Basic products	• Heat and energy utilization during naphtha pyrolysis	• Utilization of energy-saving technologies, etc. • Heat source decarbonization of naphtha cracking furnaces • Switching of raw materials using artificial photosynthesis, etc.
	Derivative products	• Use of heat and energy from polymerization of basic chemical products, etc.	• Fuel switching and electrification during heat and energy use
	End products	• Use of heat and energy during product molding	• Utilization of energy-saving technologies, etc. • Fuel switching and electrification during heat and energy use
	Recycling	• Emissions from combustion of waste plastics, etc. • Energy consumption during recycling	• Expansion of chemical and material recycling • Improvement in efficiency of chemical material recycling, development of low-carbon processes
Inorganic chemicals (Caustic soda, industrial gases)		• Use of heat and energy by electrolysis, etc. in the production of caustic soda and industrial gases	• Utilization of energy-saving technologies, etc. • Fuel switching and electrification during heat and energy use

 Reference: Voluntary Efforts in Chemical Industry

- **In May this year, the Japan Chemical Industry Association announced the stance of the chemical industry on carbon neutrality**. **Major chemical manufacturers** also **declared** this year **that they will be carbon neutral by 2050**.

Chemical industry's stance on carbon neutrality (Japan Chemical Industry Association, R 3.5) (Excerpts)

1. Elements of chemical industry's contribution to carbon neutrality (CN) - In May 2017, the Japan Chemical Industry Association (JCIA) formulated and published its "Vision for a Chemical Industry that Provides Solutions to the Problems of Global Warming." In response to the Japanese government's declaration of carbon neutrality by 2050, the chemical industry, as a solution provider, will promote and accelerate the creation of innovations that solve global issues and contribute to the growth of a sustainable society by realizing the potential of chemical.

2. Basic outline of the chemical industry's approach to CN

(1) Mechanisms of generating GHG emissions in the chemical industry and efforts to reduce them

① Sources of GHG emissions in production activities

② Efforts to reduce GHG emissions in production activities

- Process streamlining (yield improvement)
- Introduction of innovative technologies (Energy saving, BAT, DX, electrification, etc.)
- Fuel switching at in-house power generation facilities: fuel reduction, recycling, decarbonization
- Switching to purchased electricity (progress toward zero-emission electricity)
- Use of renewable energy
- Development of carbon recycling technologies
- Separation, capture and utilization of CO_2 (CCU, artificial photosynthesis, etc.)
- Use of credit

(2) Concept of contributing to GHG emissions reduction through products and services

(3) Requests to government regarding CN initiatives

Source: Japan Chemical Industry Association (2021) "Chemical Industry's Stance on Carbon Neutrality"

Table of Contents

3. Technology Pathways to Decarbonization | ①-1 "Naphtha Cracking Furnaces" Low-Carbon and Decarbonization Technology for CN

Naphtha cracking furnace

Technology	Overview	Emission Intensity/ Reduction Range*1	Implementation year*2	Main References*3
BPT (Ethylene production facilities)	✓ Improvement of operation methods, recovery of discharged energy, streamlining of processes, and improvement of facility and equipment efficiency	390,000 tons reduction*2	Already implemented	✓ Commitment to a Low Carbon Society
Fuel switching to natural gas	✓ Switching from coal and other fuels to natural gas during start-up	- *5	Already implemented	✓ Commitment to a Low Carbon Society
Fuel switching to ammonia, hydrogen, etc.	✓ Fuel switching from petroleum and heavy oil to ammonia, hydrogen, etc. ✓ Use of ammonia, hydrogen burners, etc.	0.35	2030s	✓ Green Innovation Fund - Social Implementation Plan
Use of off-gas methane as raw material	✓ Use of methane and other off-gas emissions from naphtha cracking furnaces as raw materials for plastics, etc.	0-0.35	2040s	✓ Green Innovation Fund - Social Implementation Plan

*1: Emission factors are for each process and do not include downstream processes such as the production of derivatives and resins.
*2: Regarding the Social Implementation Plan, see the start year of the introduction expansion and cost reduction phase, and for the IEA, see the available year.
*3: References to the year of implementation are underlined.
*4: The reduction range varies depending on the introduction rate and the composition of the fuel originally used.
*5: Reduction varies depending on fuel composition before switching.

