NIPPON STEEL

Trends of CCU Technology in Japan and Activities of Nippon Steel Corporation

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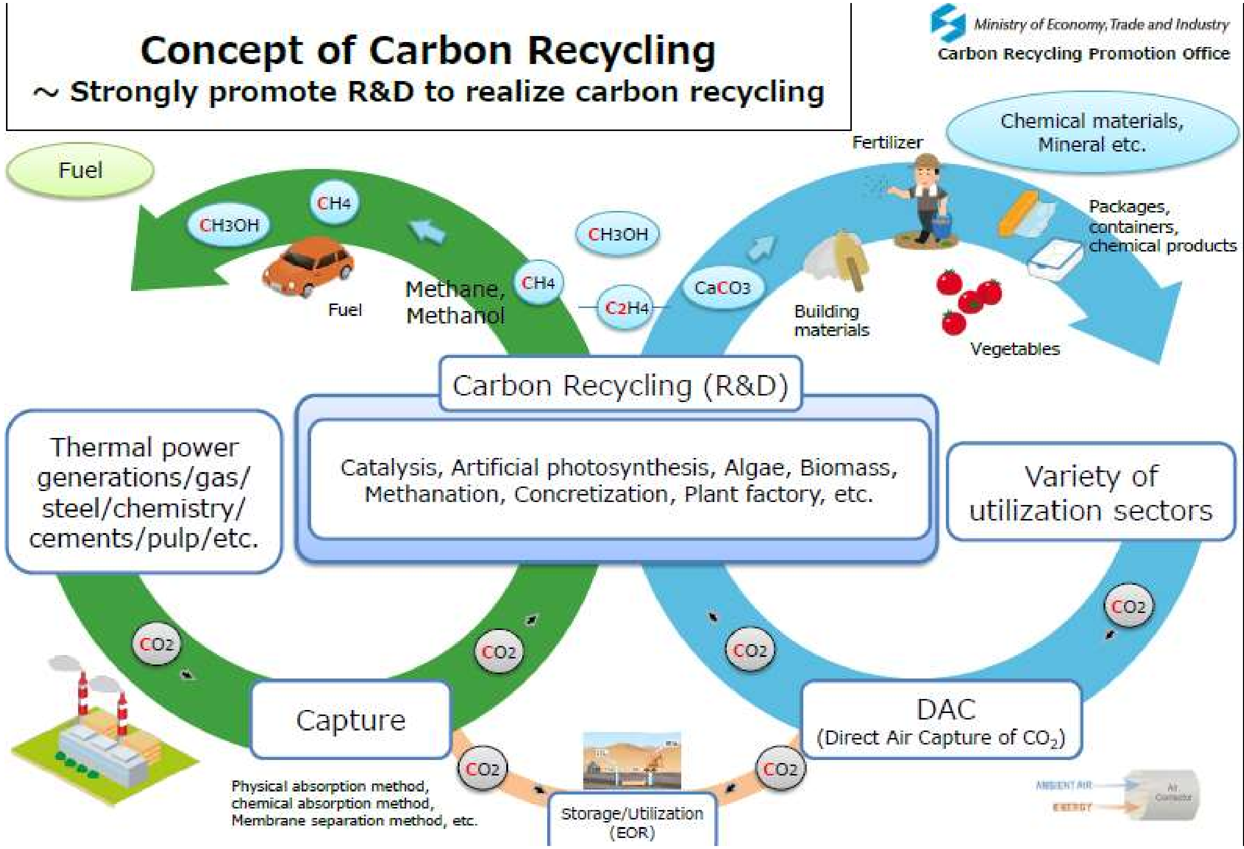
Background of CCU

The Agency for Natural Resources and Energy (ANRE) established a new office named the "Carbon Recycling Promotion Office" aiming to promote technological innovations involving capture, storage and utilization of carbon dioxide.



International Conference on Carbon Recycling was just held.

Date and time: In the afternoon of September 25 (Wed.), 2019

Venue: Tokyo metropolitan area Program: Presentations and panel discussions

Organizers: METI and NEDO

Background of CCU

There were calls to accelerate the introduction of various renewable energies — especially hydrogen. The ministers promised to step up existing international efforts to utilize hydrogen, which has long been a goal of Japan in particular.

On fossil fuels, the ministers called for using more liquid natural gas, which produces fewer carbon dioxide emissions than coal. But despite international pressure on the G20 to get out of coal, the ministers continued to show support for coal investment, especially in carbon capture and storage (CCS) and carbon capture and usage (CCU) technologies.

