AJEEP Scheme 5

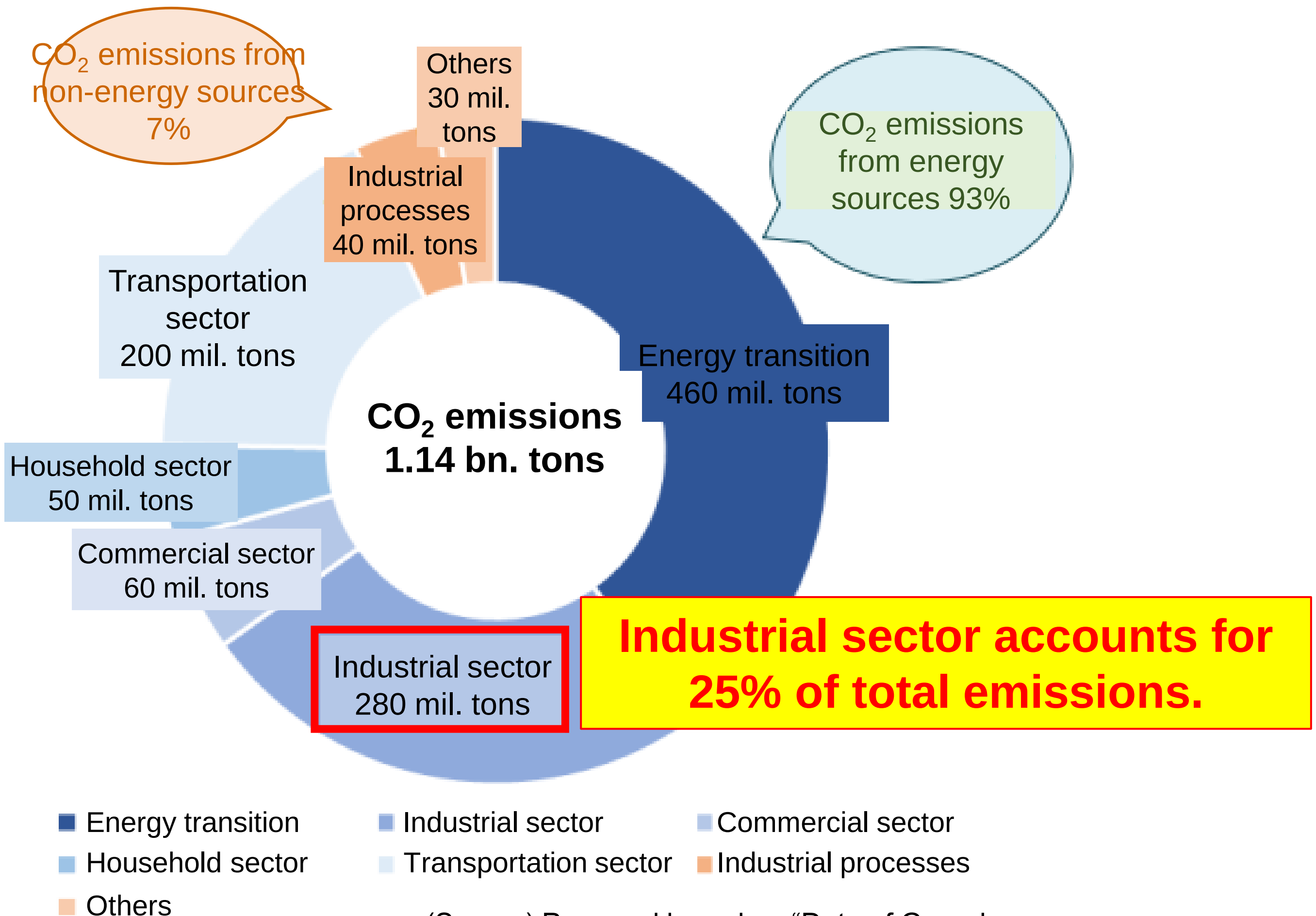
Introduction of New Technologies in Industrial Sector

October 25, 2022

Contents

1.1 CO_2 Emissions in Industrial Sector

CO_2 Emissions in Japan (2018)



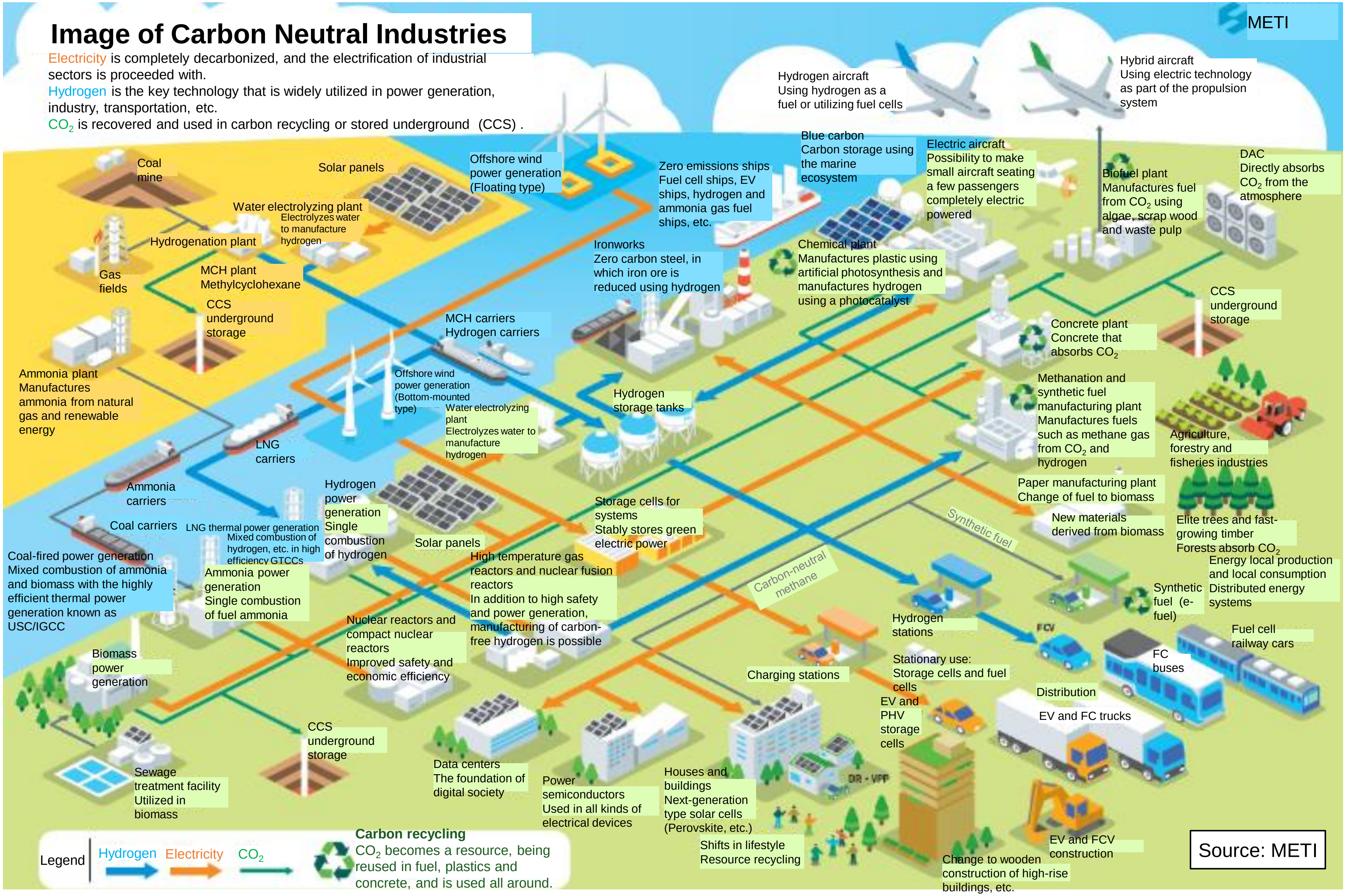
(Source) Prepared based on "Data of Greenhouse Gas Emissions in Japan" of GIO

Source: METI

1.2 Classification of New Technologies for CN in Industrial Sector

Category	Description	New Technologies
Reduction of CO_2 generation	Energy conservation (advanced energy conservation technologies)	Leveling of electricity demand, Upward/downward demand response (DR)
	Energy transition (heat to electricity)	Heat pump, electric heating, gas cogeneration
	Shift to low-carbon industry through transformation of processes	Direct reduction, COURSE50, electric furnace
	Expansion of renewable energy	Hydraulic power, solar power, wind power, geothermal heat, biomass, nuclear power
	Shift to non-fossil fuels (hydrogen, ammonia)	Use of ammonia fuels in power generation Hydrogen reduction steelmaking
CO_2 processing	CO_2 separation, capture and storage (CCUS: Carbon Capture, Utilization and Storage)	COURSE50 Capturing of CO_2 from cement manufacturing process
	Utilization of CO_2 (building materials, chemical products, methanation)	Cellulose nanofiber Carbon recycled concrete Artificial photosynthesis
Recycling technologies	Use of waste materials, plastics, and iron scraps	Plastic synthesis, concrete

1.3 Green Growth Strategy for CN



1.4 14 Key Areas in Green Growth Strategy

Growing areas are expanding from 2030 toward 2050, starting with those close daily life

Energy-related industries

(1) Offshore wind power industry
Wind turbines, components, floating wind power generation

(2) Fuel ammonia industry
Burners for power generation (Fuel for the stage of transition to a hydrogen society)

(3) Hydrogen industry
Power generation turbine, hydrogen reduction steelmaking, carrier (ship), water electrolysis equipment

(4) Nuclear industry
SMR, nuclear power for hydrogen production

Transportation- and manufacturing-related industries

(5) Automobile and storage battery industries
EV, FCV, next-generation batteries

(6) Semiconductor and information and communication industries
Data center, low-power semiconductors (Improvement of efficiency on the demand side)

(7) Marine vessel industry
Fuel cell vessels, EV vessels, gas-fueled vessels, etc. (Hydrogen, ammonia, etc.)

(8) Logistics, human logistics, and civil engineering/infrastructure industries
Smart transportation, logistics drones, FC construction machines

(9) Food and agriculture, forestry, and fisheries industries
Smart agriculture, wooden construction of high-rise buildings, blue carbon

(10) Aircraft industry
Hybrid and hydrogen aircrafts

(11) Carbon recycling industry
Concrete, biofuel, raw materials for plastic

Household- and office-related industries

(12) Housing and building industries / next-generation solar power industry (perovskite)

(13) Resource cycling-related industries
Bio-based materials, recycled materials, waste power generation

(14) Lifestyle-related industries
Local decarbonization businesses

Source: METI

1.5 Visions of Industries toward CN in 2050

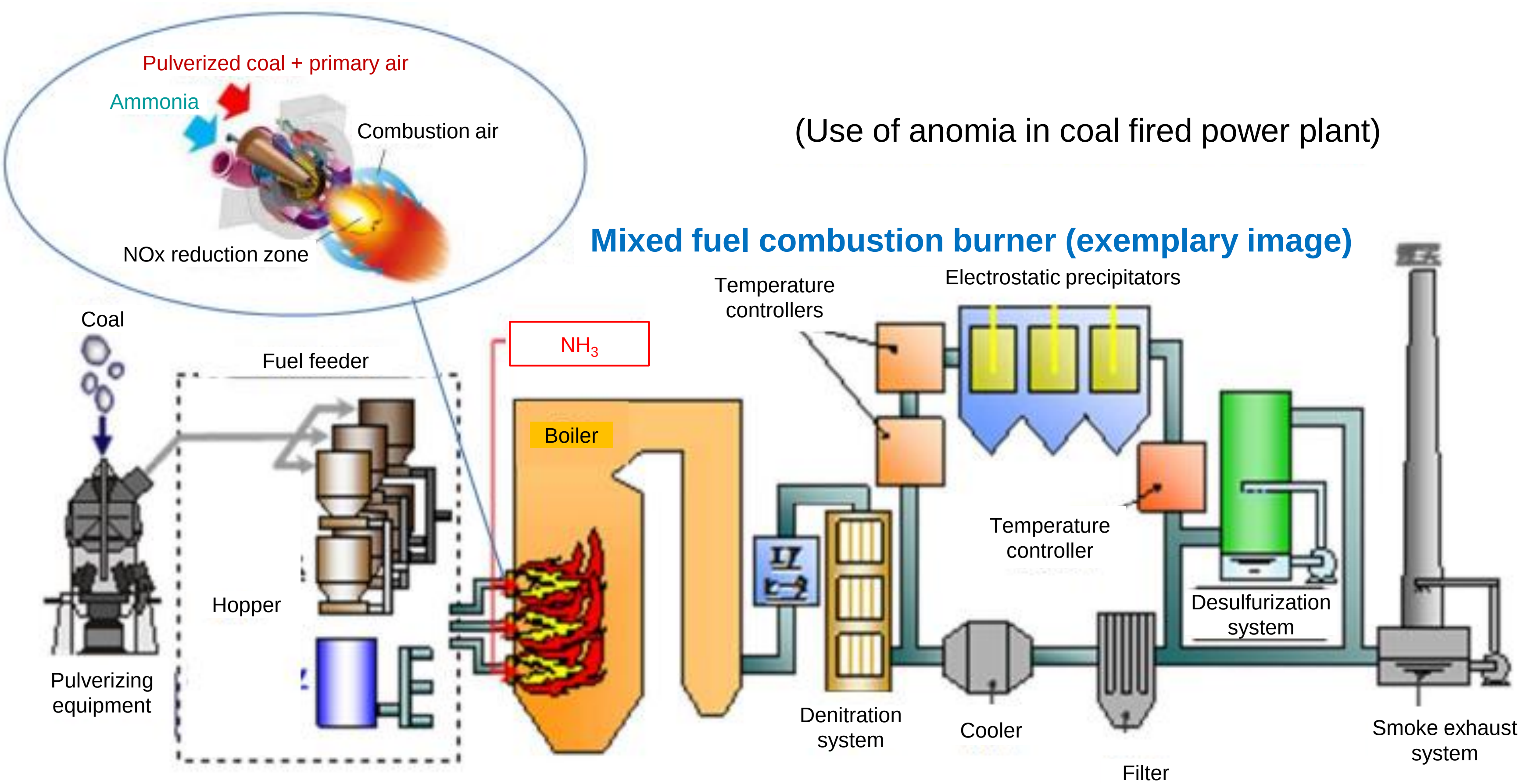
<Examples of roadmap to development and introduction of innovative technology>