Low-Carbon and Decarbonization Technology for CN

Category	Technology		Overview	Emission Intensity/ Reduction Range*1	Implementation year*2	Main References*3
Raw material switching	Raw material switching by biomass	Basic chemicals	✓ Use of biomass to produce raw materials for chemicals such as methanol and ethanol, or basic chemicals such as ethylene, propylene, and BTX	0-2.0*7 CO2 absorption: 3.14	Already implemented	✓ Green Growth Strategy, IEA ETP 2020, Material Economics, DECHEMA
Raw material switching	Raw material switching by biomass	Polymers and raw materials	✓ Production of biopolymers and their monomer raw materials using biomass ✓ Plants cultivation for bio raw materials	-	2030s	✓ Development of production technology for bio-derived products to accelerate the realization of carbon recycling
Raw material switching	Raw material switching by biomass + CO2 capture		✓ Implementation of CCS when using biomass as a chemical (including BECCS, etc.)	-	2020s	✓ IEA ETP2020
Raw material switching	Methanol production from hydrogen and CO2		✓ Production of methanol, a chemical raw material, using hydrogen and CO2 as raw materials	CO2 use: 0.6-1.373 tons	2030s	✓ Roadmap for Carbon Recycling Technologies ✓ IEA ETP2020 ✓ DECHEMA
Raw material switching	MTO･ETO		✓ Production of olefins (ethylene, propylene, etc.) from methanol and ethanol	0.0 (Renewable energy assumed)	2030s	✓ Green Innovation Fund - Social Implementation Plan, Material Economics
Raw material switching	Production of hydrocarbons such as olefins from CO2		✓ Production of hydrocarbons using electrolysis and synthesis of CO2	-	2030s	✓ Moonshot R&D Program ✓ IEA ETP2020 ✓ DECHEMA
Raw material switching	Production of functional chemicals with CO2 as raw material		✓ Production of polycarbonate, polyurethane raw materials, DMC, etc. from CO2	0.95, 0.45t CO2/t reduction (DRC, MDI) 0.35kg CO2 used as raw material	2030s	✓ Green Innovation Fund - Social Implementation Plan
Raw material switching	Production of methane from CO2		✓ Methanation using hydrogen	-	2020s	✓ First Meeting of Public-Private Council for the Promotion of Methanation (June 28, 2021) ✓ IEA ETP2020
Raw material switching	Artificial photosynthesis		✓ Artificial photosynthesis produces hydrogen, which is used as a chemical raw material of methanol, etc.	0.0 (Renewable energy assumed)	2040s	✓ Green Innovation Fund - Social Implementation Plan

*1: Emission factors are for each process and do not include downstream processes such as the production of derivatives and resins.
*2: Regarding the Social Implementation Plan, see the start year of the introduction expansion and cost reduction phase, and for the IEA, see the available year.
*3: References to the year of implementation are underlined.

Low-Carbon and Decarbonization Technology for CN

	Technology		Overview	Emission Intensity/ Reduction Range*1	Implementation year*2	Main References*3
End products	High-efficiency production technology		✓ Production of functional chemicals is done continuously by a flow method, rather than the conventional batch method	2030: 4.91M tons/year 2050: 11.7M tons/year	2020s	✓ Environment Innovation Strategy, NEDO documents
End products	Lightweight reinforced materials (Cellulose nanofibers, etc.)		✓ Manufacture of lightweight reinforced materials for automobiles and other applications using various CNF composite technologies. Technologies contributing to the reduction of petroleum-derived materials, etc.	3.73M tons CO2/year reduction*4	2020s	✓ NEDO documents*4
End products	Technology to control N_2O, etc.		✓ Technology to control N_2O control technology (technology to control GHGs other than CO2) in exhaust gas and semiconductor gas treatment; wastewater, sludge, waste, and biomass treatment; agriculture sector, etc.	-	2035	✓ NEDO documents*5
Recycling	Material recycling		✓ Production of plastic products, etc. from waste plastic	0-1.0	Already partly implemented	✓ Environment Innovation Strategy ✓ IEA ETP2020 ✓ Material Economics, etc.
Recycling	Chemical recycling	Waste plastic	✓ Production of olefins from waste plastics by gasification, liquefaction, thermal decomposition, etc.	0.8	2030s	✓ <u>Green Innovation Fund - Social Implementation Plan</u> ✓ Material Economics
Recycling	Chemical recycling	Waste rubber	✓ Production of olefins from waste rubber by gasification, liquefaction, thermal decomposition, etc.	1.2	2040s	✓ <u>Green Innovation Fund - Social Implementation Plan</u> ✓ Material Economics