Background of CCU

[G20 Energy and Environment Ministers Meeting]

・ Carbon Recycling was unanimously included in the joint statement of the G20 Energy and Environment Ministers Meeting (at Karuizawa).

・Saudi Arabia's proposal "Emissions to Value" was included. The EU, especially Germany, insisted on removing "Carbon Recycling" from the joint statement, but succeeded.

・ In Japan / Saudi Arabia, establish a forum for regular discussions on CR technology. The first meeting will be at the CR International Conference on September 25th. Saudi Arabia will be the G20 presidency next year, and CR technology will be on the agenda next year.

・ Coal-fired power is necessary to realize the SDGs. Of the G20, we have the support of 19 countries. It is the EU that is isolated.

CO2で素材・燃料生産

三菱ケミなど 商用化へ16社連合

三菱ケミカルやJパワーなど16社は、発電所などから出る二酸化炭素（CO2）を回収し再利用する技術の開発で手を組む。CO2をもとに衣料や建材の素材、燃料などを作る技術の確立を目指す。世界の発電のうち6割程度は石炭や天然ガスなどの化石燃料が占める。CO2の排出抑制を進め、地球温暖化対策とエネルギー供給の両立を図る。

16社は近く「カーボンリサイクルファンド」と呼ぶファンドを立ち上げる。素材分野にノウハウがある三菱ケミカルや火力発電が中心のJパワー、三菱重工業と日立製作所が火力発電部門を統合した三菱日立パワーシステムズ（横浜市）やIHI、川崎重工業などが参画する。約1億円で立ち上げ、民間資金や銀行の融資を呼び込んで新たな技術開発に投資する。

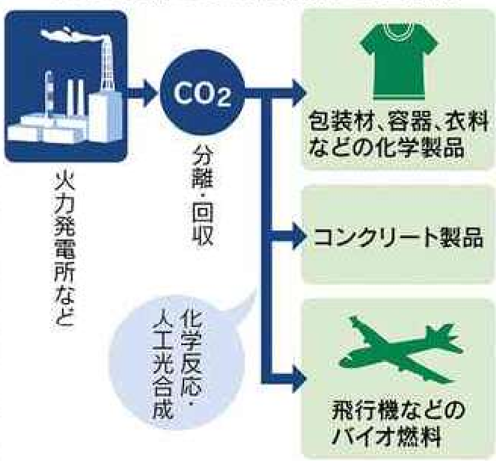
まずはCO2を回収し、別の素材に変える技術に力を入れる。CO2を原材料として、触媒による反応や化学物質との合成でコンクリートなどの素材を作る技術がある。

これらの技術は現時点では製造コストが高すぎ、商用ベースの実用化はできていない。商用化を目指してコスト低減できる技術を軸に、企業や研究者に資金を出す。研究成果などは出資者で共有し、具体的な製品や工程の開発につなげる。

ファンド設立の背景には、欧州を中心に広がる「脱炭素」の流れがある。CO2の排出が多い石炭火力発電は、機関投資家が投資対象から外すといった動きがある。

一方で世界の発電量のうち石炭火力は4割を占める。太陽光や風力が普及するドイツでも石炭火力が4割で再生エネを上回る。石炭、液化天然ガス（LNG）、石油の化石燃料が主要なエネルギー源となる構図は当面続く。温暖化対策にはCO2の排出抑制と、排出後の処理が欠かせない。

CO2を資源として再利用する主な例



炭素利用、普及に本腰

経産省 来年度 「CO2→燃料」実証

経済産業省は、二酸化炭素（CO2）を燃料・製品などに再利用する「カーボンリサイクル」について、普及に向けた取り組みを来年度から本格化させる。火力発電の高効率化や二酸化炭素回収・貯留（CCS）の大規模実証試験といった既存の事業を発展させ、回収したCO2から燃料をつくる実証などに着手する。CCS実証では、モニタリング手法の確立なども目指す。2020年度予算の概算要求では、カーボンリサイクル関連費用としてまとめて計上する見込み。

中国電力とJパワー（電源開発）が共同出資する大崎クールジェンによる石炭ガス化燃料電池複合発電（IGFC）の実証事業を通じ、高効率化に向けた取り組みを継続。経産省が6月にまとめた「カーボンリサイクル技術ロードマップ」を踏まえ、回収したCO2からバイオ燃料などをつくる技術の実証にも乗り出す。