Business/company	Innovative technology	2020	2025	2030	2050
The Japan Iron and Steel Federation	COURSE50	Research & development		Production	Dissemination
Japan Chemical Industry Association	Process of manufacturing raw materials for plastic using CO_2, etc.		Research & development and practical application		Commer-cialization
Japan Paper Association	Cellulose nanofiber		Market creation		Market expansion
Japan Cement Association	Innovative cement manufacturing process	Preliminary study	Confirmation of manufacturing conditions, economic reasonability		
The Electric Power Council for a Low Carbon Society	Thermal power technology contributing to reduction of environmental load (ammonia-mixed and hydrogen-mixed fuel burning)		Verification	Operation and increase of mixing ratio	Exclusive use of ammonia as fuel
Petroleum Association of Japan	Project for establishing large-scale hydrogen supply chain	Research & development		Verification	Practical application
The Japan Gas Association	Methanation	Research & development and verification		Practical application	Commercial expansion
Telecommunications Carriers Association	High-speed signal processing technology with super-low energy consumption using photonics-electronics convergence technology		Development of specifications		
East Japan Railway Company	Development of fuel-cell train cars	Development	Verification	Introduction	Wider introduction

Source: NEDO

2.1 Use of Ammonia Fuel in Power Generation

(Use of anomia in coal fired power plant)



Source: METI

2.2 Use of Ammonia Fuel in Power Generation

- **Reduction by 50% of CO_2 emissions in the power sector** by replacing the current power generation system with the **system of single combustion of ammonia (ammonia fired power generation)**. Even **mixing ammonia (20%) into combustion fuel in coal-fired power generation** can **reduce the emissions in the sector by 10%**.

- Meanwhile, **500 thousand tons of fuel ammonia is required per coal-fired power plant (1 million kilowatts) every year**.

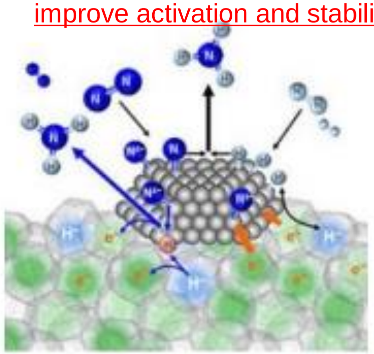
Case	20% mixed combustion (*1)	50% mixed combustion (*1)	100% ammonia combustion (*1)	(Ref.) 20% mixed combustion per plant
Reduction of CO_2 emissions (*2)	**Approx. 40 million tons** Around 10% of CO_2 emissions in the power sector	Approx. 100 million tons	**Approx. 200 million tons** Around 50% of CO_2 emissions in the power sector	Approx. 1 million tons
Required amount of ammonia	Approx. 20 million tons	Approx. 50 million tons	Approx. 100 million tons	Approx. 0.5 million tons

Source: METI

2.3 Establishment of Fuel Ammonia Supply Chain

Ammonia synthesis technology

- For reducing the cost of blue ammonia synthesis (15% or more reduction of the operating cost), a new technology capable of synthesizing ammonia at lower temperature and pressure as compared to the Haber-Bosch process has been developed.
- It is necessary to develop a catalyst and improve activation and stability.



(Source) NEDO publication

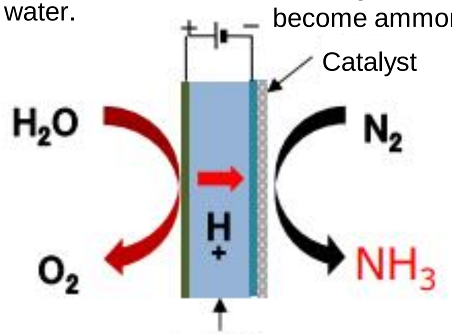
* Nitrogen and hydrogen molecules are broken down into atoms with the effect of catalyst, and the atoms are bonded as ammonia.

Green ammonia synthesis

- For reducing the cost of green ammonia, a new manufacturing method without requiring hydrogen in the process of the synthesis has been developed.
- It is necessary to develop an electrode catalyst and electrolyte to be used in the synthesis.

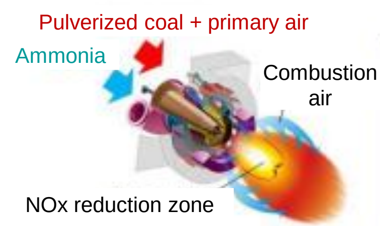
* Extract hydrogen from water.

* The extracted hydrogen is bonded to nitrogen to become ammonia.



Manufacturing of mixed and single fuel combustion burners

- For high-rate mixed combustion and single combustion in boilers and turbines, high-rate mixed/single fuel burners (50% or more in actual system) necessary for such combustion have been developed.
- It is necessary to develop new burners capable of solving technical issues of increased NOx emissions, lower heat recovery, and instable ignition associated with the increased ammonia mixing rate. Additionally, the new burners must be actually used to review proper flow rate, flow velocity, blowing position, etc. through a verification process.



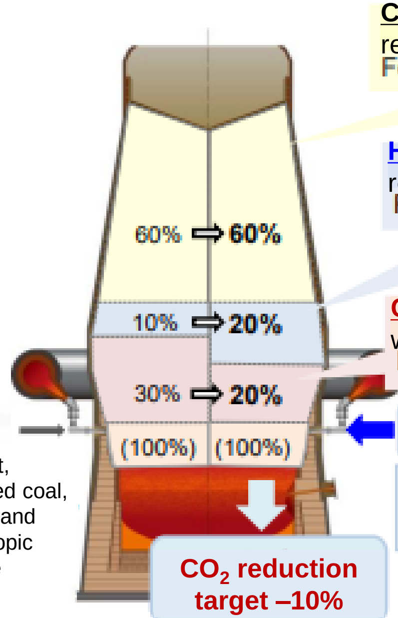
(Source) IHI press release

Source: METI

2.4 Technology of Reduction Utilizing Hydrogen

Development goal:
Comprehensively verify and evaluate the process operations for **reducing CO_2 released from a blast furnace by 10%** in terms of both experimental and logical aspects, so as to establish a technology for controlling reduction responses using hydrogen.

Existing blast furnace | **COURSE50 blast furnace**



Carbon monoxide reduction: Exothermic reaction with a four-figure heat amount
$FeO + CO \rightarrow Fe + CO_2 + 4{,}136$ kcal/kmol

Hydrogen reduction: Endothermic reaction with a four-figure heat amount
$FeO + H_2 \rightarrow Fe + H_2O - 5{,}702$ kcal/kmol

Carbon reduction: Endothermic reaction with a five-figure heat amount
$FeO + C \rightarrow Fe + CO - 37{,}084$ kcal/kmol

Hot blast, pulverized coal, oxygen, and hygroscopic moisture

Hydrogen-based gas injection

- Increase in hydrogen reduction →
- Decrease in carbon reduction →
- Reduction of carbon consumption (CO_2) at the blast furnace

CO_2 reduction target –10%

(The percentage refers to a ratio of the reduction response to entire reduction)

Concept of the technology of reduction utilizing hydrogen

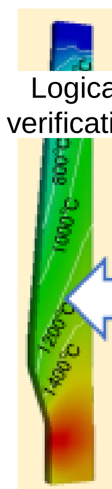
New Energy and Industrial Technology Development Organization

Development topic (element technology)

SG6: Process evaluation technology using a test blast furnace
- Verification of process operations by experiment

SG3: Development of technology for manufacturing high performance caking additives
(Technology for manufacturing coke for the COURSE50 blast furnace)
- Manufacturing of coke suitable for hydrogen reduction

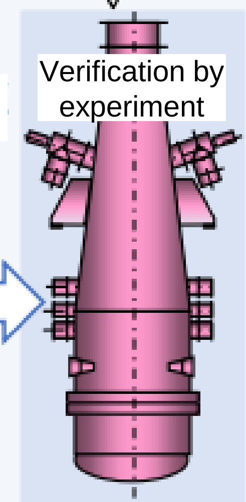
SG1: Technology for using hydrogen in iron ore reduction
- Logical verification of process operations with mathematical models
- Designing of hydrogen-based gas injection lance



Logical verification

Mathematical model for blast furnace

Verification by experiment

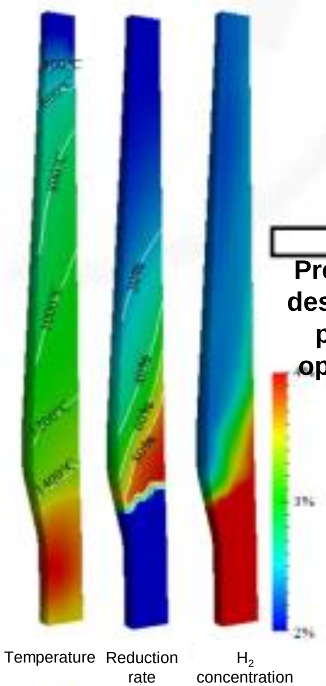


12 m^3 test blast furnace

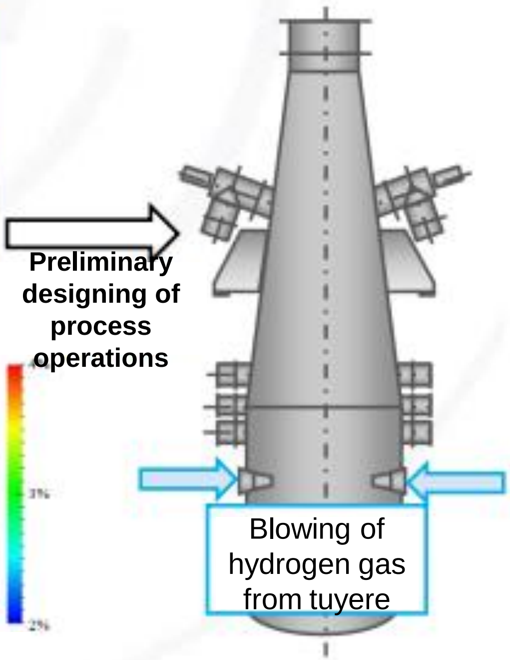
SG7: Development of process technology based on partial verification of actual blast furnace
- Verification of process operations on an actual furnace