*1: Emission factors are for each process and do not include downstream processes such as the production of derivatives and resins.
*2: Regarding the Social Implementation Plan, see the start year of the introduction expansion and cost reduction phase, and for the IEA, see the available year.
*3: References to the year of implementation are underlined.
*4: Excerpt from the FY2030 performance targets in the explanatory material on NEDO's Development of Cellulose Nanofiber Technologies that Contribute to a Carbon-Recycling Society
*5: NEDO, Toward the Formulation of a Technical Strategy in the Sector of N2O Greenhouse Gas Control, Vol. 105 June 2021

Low-Carbon and Decarbonization Technology for CN

		Technology	Overview	Emission Intensity/ Reduction Range*1	Implementation year*2	Main References*3
Inorganic chemicals	Gas industry	**BPT**	✓ Energy-saving/high-efficiency technologies: Introduction of high-efficiency deep-cooling separators etc., use of inverters for pumps and compressors, review of distribution bases, etc.	–	Already implemented	✓ JIMGA Energy-Saving Case Studies
	Soda electrolysis	**BPT**	✓ Energy-saving/high-efficiency technologies: Advanced control/Upgrade & use of high-efficiency equipment/Introduction of zero-cap electrolytic cells/Introduction of bipolar electrolytic cells/Heat recovery in concentration equipment, etc.	780,000 tons reduction	Already implemented	✓ Commitment to a Low Carbon Society
In-house steam & in-house electricity, etc.		**BPT**	✓ Miniaturization of boilers, operation control, energy-saving distillation technology, expanded application range of energy-saving steam traps, cogeneration, heat pumps, etc.	780,000 tons reduction	Already implemented	✓ Commitment to a Low Carbon Society
		Fuel switching to natural gas	✓ For in-house electricity and steam, switch from coal, heavy oil, etc. to natural gas	0.32~0.415 *4 (kgCO2/kwh)	Already implemented	✓ Commitment to a Low Carbon Society ✓ Green Growth Strategy Through Achieving Carbon Neutrality in 2050 ✓ BAT reference tables, etc.*5
		Fuel switching to biomass	✓ Biomass mixed-fuel firing/mono-fuel firing, etc.	–	Already implemented	✓ IEA ETP2020
		Fuel switching to hydrogen, ammonia, etc.	✓ Hydrogen power generation, ammonia mixed-fuel firing, ammonia mono-fuel firing technology in gas turbines, etc.	Max. 100% reduction	2020s and beyond	✓ <u>Green Innovation Fund - Social Implementation Plan</u> ✓ <u>Green Growth Strategy Through Achieving Carbon Neutrality in 2050</u> ✓ IEA ETP2020
		Electrification	✓ Manufacture of steam by electric heating ✓ Introduction of renewable energy (solar cells, hydropower, etc.)	Max. 100% reduction (when using renewable energy)	–*6	✓ DECHEMA
		Separation and capture of CO2 from exhaust gas, etc.	✓ CO2 capture from natural gas thermal power plants, chemical processes, incineration, etc. ✓ Chemical absorption, chemical adsorption, physical absorption, membrane separation, etc. ✓ Introduction of CCS	Max. 100% reduction	2030s	✓ Green Growth Strategy Through Achieving Carbon Neutrality in 2050 ✓ <u>Green Innovation Fund - Social Implementation Plan</u> ✓ IEA ETP 2020

*1: Emission factors are for each process and do not include downstream processes such as the production of derivatives and resins.
*2: Regarding the Social Implementation Plan, see the start year of the introduction expansion and cost reduction phase, and for the IEA, see the available year.
*3: References to the year of implementation are underlined.
*4: CO2 emissions per unit of power generated by natural gas-fired thermal power generation (conventional LNG-fired thermal power generation and GTCC) are listed
*5: Ministry of the Environment - Evaluation of progress in global warming countermeasures in the electric utility sector
*6: Described as TRL 7 in DECHEMA (2017).