また、北海道苫小牧市で実施されているCCSの大規模実証事業では、2016年度から開始したCO2の圧入試験が8月までに累計27万トンに到達。当初目標の30万トンが今年中にも達成できる見通しになった。

圧入後の挙動を確認するモニタリング手法なども合わせて確立させた上で、来年度以降は利用面での展開を図る。

カーボンリサイクルを巡って、経産省は今年2月に専門部署を立ち上げ、省内の体制を一元化した。G20（主要20カ国・地域）エネルギー・環境関係閣僚会合では、国際協力を呼び掛けるなど、普及を見据えた取り組みを本格化させている。

一方、予算に関してはこれまで各事業を個別に計上してきた。20年度予算の概算要求では、カーボンリサイクルのイノベーション創出に向けた関連費用としてまとめて計上する予定。500億円規模で調整している。

ドル建て社債 5年物5億ドル

中国電力

中国電力は21日、機関投資家向けに米ドル建ての5年物普通社債5億ドル（約532億円）を発行すると発表した。利率は年2・401%。払込期日は27日で、償還期限は2024年8月27日。外貨建ての社債は今年2月にも発行しており、今年度は初めて。同社は電力の小売り全面自由化などの事業環境の変化を踏まえ、資金調達手段の多様化や投資家層の拡大を進めている。今回のドル建て社債発行もこうした取り組みの一環となる。

19年度の長期資金調達は3500億円を上限に計画しており、今年度の調達額は今回を含めて約1232億円となった。

平均単価は同1円70銭高の19円23銭（前月比…51銭安）だった。

5月単月のスイッチング（供給者変更）件数は全国で36万26…7件（前月比4万25…39件減）。内訳は、みなし小売電気事業者から新電力が26万88…22件（前月比1万9…874件減）、新電力からみなし小売電気事業者が1万6832件（前月比4426件…