Source: MOE

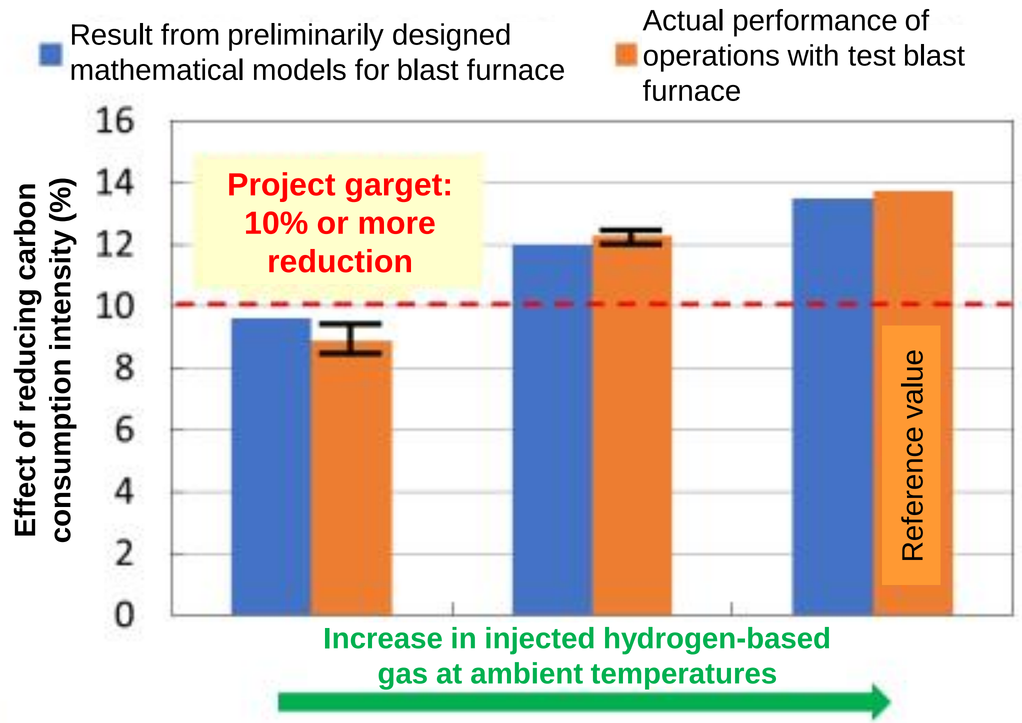
2.5 Technology of Utilizing Hydrogen in Iron Ore Reduction (Achievement)



SG1: Process simulation



SG6: Operation of test blast furnace

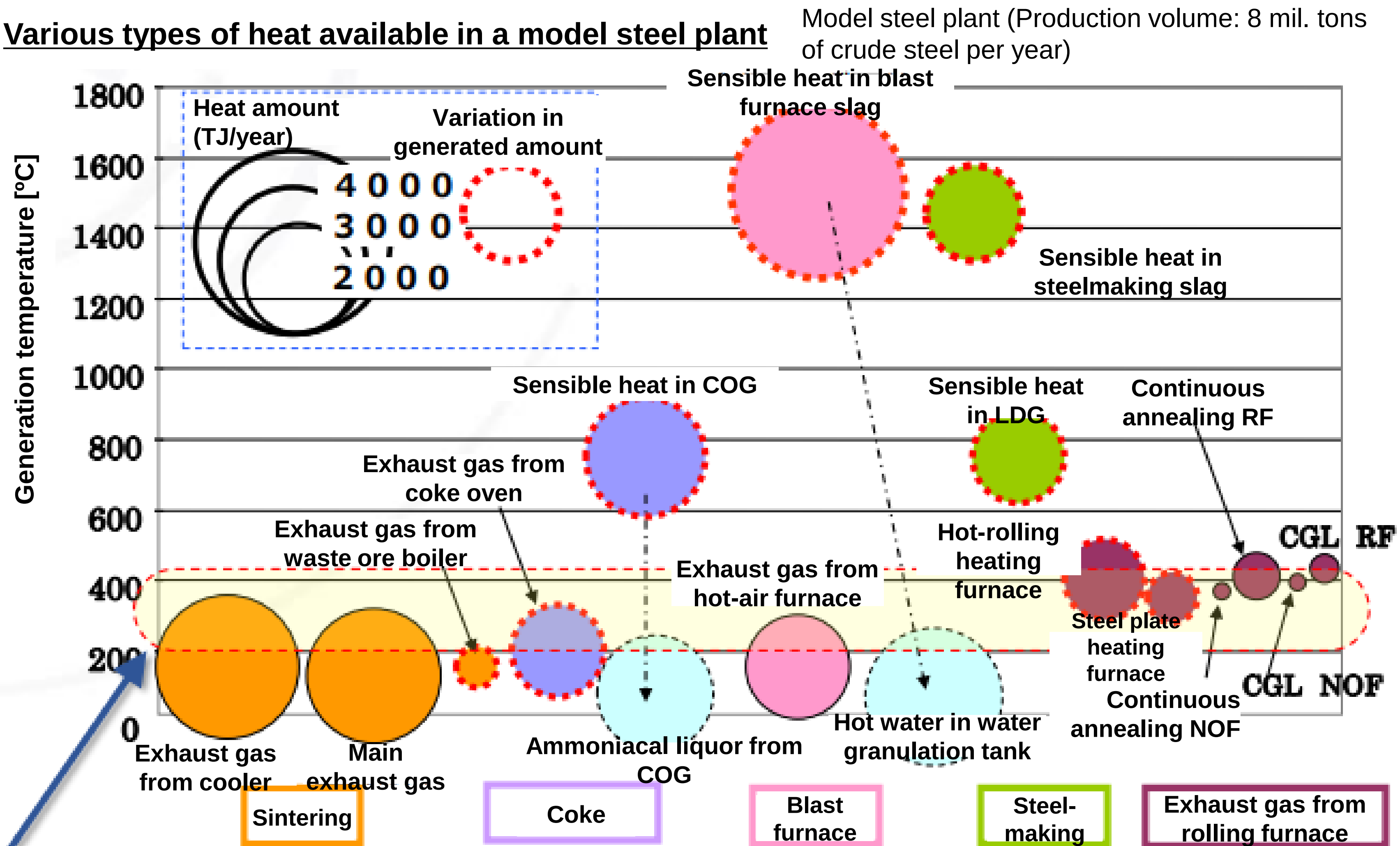


Carbon reduction effect caused by three-dimensional mathematical models for blast furnace and operation of test blast furnace

Analysis on operations of a test blast furnace has found an expected reduction of CO_2 emissions from blast furnaces by 10% or more. Some more examination on the amount of reduction gas to be injected and different types of reduction gas, taking account of compatibility with actual furnace to be used, is planned.

Source: MOE

2.6 Technology of Recovering Unused Exhaust Heat (Achievement)



Currently, exhaust heat at around 200 to 400ºC released to the air is recovered and utilized for a heat source in a chemical CO_2 absorption process, etc.

Source: MOE

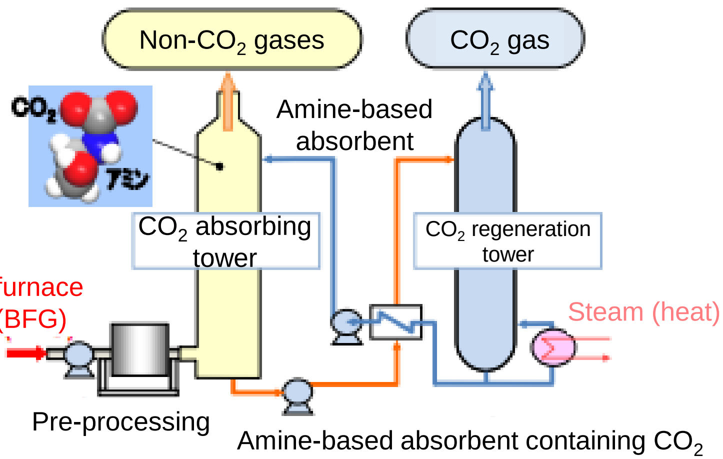
3.1 CO_2 Separation and Capture Technologies

Development goal: <u>Develop CO2 separation and capture technologies suitable for blast furnaces gas</u> that can realize Co2 separation and recovery cost of 2,000 yen/t-CO2, and **<u>establish technologies for reducing CO2 emissions by approx. 20%.</u>**

<u>Development topic (element technology)</u>

<u>SG4</u>-1: CO_2 separation and capture technologies using chemical absorption technique

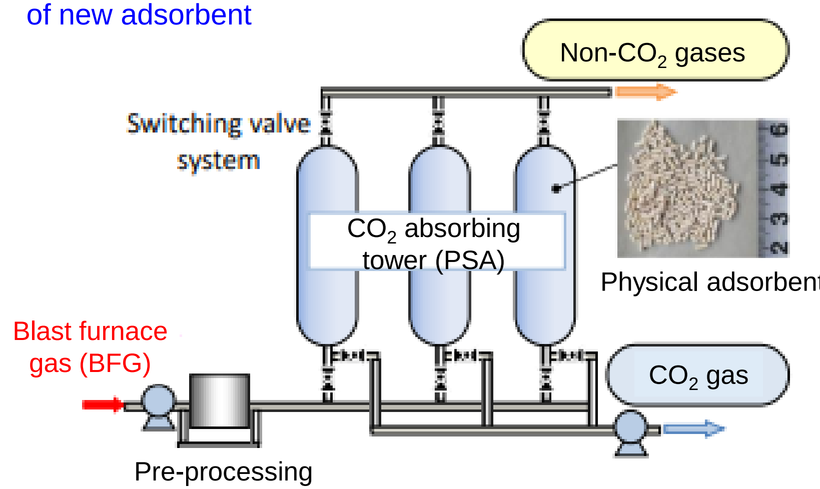
- Development of high-performance liquid chemical absorbent



Reduction of energy required for separating and capturing CO_2
(Conventional) 4.0 → (Development Phase I) 2.0 →
(Target) 1.6 GJ/t-CO_2

SG4-2: CO_2 separation and capture technologies using physical adsorption technique

- Improvement of efficiency of adsorbing tower and development of new adsorbent



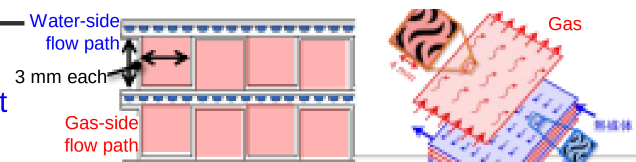
Reduction of electric power required for separating and capturing CO_2
Electric power intensity: 145 → **(Target) 130 kWh/t-CO_2**

Heat required for CO_2 regeneration is supplied

* Development completed at Phase I of COURSE50

SG5: Unused exhaust heat recovery technology

- Development of an <u>efficient heat exchanger</u> for exhaust heat recovery

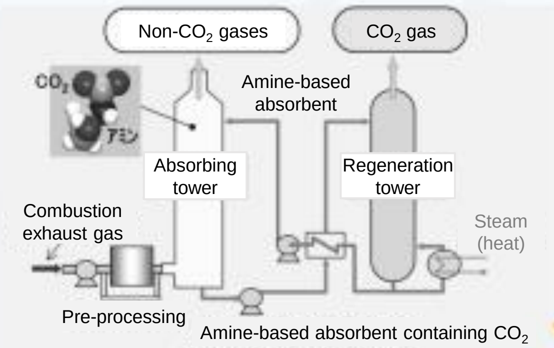


Cross-section of micro heat exchanger

Source: MOT

3.2 CO_2 Separation and Capture Technologies (Achievement)

COURSE50 research and development facilities: CO_2 separation and capture (chemical absorption technique)

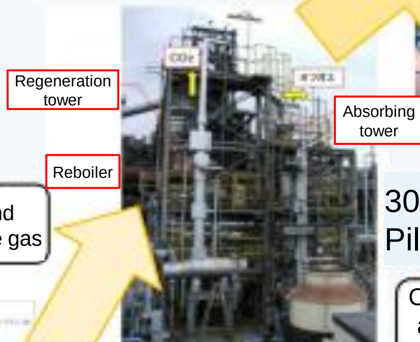


Chemical absorption technique

CAT30

30 t-CO_2/d Pilot-scale

CO_2 separation and capture using actual blast furnace exhaust gas (BFG)



CAT1

1 t-CO_2/d Bench-scale

CO_2 separation and capture using sample gas

CAT-LAB

5 kg-CO_2/d Laboratory-scale

ESCAP™※

Commercialized facilities: 2

Purity of produced CO_2 > 99.9 vol%

- **Liquid chemical absorbent: Nippon Steel & RITE**
- **Chemical process: Nippon Steel Engineering**

Commercialized CO_2 separation and capture facilities

(Photo: Facilities of Air Water Carbonic Inc. in the site of Muroran Steel Works)

Applied to:

1) Air Water Carbonic Inc.: **120 t-CO_2/d**

2) Niihama west thermal power station, Sumitomo Joint Electric Power Co., Ltd.: **143 t-CO_2/d**

Progress of ESCAP

(1) Development and introduction of remote monitoring functions and operational optimization (operational cost minimization) control technologies

(2) Applying the process to overseas large-scale CO_2 capturing applications (e.g. Enhanced Oil Recovery (EOR)) is under consideration.