②-1 Technology Roadmap (Naphtha Cracking, Raw Material Switching, End Products)

2020 | 2030 | 2040 | 2050

Ways for Decarbonization (include collaboration with other industries)

Petrochemicals Basic products

Naphtha cracking (including fuel switching)

- **Energy saving/high efficiency:** Improvement of operation methods, recovery of discharged energy, streamlining of processes, and improvement of facility and equipment efficiency
- Switching to natural gas → Fuel switching to ammonia, hydrogen, etc.
- Use of off-gas methane as raw material

+CCUS

- Pursuit reduction of CO2 emissions through energy-saving, improved efficiency, and fuel switching.
- Introduce CO2 capture.

Raw material switching

- Production of basic chemicals with biomass as raw material
- Production of polymers and raw materials from biomass
- Artificial photosynthesis
- Methanol production from hydrogen, CO2, and synthetic gas
- MTO・ETO
- Production of hydrocarbons such as olefins from CO2
- Production of functional chemicals with CO2 as raw material
- Production of methane from CO2

+Carbon free electricity/CCUS

- Establish production technology with CO2 and biomass as raw materials.
- Synthetic fuels such as e-fuel may also be used.
- Can be regarded as decarbonization if process emissions become zero with the use of renewable energy.

End products

- Lightweight reinforcing materials (Cellulose nanofibers, etc.)
- High-efficiency production technology
- Technology to control N_2O, etc.

+Carbon free electricity /CCUS

- Various technologies for improving efficiency and reducing GHG emissions.

*Products contributes to decarbonization (Eco-products, noted in P7) are not listed in the Technology Roadmap, though can still be the use of proceeds for transition finance.

 Reference: Flow to Practical Application (Naphtha Cracking, Raw Material Switching, End Products)

R&D · Demonstration · Deployment

2020 · 2030 · 2040 · 2050

Naphtha cracking (including fuel switching)

Promoting the improvement of existing facilities. From 2035 onward, promoting decarbonization of heat source using ammonia, etc.

Energy saving/high efficiency	(Deployment through 2050)
Natural gas	(Deployment through 2050)
Fuel switching to ammonia, etc.	Development of ammonia burner and furnace → Demonstration in test furnace on a scale of tens of thousands of tons/year → Demonstration in existing furnaces, etc. → Application to commercial furnaces
Use of off-gas methane as raw material	Development of elemental technologies → Demonstration → Commercialization

Raw material switching

Promoting the improvement of existing facilities. From 2035 onward, promoting decarbonization of heat source using ammonia, etc.

Production of basic chemicals with biomass as raw material	(Deployment through 2050)
Raw material switching by biomass Polymers and raw materials	R&D → Demonstration → Commercialization
Production of basic chemicals with biomass as raw material +CCUS	Demonstration → Commercialization
Artificial photosynthesis	Demonstration of 100m²-class photocatalyst panels with a photocatalytic conversion efficiency of 7% → Demonstration of photocatalytic panels of a few ha to several sq km with very mass-producible photocatalyst and 10% conversion efficiency → Achieve CN through overseas expansion and large-scale manufacturing
Methanol production from hydrogen and CO2 (synthetic gas)	Demonstration at thousands to tens of thousands of tons/year → Commercialization
MTO･ETO	Development of catalyst with high selectivity, demonstration at thousands to tens of thousands of tons/year → Commercialization
Production of hydrocarbons such as olefins from CO2	R&D → Demonstration → Commercialization
Production of functional chemicals with CO2 as raw material	Establishment of basic technology at several hundred to several kg/year → Development and large-scale demonstration of process CO2 reduction → Considering mass production
Production of methane from CO2	R&D → Demonstratio n → Commercialization