Contents of today's presentation

1. CCU Roadmap in JAPAN
2. Activities
   in Nippon Steel Corporation
3. Blue Carbon Technology
4. Conclusions

Roadmap for Carbon Recycling Technologies

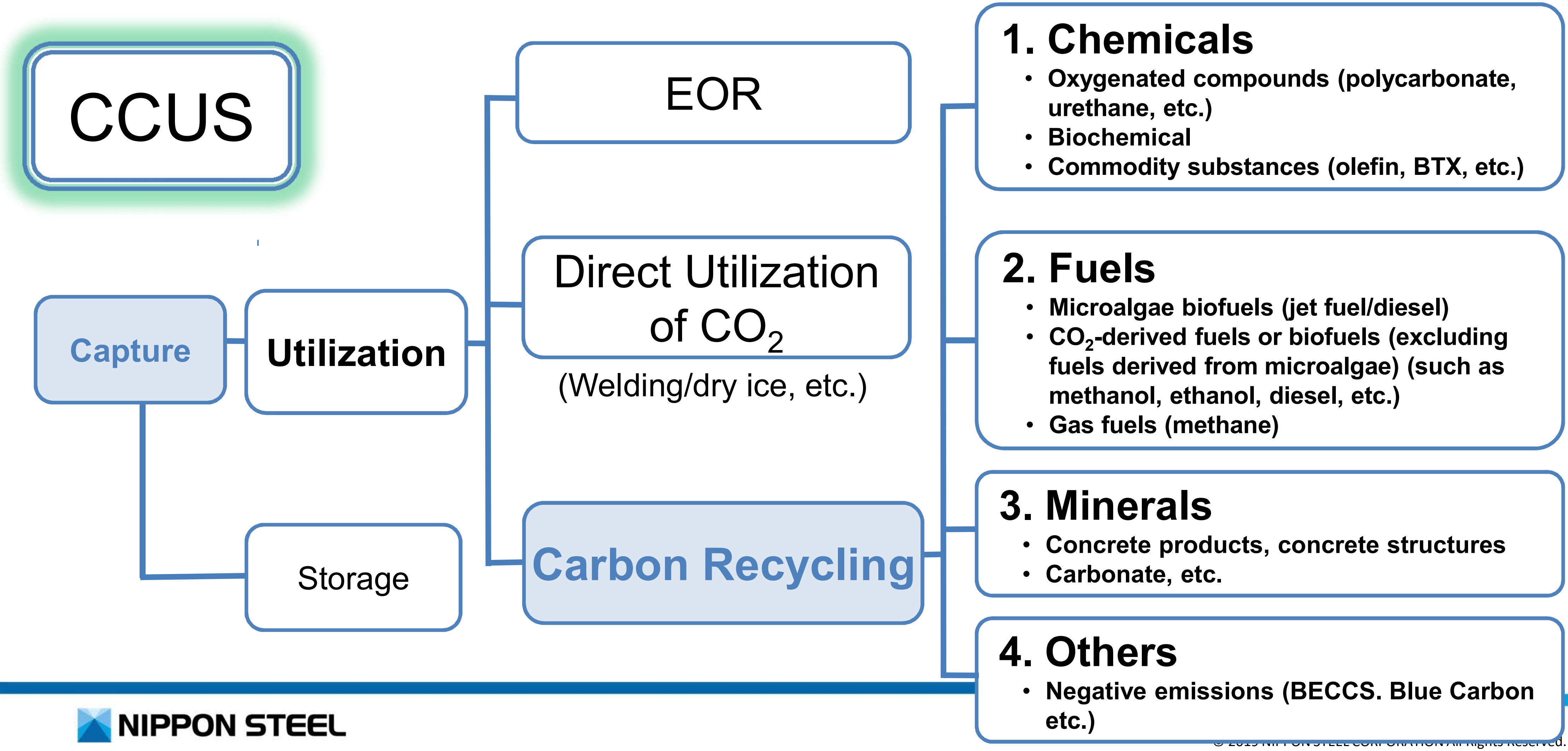
June 2019

Ministry of Economy, Trade and Industry

Cooperation of Cabinet Office,
Ministry of Education, Culture, Sports, Science and Technology &
Ministry of the Environment

CCUS/Carbon Recycling

- Carbon Recycling technology, recognizing carbon dioxide as a source of carbon, capturing and recycling it as raw materials and fuels by mineralization, artificial photosynthetic or Methanation as well as controlling the CO_2 emissions to the air.
- Carbon Recycling technology focuses upon the research and development of CO_2 Utilization in collaboration among industries, academia and governments around the world and promotes disruptive innovation.
- Carbon Recycling is one of key technology for the world together with energy saving, renewable energy and CCS



Roadmap for Carbon Recycling Technologies

Volume level of utilized CO_2

Chemicals (polycarbonate, etc.)

For the polycarbonate, further reduction volume of CO_2.

Liquid Fuels (Bio-jet fuel, etc).

Cost must be reduced by around1/8 - 1/16 of current one.

Concrete Products (Road curb blocks, etc.)

Cost must be reduced by 1/3 – 1/5 of current one

Phase 1

- Any technology that is suitable for carbon recycling initiatives must continue to be developed.
- Special efforts must focus on technologies requiring no hydrogen and technologies used to produce high-value added articles, both of which shall be expected to spread from around 2030 onwards.

Phase 2

- Attempt to make a cost reduction of technologies that are expected to spread from 2030 onwards.
- Of the technologies that are expected to spread from 2050 onwards when reasonable price of hydrogen will be supplied, focusing on R&D on those that are used to produce large demand products. Attempt to reach equivalent cost of existing energy and products towards 2050 onward.

Expected to Spread from 2030

- Chemicals
  Polycarbonate, etc.
- Liquid Fuels
  Bio-jet fuel, etc.
- Concrete Products
  Road curb blocks, etc.

Phase 3

- Address further cost reduction

Expected to be highly consumed from 2030

- Chemicals
  Polycarbonate, etc.
- Liquid Fuels
  Bio-jet fuels, etc.
- Concrete Products
  Road curb blocks, etc.

Expected to Spread from 2050

- Chemicals
  Commodity (Olefin, BTX, etc.)
- Fuels
  Gas, Liquid
- Concrete Products
  Commodity

Hydrogen JPY 20/Nm^3 (cost at plant delivery)

CO_2 capturing technology Reducing cost Less than ¼ of current cost

Current 2030 From 2050 onwards

Review: Adding technologies flexibly based on the state of the international technology obtained through the International Conference on Carbon Recycling among Industry-Academia-Government, or new proposals, and review the roadmap in five years and if needed, as well as taking into account the revision of "Long term Strategy for Growth strategy based on the Paris Agreement (tentative translation)".

Summary of Carbon Recycling Technology R&D

※1 Price researched by secretariat
※2 Basic substances, chemicals(excluding some oxygenated compounds), many technologies for fuels require large amounts of inexpensive CO_2-free hydrogens
Biomass-derived fuels may require hydrogen for hydrogenation treatment, etc.