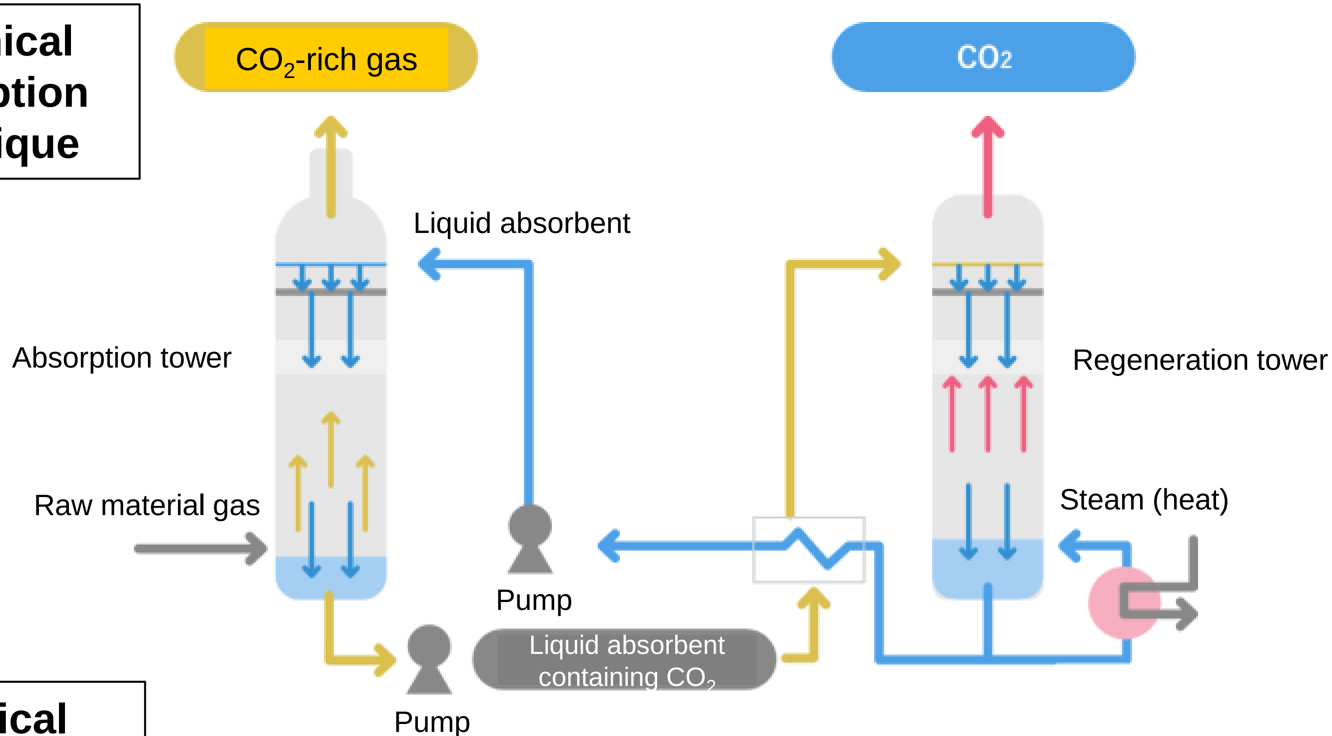
(3) Some cases of capturing and effective utilization of CO_2 from multiple emission sources in Japan are under consideration.

* **ESCAP** (Energy Saving CO_2 Absorption Process) is the registered trademark of Nippon Steel Engineering Co., Ltd.

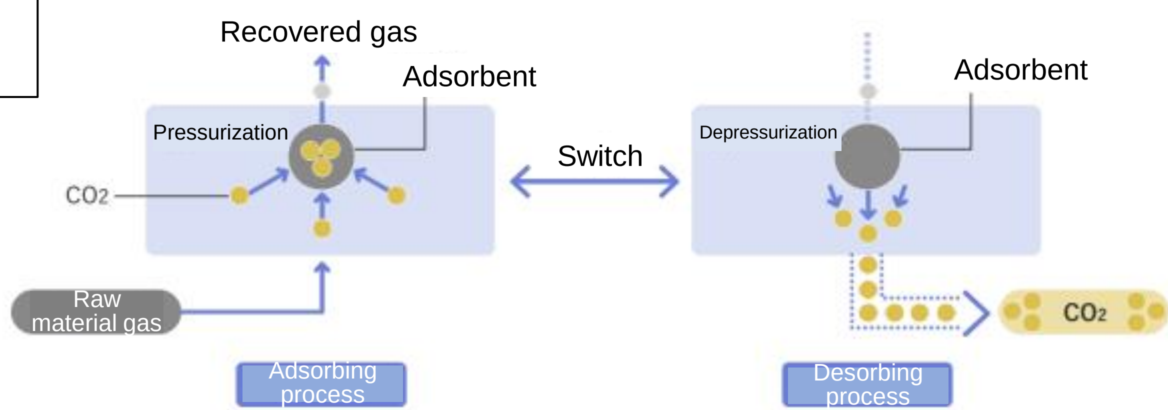
Source: MOT

3.3 CO_2 Separation and Capture Technologies

Chemical absorption technique



Physical adsorption technique

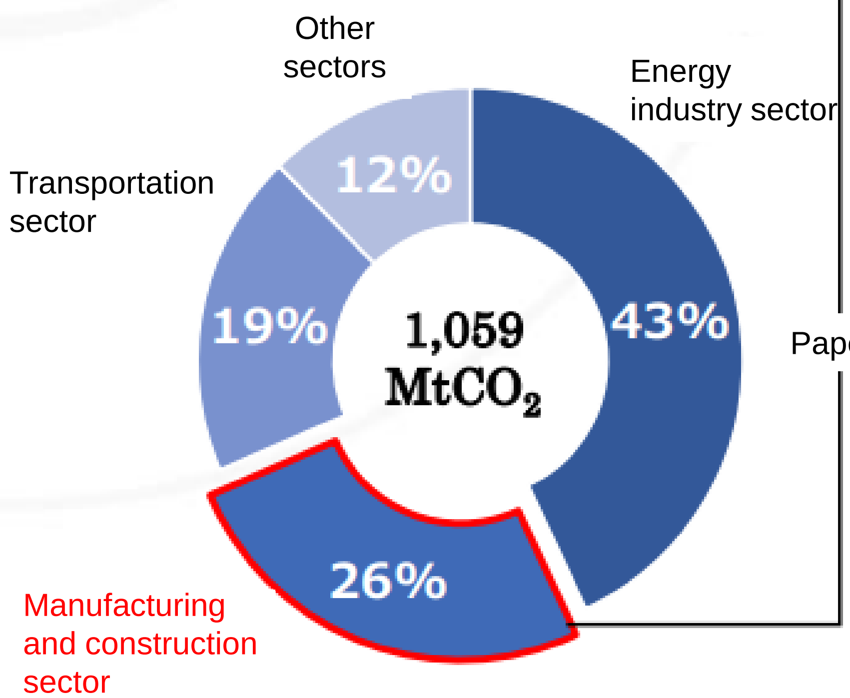


Source: The Japan Iron and Steel Federation

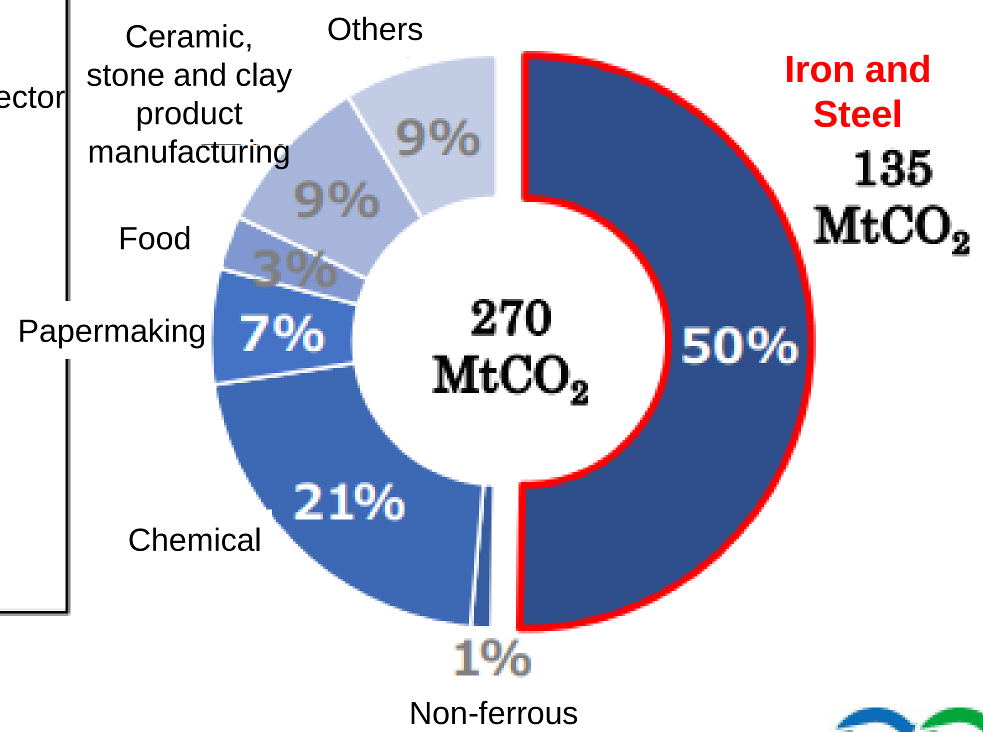
3.4 COURSE50 Technology (Iron and Steel Industry)

Iron and Steel Industry accounts for approx. 13% of total CO_2 emissions from energy sources in Japan.

Proportion of different sectors in the entire fuel combustion area in Japan



Proportion of different industries accounting for CO_2 emissions in the manufacturing and construction sector



Prepared based on "2018 Greenhouse Gas Emissions" of Ministry of the Environment and "Greenhouse Gas Inventory Office" of National Institute for Environmental Studies

3.5 COURSE50 Technology (Iron and Steel Industry)

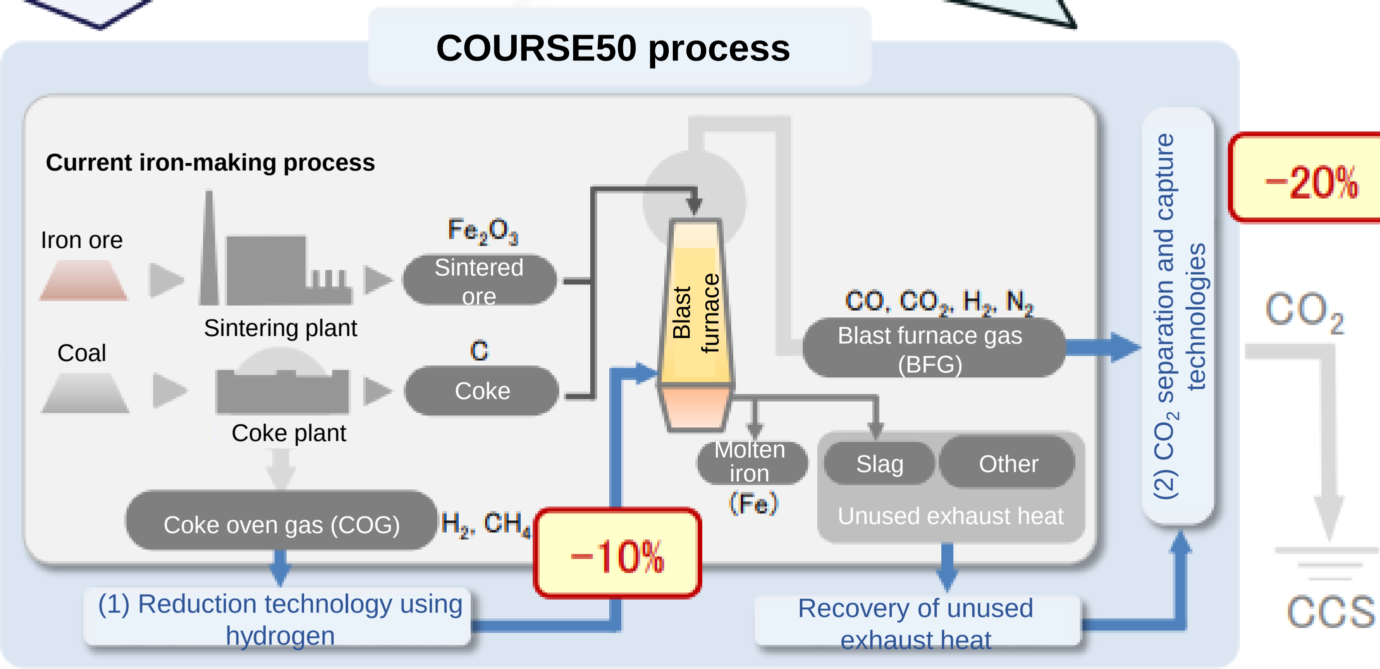
Overview of COURSE50 technological development

(CO_2 Ultimate Reduction System for Cool Earth 50)

Aiming at reduction of CO_2 emissions by 30% through world first utilization of the hydrogen reduction technique and CO_2 separation and capture