End products

Promoting higher efficiency and switching to renewable energy

Energy saving/high efficiency	(Deployment through 2050)
Lightweight reinforced materials (Cellulose nanofibers, etc.)	Cost reduction, development of applications, etc. (Deployment through 2050)
High-efficiency production technology	Catalyst development → Demonstrations and social implementation as needed (Deployment through 2050)
Technology to control N_2O, etc.	R&D → Demonstration → Commercialization

②-2 Technology Roadmap (Recycling, Inorganic Chemicals, In-House Use)

2020 | 2030 | 2040 | 2050

Ways for Decarbonization (include collaboration with other industries)

Recycling (Raw material circulation)
- Material recycling
- Chemical recycling (waste plastic)
- Chemical recycling (waste rubber)

+Carbon free electricity/CCUS

- Expanding material and chemical recycling.
- Collaboration with other industries and local governments is also important.

Inorganic chemicals

Electrolyzed soda
- Various types of energy saving/high efficiency: Advanced control/Upgrade & use of high-efficiency equipment/Introduction of zero-cap electrolytic cells/Introduction of bipolar electrolytic cells/Heat recovery in concentration equipment, etc.

Industrial gases
- Various types of energy saving/high efficiency: Introduction of high-efficiency deep-cooling separators, etc., use of inverters for pumps and compressors, review of distribution bases, etc.

+ Decarbonization of in-house steam and electricity

+ Carbon free electricity

- Pursuit reduction of CO2 emissions through energy-saving, improved efficiency, and fuel switching.
- CO2 capture and electrification can also be considered.

[Multi-sector technology]

In-house steam & in-house electricity (Fuel switching)
- **Various types of energy saving/high efficiency**: Miniaturization of boilers, operation control, inverters for induction blowers, expanded application range of energy-saving steam traps, cogeneration
- Switching to natural gas
- Switching to biomass
- Fuel switching to hydrogen, ammonia, etc.
- Electrification