Category	Substance After CO_2 Conversion	Current Status※1	Tasks/ Challenges	Price of the Existing Equivalent Product※1	In 2030	From 2050 Onwards
Basic Substance	Syngas/Methanol, etc.	Partially commercialized. Innovative process (light, electricity utilization) is at R&D stage	Improvement of conversion efficiency and reaction rate, improvement in durability of catalyst, etc.	—	Reduction in process costs	Further reduction in process costs
Chemicals	Oxygenated Compounds	Partially commercialized (polycarbonates, etc.), Others are at R&D stage [Price example] Price of the existing equivalent product (Polycarbonate)	Reduce the amount of CO2 emission for polycarbonate. Other than polycarbonate, etc. commercialized (Improvement in conversion rate/selectivity, etc.)	Approx. JPY 300-500/kg (polycarbonate (domestic sale price))	Costs: similar to those for existing energy/products	Further reduction in costs
	Biomass-derived Chemicals	Technical development stage (non-edible biomass)	Cost reduction/effective pretreatment technique, etc. conversion techniques, etc.	—	Costs: similar to those for existing energy/products	Further reduction in costs
	Commodity (olefin, BTX, etc.)	Partially commercialized (Syngas, etc. produced from coal, etc. is utilized)	Improvement in conversion rate/selectivity, etc.	JPY 100/kg (Ethylene (domestic sale price)	—	Costs: similar to those for existing energy/products
Fuels	Liquid Fuel (microalgae biofuel)	Demonstration Stage [Price example] Biojet Fuel: JPY 1600/L	Improvement productivity, cost reduction/ effective pretreatment technique, etc.	JPY 100/L level (bio-jet fuel (domestic sale price))	Costs: similar to those for existing energy/products (JPY 100-200/L)	Further reduction in costs
	Liquid Fuel (CO_2-derived fuels or biofuels (excluding microalgae-derived ones))	Demonstration stage (E-Fuel, etc.), partially commercialized for edible biomass-derived bioethanol	Improvement in current processes, system optimization, etc.	JPY 50-80/L (alcohol as raw material (imported price) JPY approx. 130/L Industrial alcohol (domestic sale price)	—	Costs: similar to those for existing energy/products
	Gas Fuel (Methane)	Demonstration Stage	System optimization, scale-up, etc.	JPY 40-50/Nm^3 (Natural gas (imported price))	Reduction in costs for CO_2–derived CH_4	Costs: similar to those for existing energy/products
Minerals	Carbonates/Concrete products, concrete structures	Partially commercialized. R&D for various technologies techniques are underway towards cost reduction. [Price example] JPY a few 100/t (Road curb Block)	Separation of effective components to respond to CO_2, pulverization, etc.	JPY 30/kg (Road curb block (domestic sale price))	Road curb Block costs: similar to those for existing energy/products	Other products, except road curb block costs: similar to those for existing energy/products
common Technology	CO_2 Capture	Partially commercialized (chemical absorption). Other techniques are at research/ demonstration stage [Price example] Approx. JPY4000/t-CO_2 (Chemical Absorption Technique)	Reduction in the required energy, etc.	—	JPY 1000-2000/t-CO_2 level (chemical absorption, solid absorption, physical absorption, membrane separation)	JPY 1000/t-CO_2 or lower
Basic Substance	Hydrogen	Technologies have been roughly established (water electrolysis, etc.) R&D for other techniques are also underway towards cost reduction	Cost reduction, etc.		JPY 30/Nm^3	JPY 20/Nm^3 (cost at plant delivery)

Scope of Carbon Recycling Technology Roadmap

The carbon recycling technology considers to use CO_2 as resource, thus CO_2 can be utilized even if the replacement of existing products with new ones (resulting from this technology) has occurred in small quantity. Therefore, with cost effectiveness in mind, we continue aiming to allow this technology to be established and spread in as many different fields as possible.
In that case, 2030 shall be set as a relatively-short-term target while 2050 onward as a mid- to long-term target.