① **Development of technologies for reducing CO_2 emissions**
Iron ore reduction by partially replacing coke with hydrogen to reduce CO_2 emissions by 10% or more

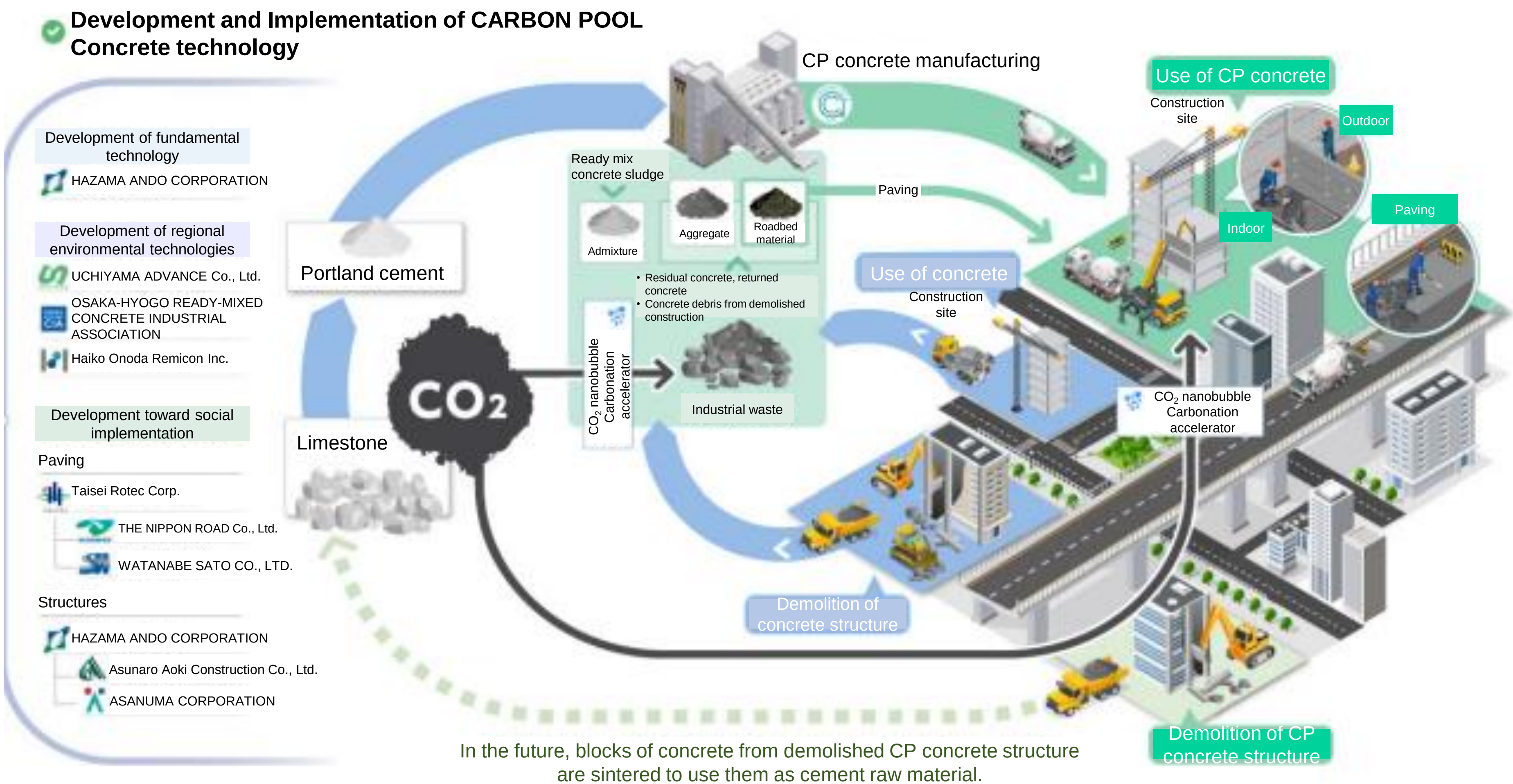
② **Development of CO_2 separation and capture technologies**
Separation and capture of CO_2 from blast furnace gas to reduce CO_2 emissions by 20%



New Energy and Industrial Technology Development Organization

Source: MOT

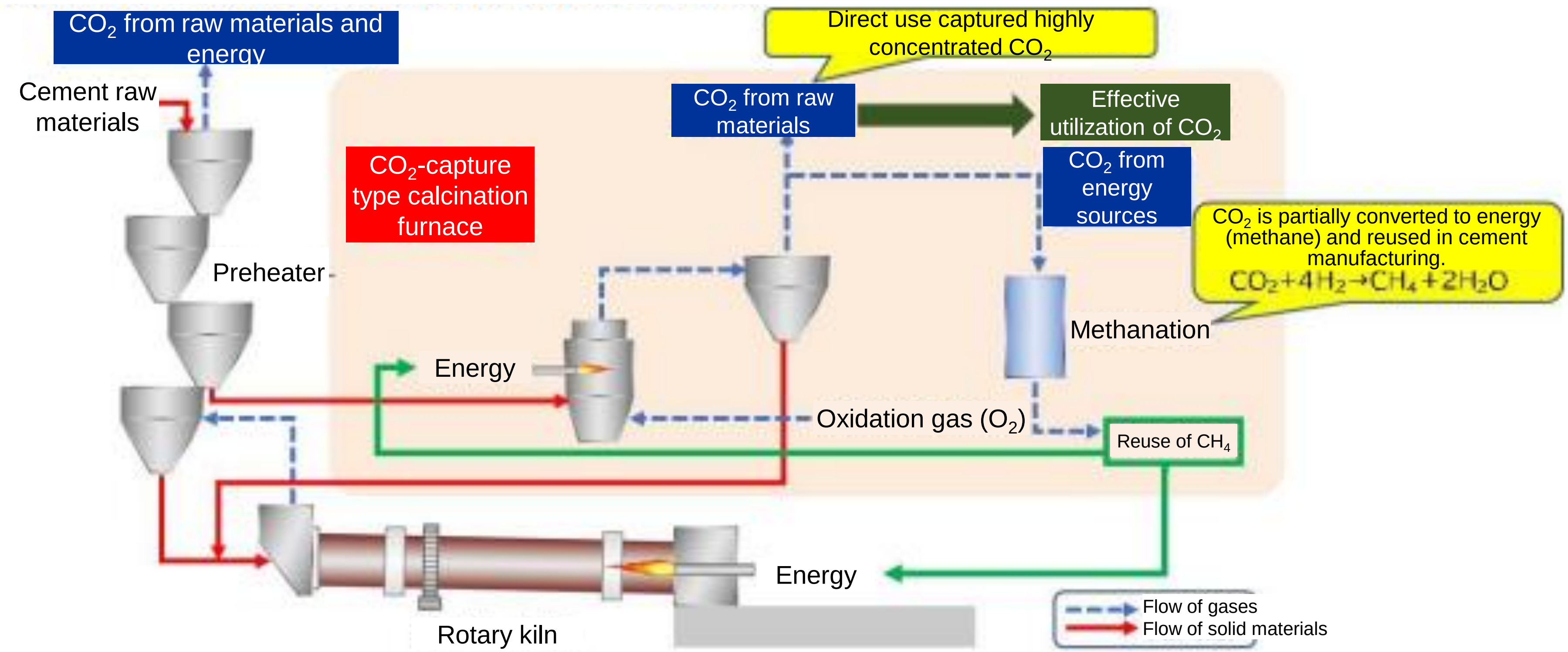
3.6 Use of CO_2: Carbon Pool Concrete Manufacturing Process



Source: MOT

3.7 CO_2 Capture System in Cement Manufacturing Process

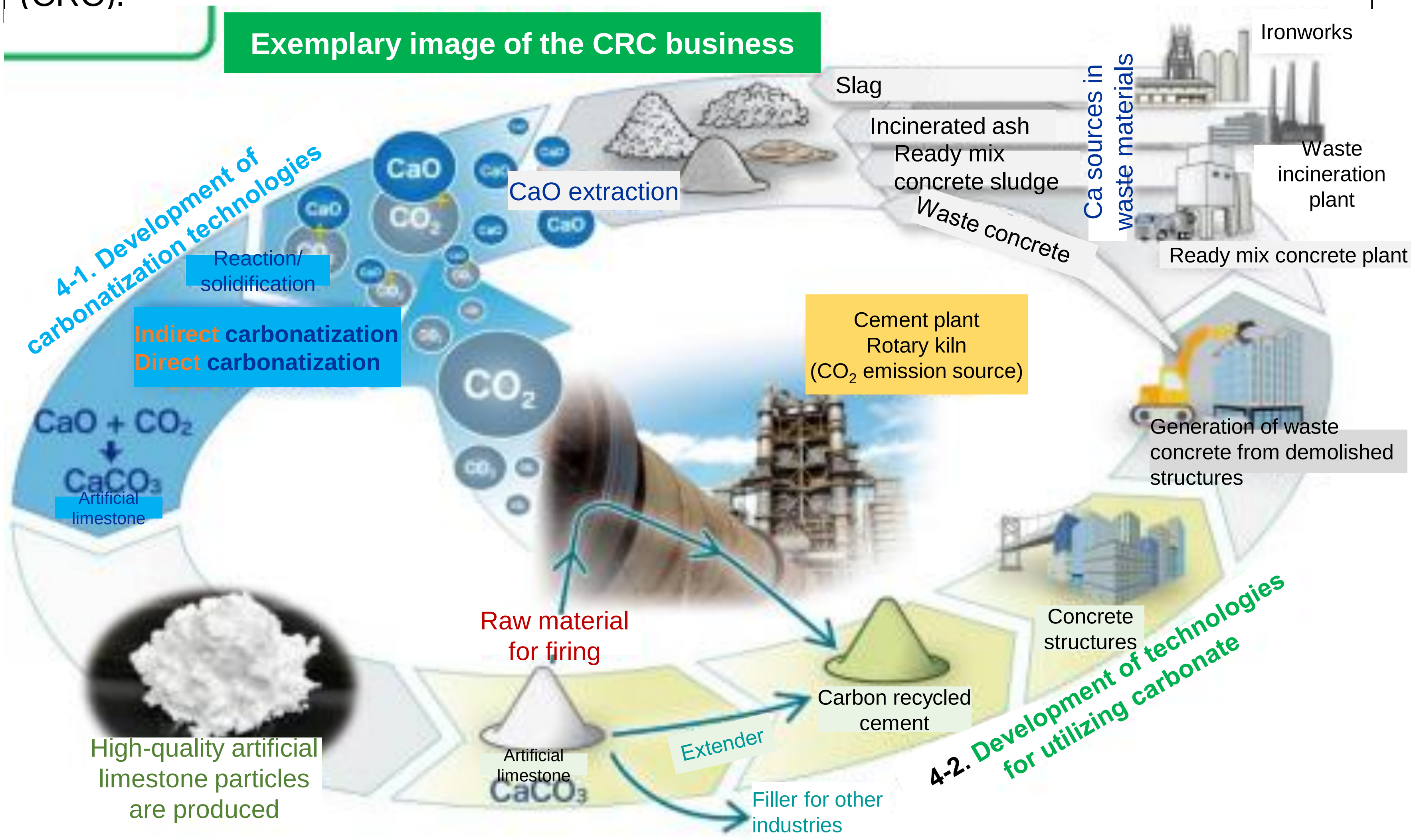
Cement manufacturing process with integrated CO_2 capture system



Source: NEDO

3.8 Carbonatization Technology Using Calcium Sources

CaO is extracted from waste materials and recombined to CO_2 to create artificial limestone, which is used as a raw material to manufacture carbon recycled cement (CRC).