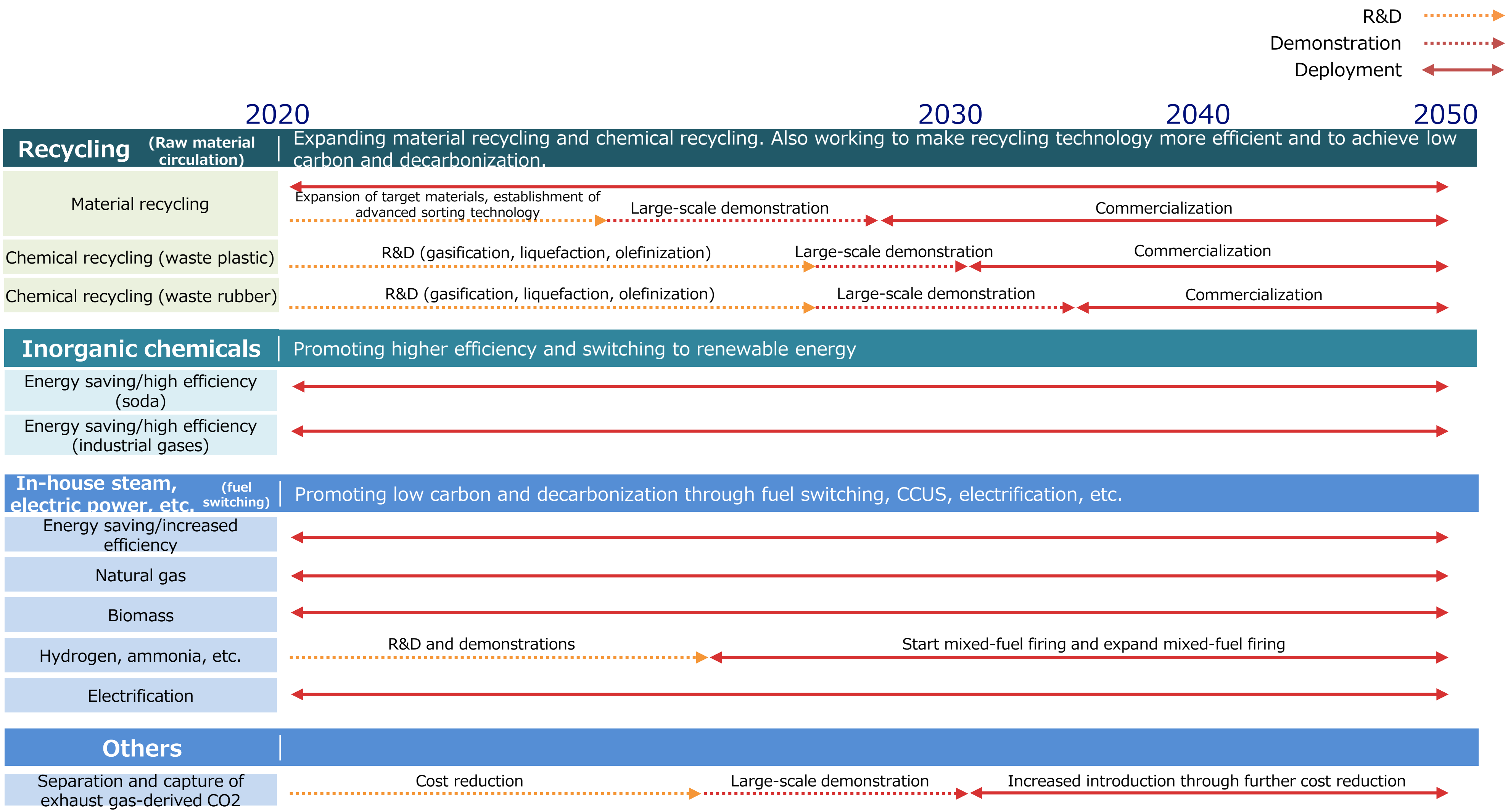
+Carbon free electricity/CCUS

CO2 separation & capture
- CO2 separation and capture (chemical processes, cogeneration boilers, etc.)

+ Carbon free electricity

- Energy saving, increased efficiency, renewable energy switching.
- Collaboration with other industries and local governments is also important.

Reference: Flow to Practical Application (Recycling, Inorganic Chemicals, In-house Use)



③Scientific Basis/Alignment with the Paris Agreement

- The Technology Roadmap, which is based on Japan's various policies and international scenarios aimed at achieving carbon neutrality by 2050, is aligned with the Paris Agreement.
- Carbon neutrality will be achieved by 2050 through the introduction of innovative technologies such as artificial photosynthesis, in addition to the steady achievement of low-carbon through various energy-saving and efficiency improvements, fuel switching, and increased recycling.