2030: Technologies aiming at achieving commercialization as early a stage as possible.
(1) Establish an environment where easy utilization of CO_2 (reducing costs for capture/recycle of CO_2)
(2) Technologies which basic technology is established, can replace the existing products by reducing costs
(Products to manufacture do not require inexpensive hydrogen as well as products with high-value added which easily replacing existing products)

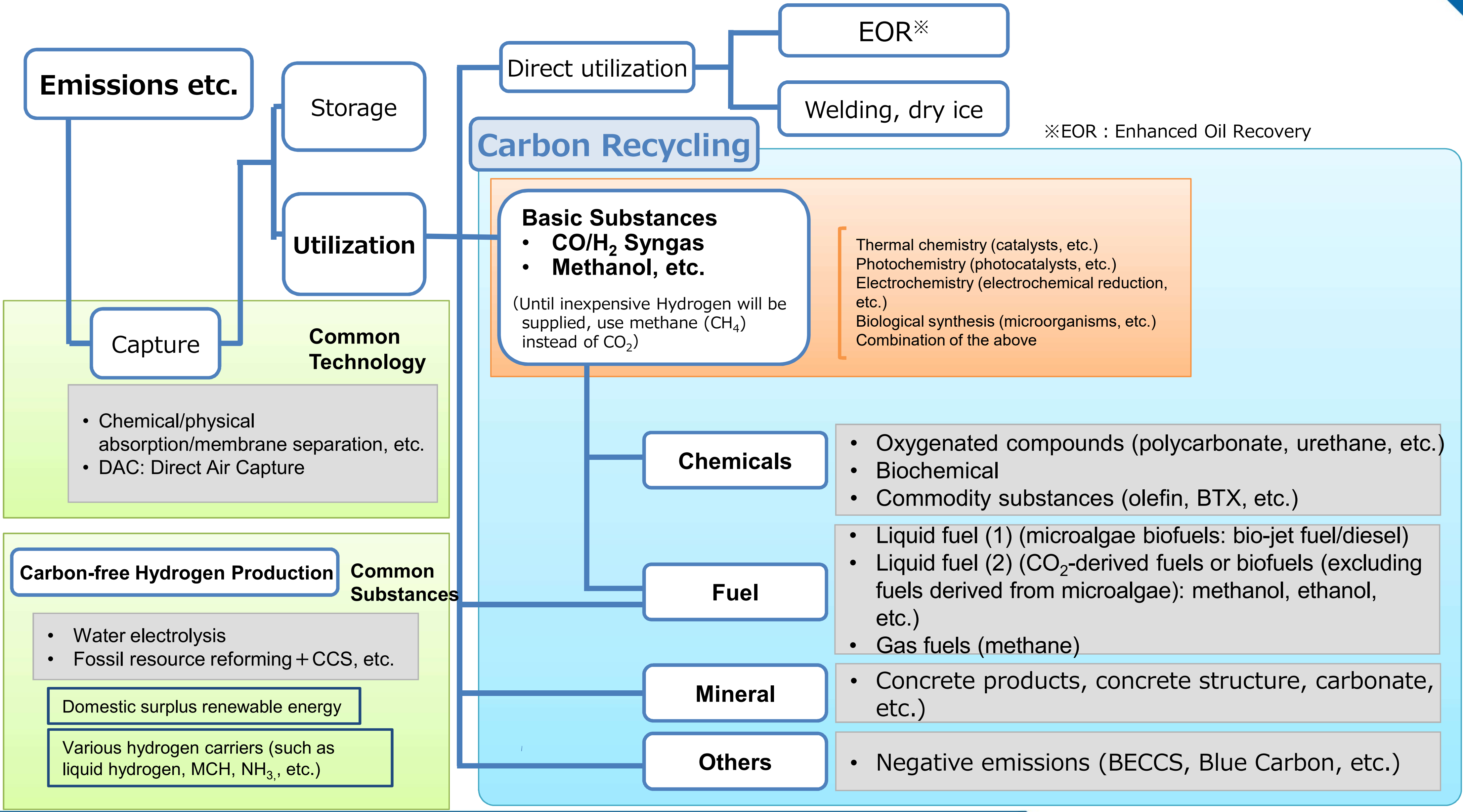
2050: Technologies aiming at achieving commercialization in the mid- to long-term.
○ Technologies that has not yet been established, but that has great impacts on the use of large amount of CO_2 if the technologies have been realized
(Technologies require utilization of hydrogen at low costs)

	2030 (short-term)	2050 onward (mid-to long-term)
Field	Technology requiring no hydrogen and/or high value added products will be commercialized as a start: • Chemicals (polycarbonate, etc.) • Liquid fuels (bio-jet fuel, etc.) • Concrete products (road curb blocks, etc.)	Extended to products that have large demand: • Chemicals (commodity: olefin, BTX, etc.) • Fuels (gas, liquid) • Concrete products (commodity)

Individual technologies

CCUS/ Carbon Recycling

- Carbon Recycling technology, recognizing carbon dioxide as a source of carbon, capturing and recycling it as raw materials and fuels by mineralization, artificial photosynthetic or Methanation as well as controlling the CO_2 emissions to the air.