3.9 Green Concrete (CO_2-SUICOM)

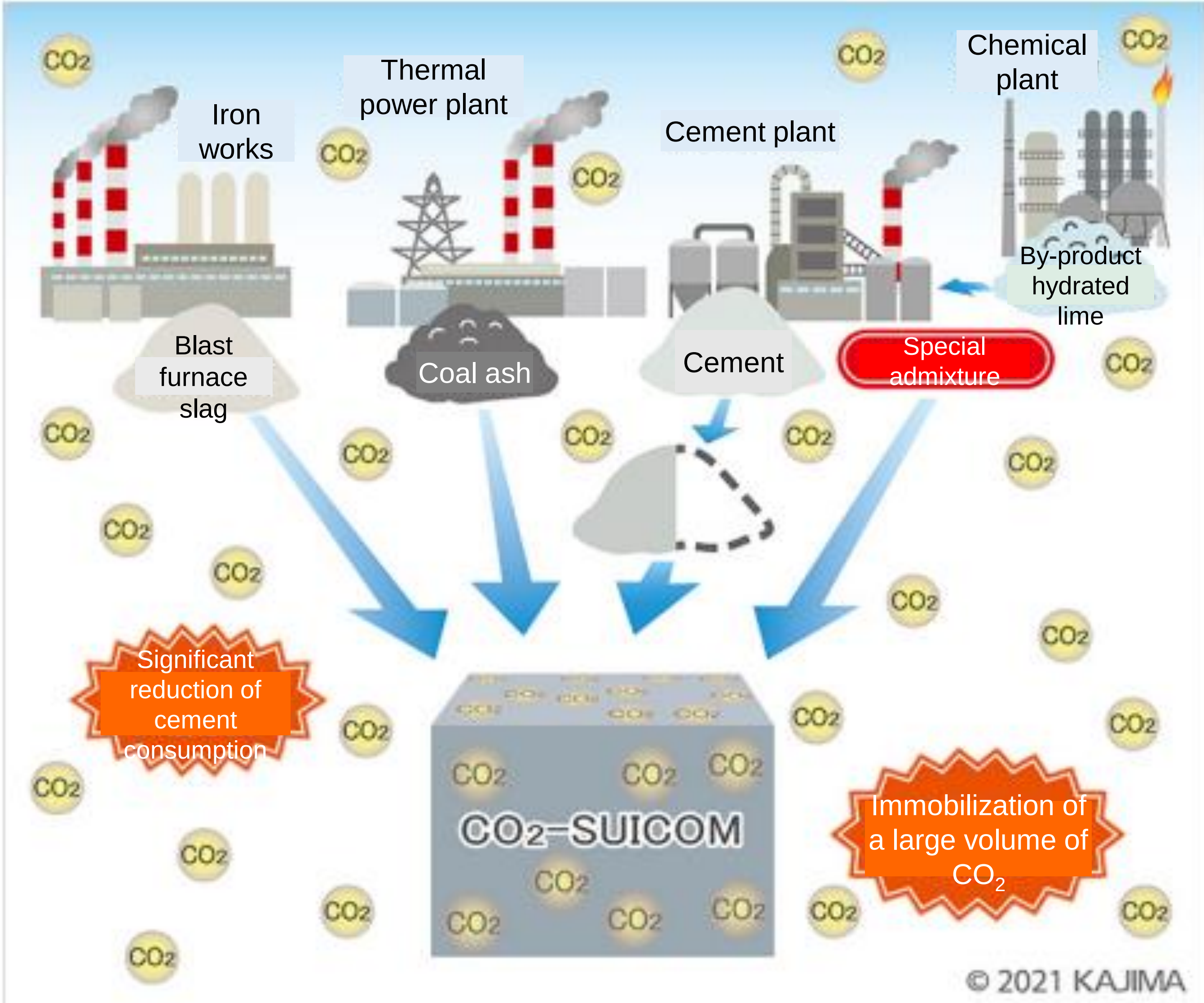
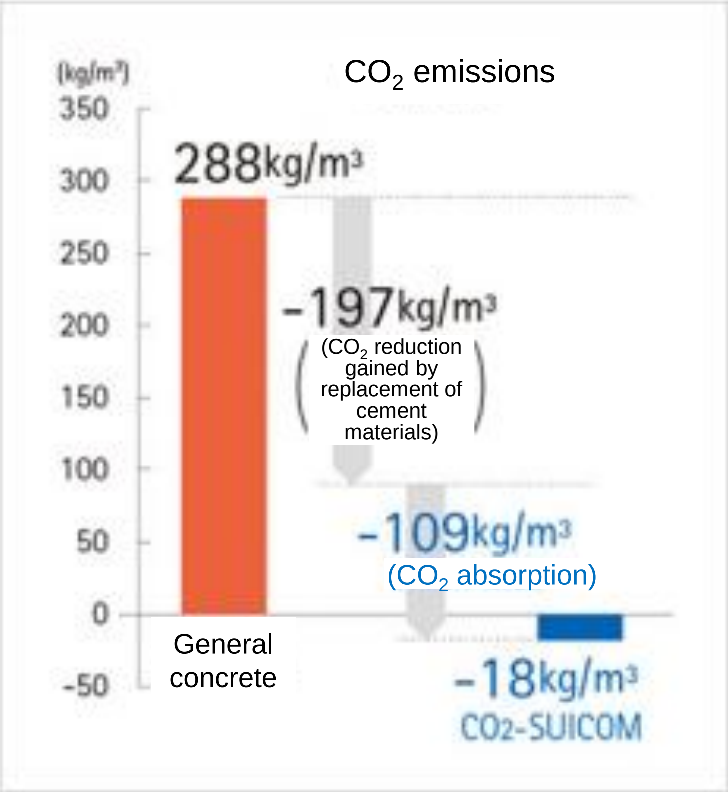


Image of CO_2-SUICOM

Source: KAJIMA CORPORATION

3.10 Green Concrete (CO_2-SUICOM)

Result of estimated CO_2 emissions



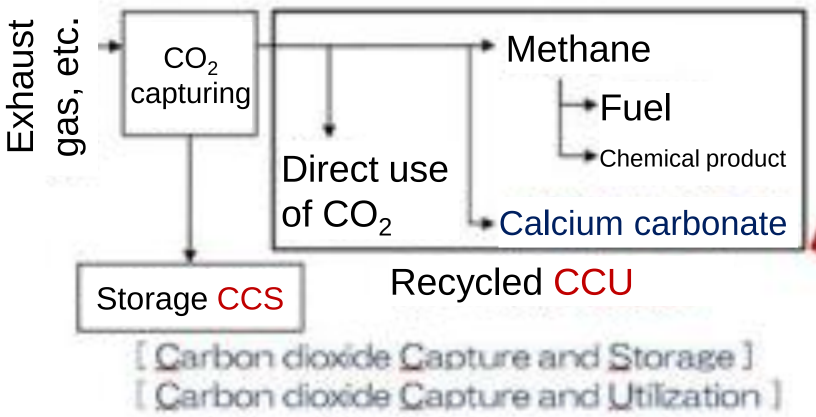
Affinity to plants

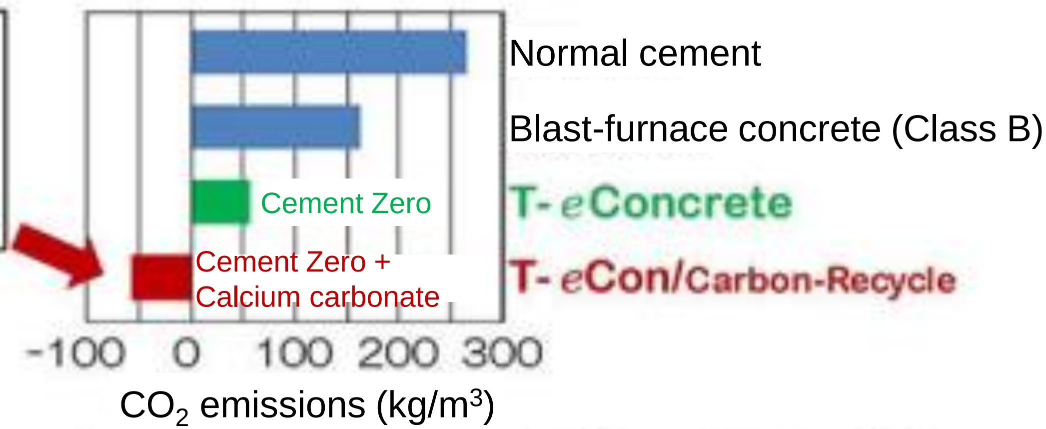
Seeds of brassica rapa were planted on the soil created by mixing each of different types of cement paste (W/C=50%) with sand or black soil at a ratio of 1:1.

Source: KAJIMA CORPORATION

3.11 Carbon Recycled Concrete

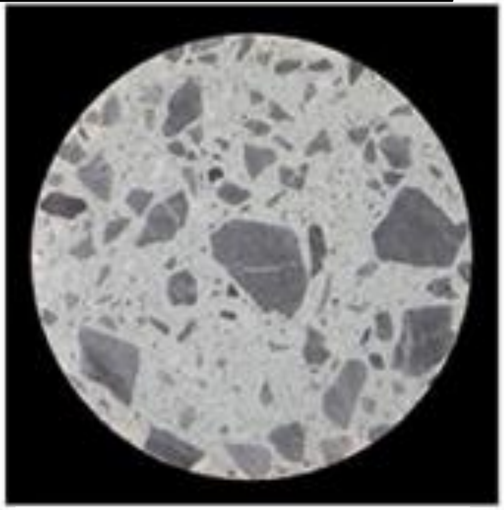
Immobilization of CO_2 inside concrete



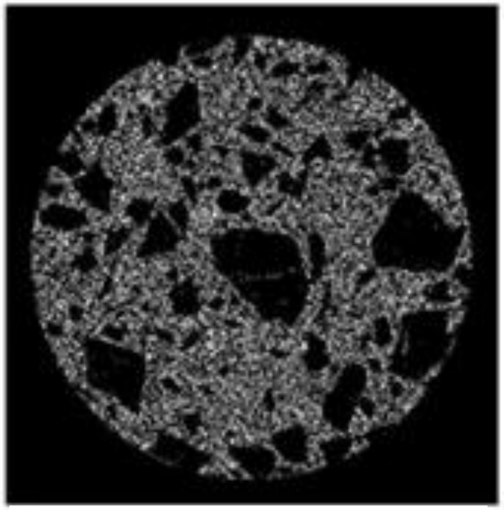


(Assumption: 0.5 kg of CO_2 is emitted from manufacturing of calcium carbonate with 1 kg of immobilized CO_2)

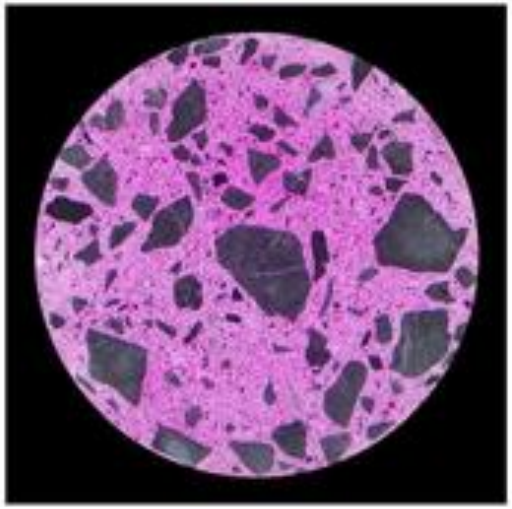
Cross-sectional views



(Cross section (Diameter: 10 cm)



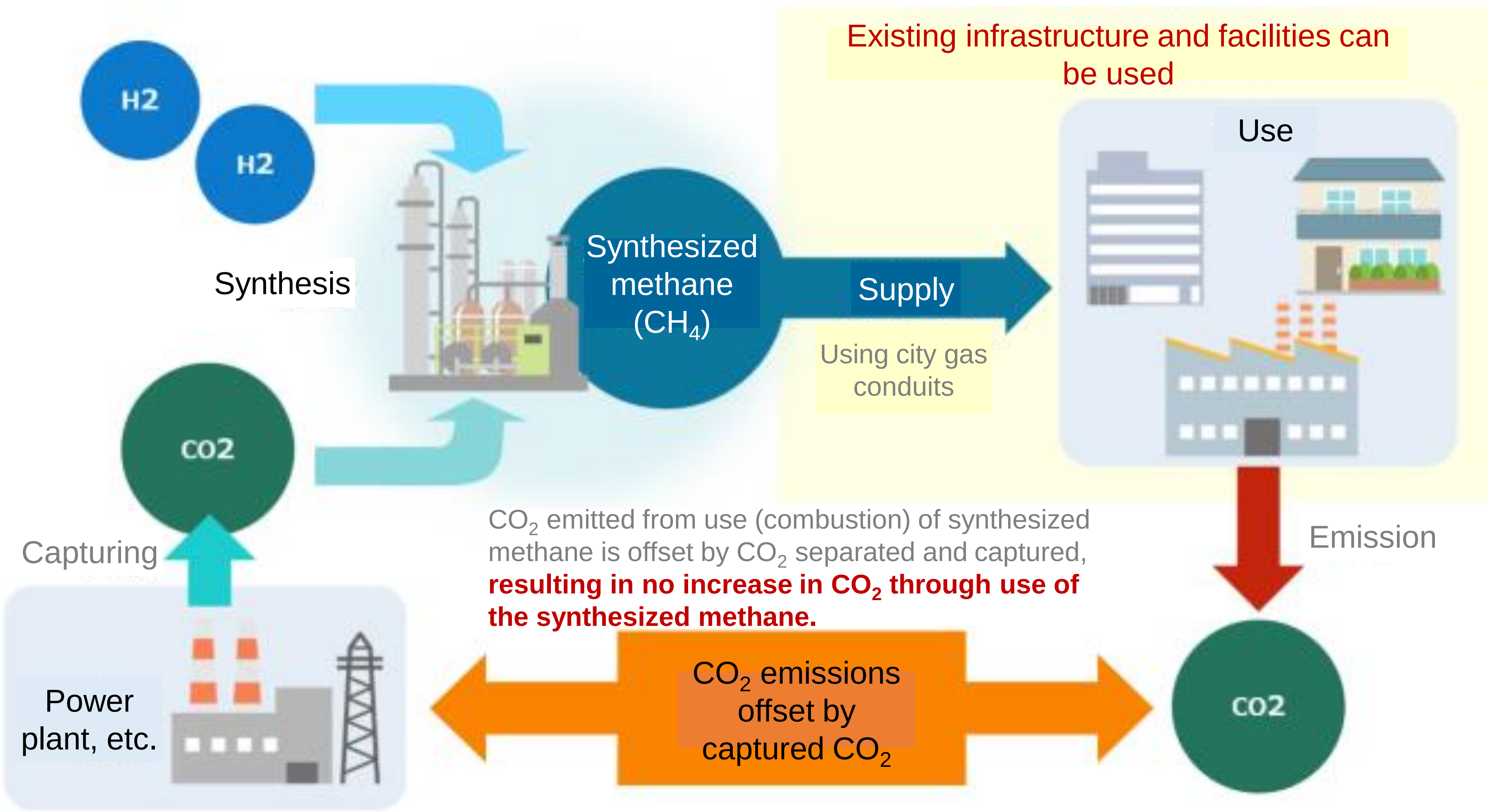
Distribution of immobilized CO_2 (carbon) (white dots)