Main references/evidence

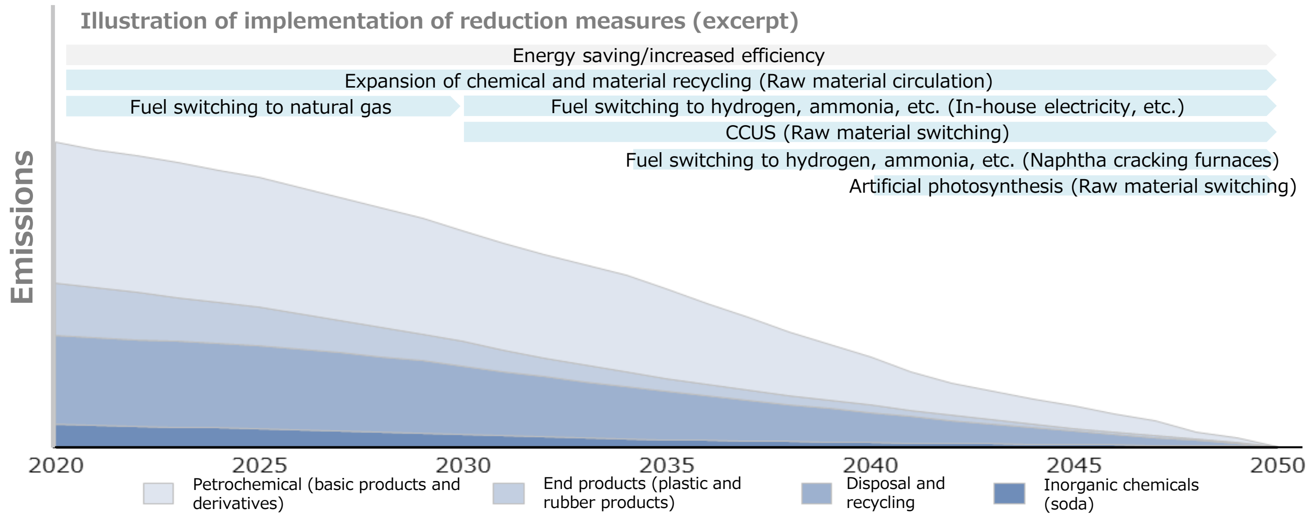
Government Policies

- ✓ Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (Carbon recycling, materials industry)
- ✓ "Carbon recycling-related" project related R&D and Social Implementation Plan
- ✓ Environment Innovation Strategy
- ✓ Strategic Energy Plan
- ✓ Global Warming Prevention Plan
- ✓ Roadmap for Carbon Recycling Technologies

International scenarios, roadmaps, etc. aligned with Paris Agreement

- ✓ Clean Energy Technology Guide (IEA)
- ✓ Energy Technology Perspective 2020 (IEA)
- ✓ Industrial Transformation 2050 (Material Economics)
- ✓ Science Based Target initiative

Assumed CO2 Reduction Pathway*[1, 2]



Main reduction methods	Target	Overview
(1) Fuel switching	All sectors	• Fuel for naphtha cracking furnaces and in-house power generation will be switched to natural gas in the short term, and hydrogen, ammonia, etc. in the medium to long term.
(2) Raw material circulation (Recycling)	Disposal & recycling, petrochemicals	• Incineration and thermal recycling of waste plastics and waste rubber will be reduced, and chemical and material recycling will be expanded.
(3) Raw material switching	Petrochemicals End products	• Chemicals and products will be switched to those that use biomass and CO2-derived raw materials. Artificial photosynthesis technology will also be used.

*1: Expected reduction in emissions in Japan's chemical industry as the sector covered by this Roadmap. In fact, chemical companies will all aim to achieve carbon neutrality under their own long-term strategies, so they are not required to conform with the above path.

*2: Advances in energy-saving technologies, a stable and inexpensive supply of new fuels such as hydrogen and ammonia, CCUS and related infrastructure including DAC and others in collaboration with other industries, and the establishment of new social systems such as a circular economy are assumed to be in place.

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4. Toward Decarbonization and Achievement of the Paris Agreement

- The Technology Roadmap is intended to exemplify low-carbon and decarbonization technologies envisioned today and indicate an estimation of when these technologies are to be established for commercialization.
- Technology development is assumed to require long-term development, and it is possible that other low-carbon and decarbonization technologies which are not described in the Technology Roadmap will be developed and adopted. In addition, there exists some uncertainties, including as economic feasibilities.
- Commercialization of low-carbon and decarbonization technologies in the chemical industry will also depend on the development of societal systems, such as decarbonized power sources, hydrogen supply, and CCUS. Carbon neutrality in the chemical sector will be achieved in coordination with other sectors.
- Therefore, the Technology Roadmap will be revised and updated regularly and continuously to maintain the credibility and usability of the Technology Roadmap by considering the progress of other technologies, the trends of businesses and policies, and dialogues with the investors.
- Chemical and petrochemical manufacturers will aim to achieve carbon neutrality by making the best combination of technologies listed in the Technology Roadmap according to their business decision based on long-term strategy.
- In addition, efforts for reducing CO2 emissions may include the utilization of carbon credits and the purchase of carbon offset products, not limited to “the technology” of the technology roadmap.

Taskforce Formulating Roadmaps for Climate Transition Finance
Chemical Sector: List of Committee Members

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