Common Issues: Overall optimization of heat/pressure/materials (cost reduction, etc.) and LCA (comparison with the current process)

Common technology

• CO_2 Capture Technology

<Technological Challenges>

- Reduction in equipment/operational costs and in required energy
  Development of new base materials (absorbents, adsorbents, separation membrane)
  (for selectivity/capacity/durability improvements)
  Reduction in production costs of base materials
  Optimization of processes(in terms of heat/substance/power, etc.)
- Selection of the types of separation and capture techniques based on the CO_2 emission source/use application
- Establishment of CO_2 separation and capture systems suitable for the carbon recycling that ensures cooperation between CO_2 emission sources and demanders/suppliers (co-production)
- Transportation & storage

<Respective Technologies>

- Chemical absorption technique (temperature difference (current process))
  Approx. JPY 4,000/t-CO_2
  Required energy: Approx.2.5GJ/t-CO_2
- Physical absorption technique (pressure difference (demonstration stage))
- Solid absorption technique (temperature difference) (R&D stage)
- Physical adsorption technique (pressure/temperature difference, less advantages from upsizing, improvements in selectivity/capacity/endurance)
- Membrane separation (pressure difference)
- Others include: cryogenic separation technique, Direct Air Capture, etc.

<Process Technologies to facilitate CO_2 Capture>

- Oxygen-enriched/closed IGCC
  Development of low cost oxygen supply technology
- Chemical Looping
  Development of low-cost, long-lasting oxygen carriers

Target for 2030

- For Low-pressure gas (CO_2 separation from flue gas, blast furnace gas, etc.)
  JPY2,000 level/t-CO_2
  Required energy 1.5 GJ/t-CO_2
  Chemical absorption, solid absorption, etc.
- For high-pressure gas (CO_2 separation from chemical process/fuel gas, etc.)
  JPY1,000 level/t-CO_2
  Required energy 0.5GJ/t-CO_2
  Physical absorption, membrane separation, etc.
- Overall review of other processes
  Closed IGCC/Chemical looping, etc.
  JPY1,000 level/t-CO_2
  Required energy 0.5GJ/t-CO_2

<Establishing a CO_2 Separation and Catch system>

- Realization of an energy-saving, low cost CO_2 Separation and Catch System that is suitable for each CO_2 emission source/usage
- Realization of 10,000 hour continuous operation8 (to demonstrate the durability & reliability)

Target from 2050 Onwards

<Commercialization of separation and capture technology>

- Achieve JPY1,000/t-CO_2 or lower
- Improve the durability/ reliability of CO_2 separation and capture systems
- Optimize CO_2 separation and capture systems based on the emission source/the type of operation in the field of application
- Full-fledged spread of CO_2 separation and capture systems

Common technology

- Explanations on CO_2 capture technologies

Capture technologies	Technology overview	Scope of application
Chemical absorption	• This is a technology to separate and capture CO_2 , by using a chemical reaction between CO_2 and liquid.	Fire plant/cement/steel & iron/petroleum refinery/chemical industry/natural gas mining
Physical absorption	• This is a technology to separate and capture CO_2 by dissolving CO_2 into liquid. • The absorbing power depends the solubility of CO_2 relative to the liquid used.	Fire plant (high voltage)/petroleum refinery/chemical industry/natural gas mining
Solid absorption	• This is a technology to separate and capture CO_2 by utilizing solid absorbents. • Examples of application of this technology rely on the use of porous materials in which amines, etc. are impregnated (for low temperature separation) or on the use of a solid absorbent that is capable of absorbing CO_2 (for high temperature separation).	Fire plant/cement/petroleum refinery/chemical industry
Physical adsorption	• This technology, which utilizes a porous solid such as zeolite, is an adsorption/desorption operation by rising and falling the pressure on the solid (pressure swing) or by rising and falling the temperature on the solid (temperature swing).	Fire plant/steel & iron/cement/ petroleum refinery/chemical industry
Membrane separation	• This technology, which utilizes an membrane with separation functions, is a method to separate a target gas (CO_2) from gas mixture, with the aid of the permselectivity of the membrane.	Fire plant (high voltage)/petroleum refinery/chemical industry/natural gas mining

Basic substances

- Methane Chemistry, etc.
  (Until inexpensive Hydrogen will be supplied, use methane (CH4) instead of CO2.)