After spraying pH indicator (Pink color indicates strong alkaline)

Source: TAISEI CORPORATION

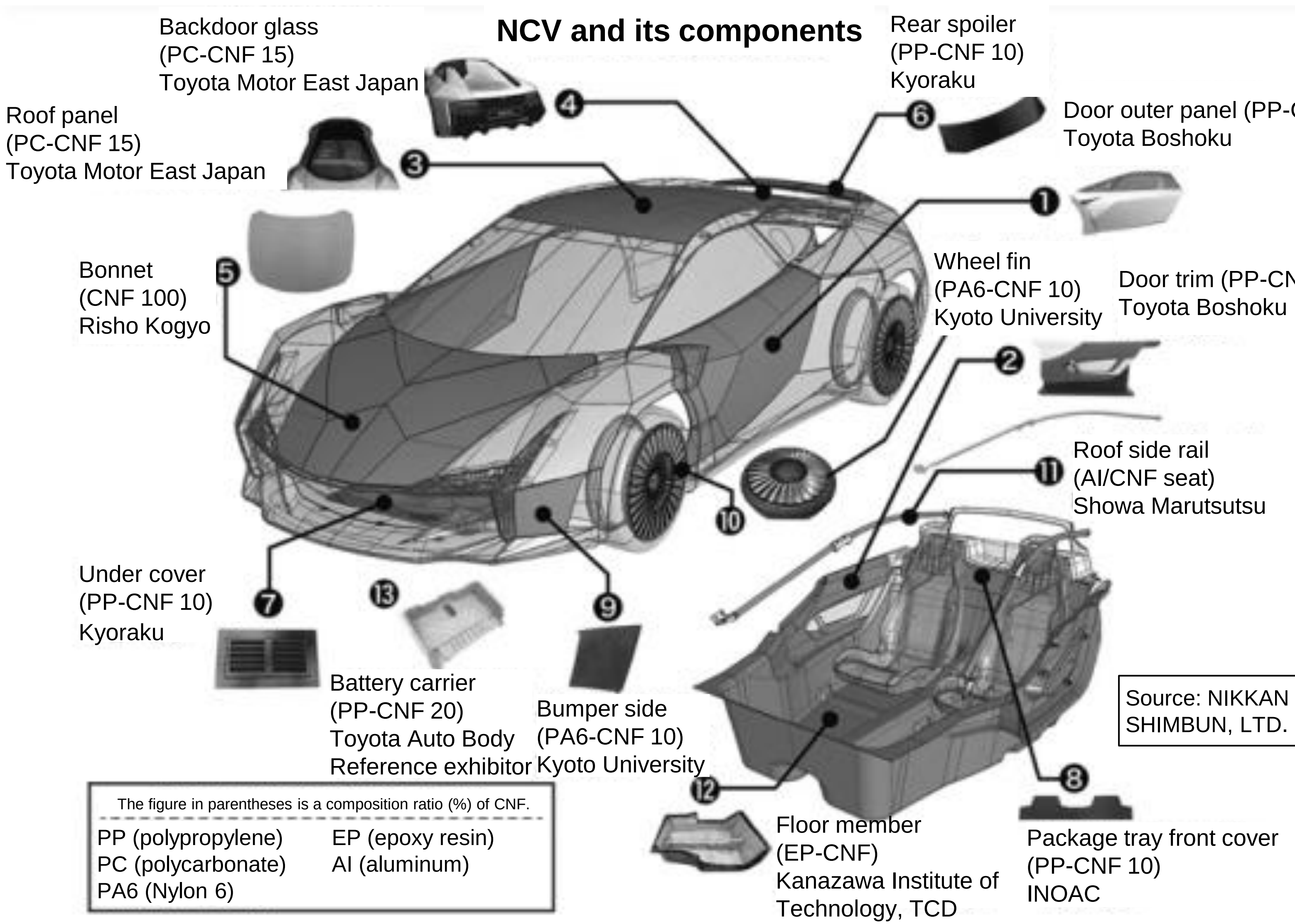
3.12 Use of CO_2: Methanation



(Source) Partially revised the "Carbon Neutral Challenge 2050 Action Plan", The Japan Gas Association

3.13 Use of CO_2 : Cellulose Nanofiber (CNF)

Use of CNF materials leads to decrease in weight by 16% and improvement in fuel efficiency by 11%.



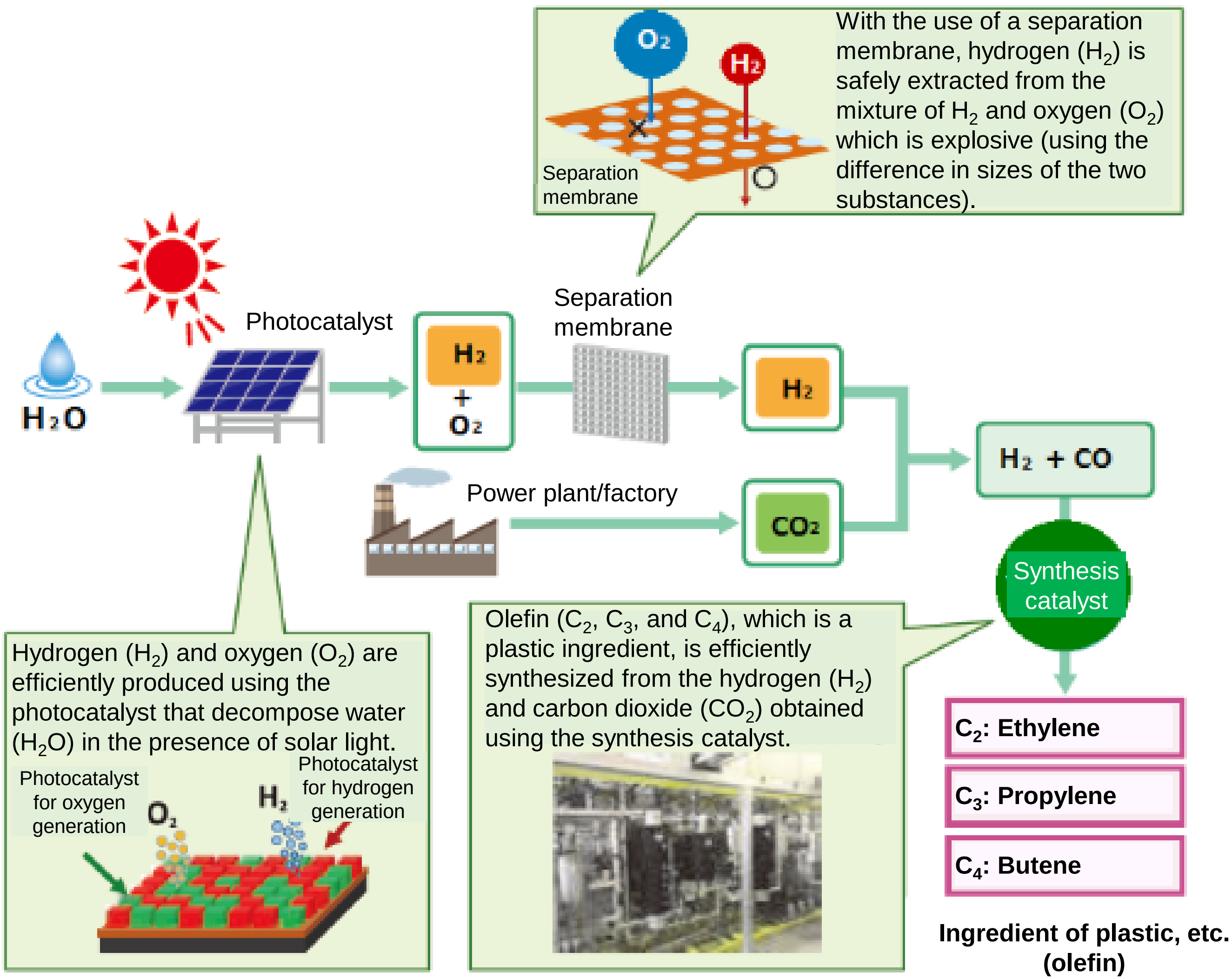
Source: NIKKAN KOGYO SHIMBUN, LTD.

The figure in parentheses is a composition ratio (%) of CNF.

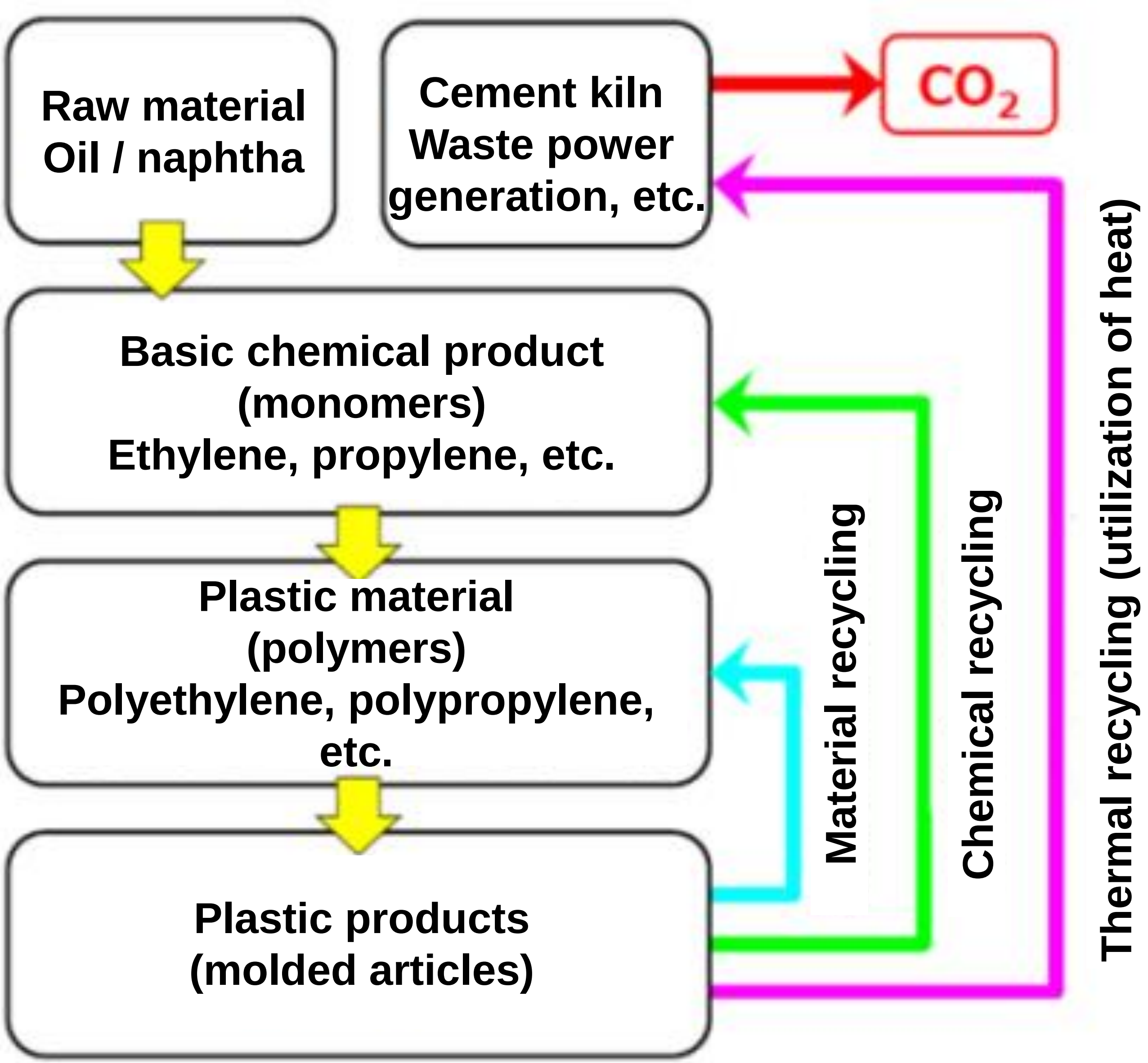
PP (polypropylene)
PC (polycarbonate)
PA6 (Nylon 6)
EP (epoxy resin)
Al (aluminum)

3.14 Use of CO_2 : Artificial Photosynthesis

Process of manufacturing olefin using artificial photosynthesis

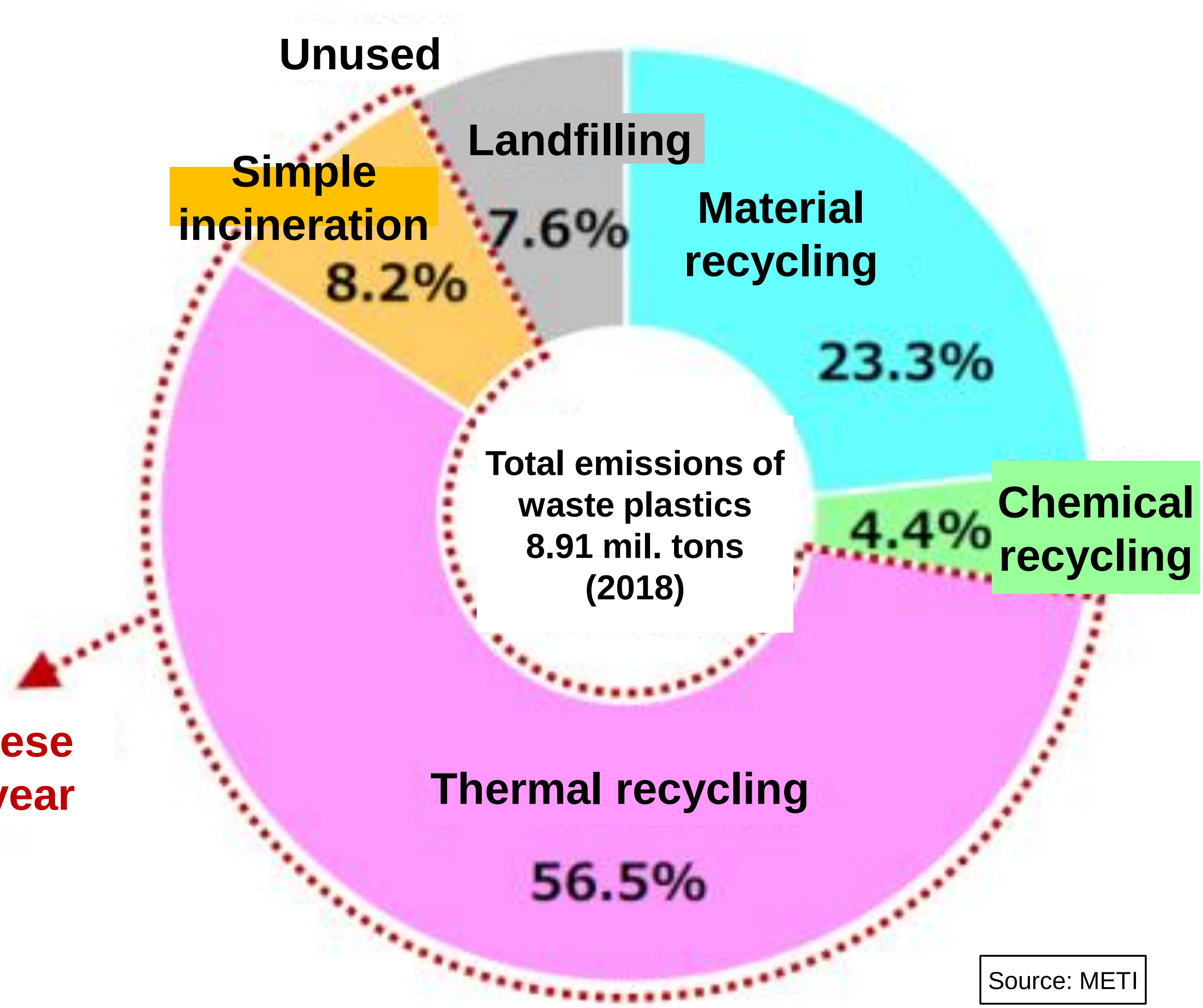


4.1 Recycling Technologies (Plastic Manufacturing)



Source: METI

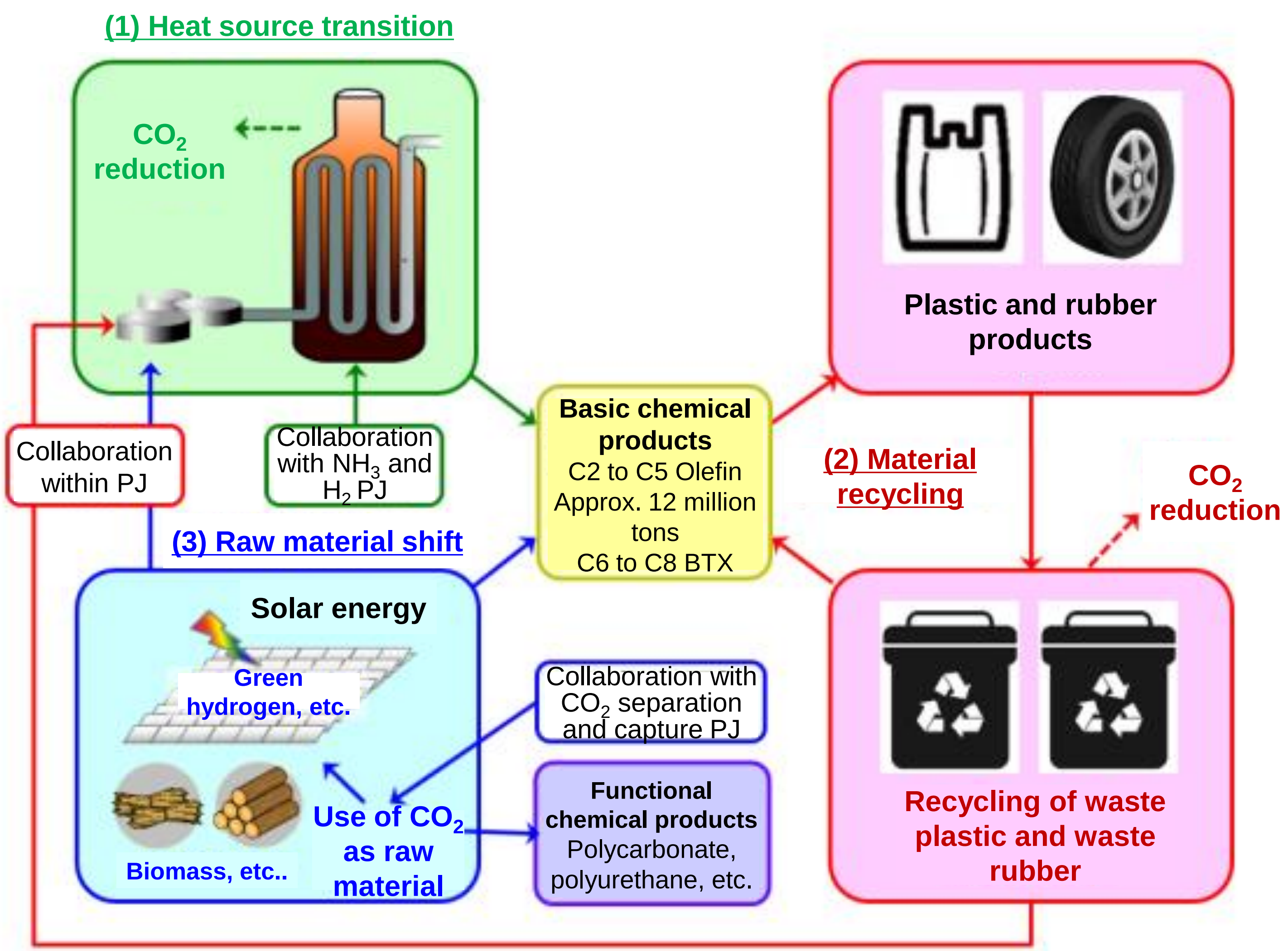
4.2 Recycling Technologies (Plastic Manufacturing)



CO_2 emitted from these 16 million tons per year

Source: METI

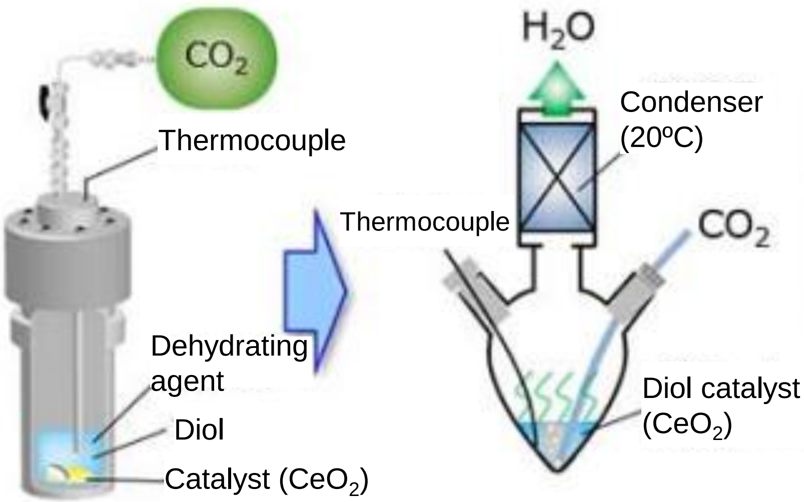
4.3 Recycling Technologies (Plastic Manufacturing)



4.4 Synthesis of Plastic from CO_2

Removed by distillation

CO_2 + Diol $\xrightarrow[210℃]{CeO_2}$ Polyurethane intermediate (polycarbonate diol) + H_2O



General method

New method (distillation)

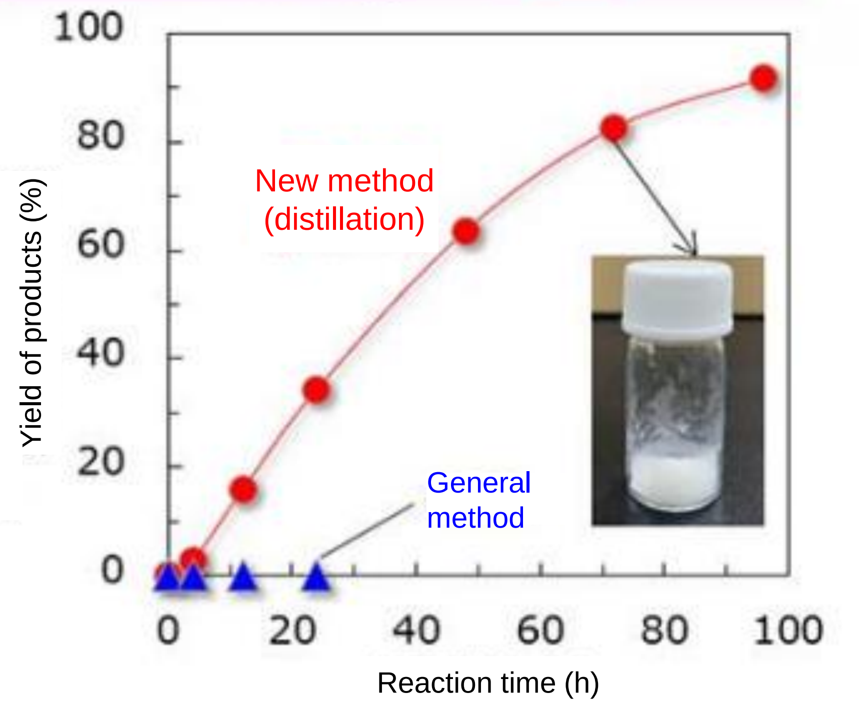


Fig. Dependency of yield of polycarbonate diol on reaction time

$$\text{Yield of products (\%)} = \frac{\text{Produced polymer (mmol)}}{\text{Diol put in a flask (mmol)}} \times 100$$

Source: EMIRA