[CH_4→Syngas (1)]
- Established as a commercial process
- Partial oxidation/ATR, dry reforming: There is a room for improvement, such as making the reaction temperature lower, searching suitable catalysts, improving durability, etc.

[CH_4→Others]
- Separation under high temperature conditions (hydrogen & benzene, etc.)
- Direct synthesis of methanol(2) and of ethylene (3) are still at R& D stage.
- Methane thermal cracking where CO_2-free hydrogen can be obtained is still at R& D stage (catalyst development, carbon removal/utilization technology)

[Wastes→Useful Substances]
- Sophisticate a recycling technology that utilizes waste plastics(physical selection of plastics, removal of impurities, halogen-resistant catalysts, etc.)
- Establishment of industrialized process

<Other Challenges>
- Heat management, equipment costs, development of low-cost oxygenation (such as the utilization of oxygen concurrently produced during electrolysis)

Target for 2030

<Technological Goal>
- CH_4→Syngas Reaction temperature: 600°C or lower
  (Catalyst: life of approx. 8000hr)
- Development a hydrogen separation membrane that is usable even at 600°C

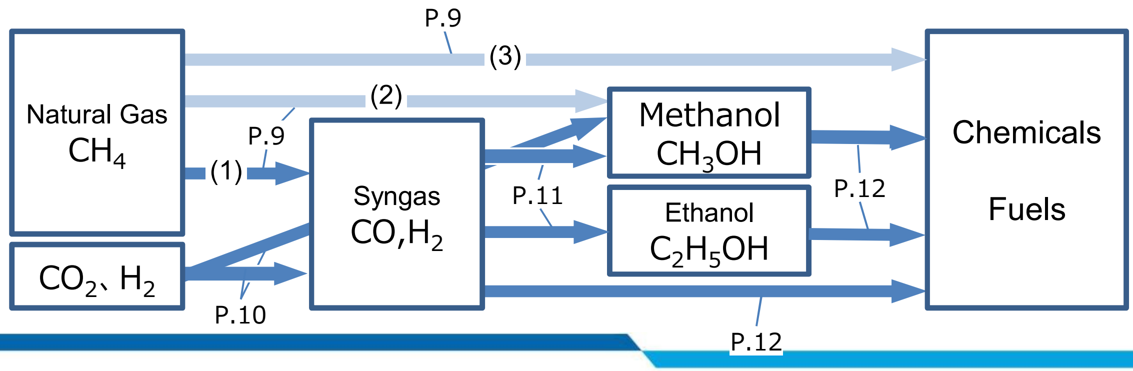
<Costs>
- Costs are similar to those for existing energy/products

<CO_2 Emission Intensity>
- In LCA, the amount of emissions from the current process (crude oil derived) must be equal to or lower than the CO_2 emission intensity

Target from 2050 Onwards

<Costs>
- Raw materials are replaced with CO_2 (Slide 10&11) and the costs are similar to those for existing energy/products

<CO_2 Emission Intensity>
- Further reduction



Basic substances

- Technologies to produce syngas containing Carbon Mono-oxide & Hydrogen

Thermal Chemistry (catalysts, etc.)

<Technological Challenges>
- Further improvement in current processes (reverse-shift reaction)

<Other Challenges>
- Capture & reuse of the CO_2 produced as a byproduct in reaction system

<Example of specific efforts>
- Thermal cracking of CO_2 utilizing solar heat

Photochemistry (photocatalysts, etc.)

Artificial Photosynthesis (photocatalysts)

<Technological Challenges>
- Catalyst Development
  - Hydrogen synthesis (photocatalysts) → Reverse shift reaction
  - Direct synthesis of CO
    - Improvement in conversion efficiency & separation of gas generated

<Other Challenges>
- System design of a plant whose commercialization is viable
- Examination & comparison with the current CO production process (methane-derived)

Electrochemistry (electrochemical reduction, etc.)

Artificial Photosynthesis (PV-electrochemical cell)

<Technological Challenges>
- Development of a catalyst electrode that is suitable for high current density (improve reaction rate)
- Development of integration technology for catalyst electrodes (improve the current density per unit volume)
- Production of syngas through co-electrolysis (respond to load change, equipment scale)

<Other Challenges>
- System design of a plant whose commercialization is viable
- Examination & comparison with the current CO production process (methane-derived)
- Securing reasonable and stable, large amounts of power derived from renewable energy

Synthesis utilizing organisms (such as microorganisms)

- Implement various types of R&D

Target for 2030

<Conversion Efficiency (Photochemistry)>
- Solar energy conversion efficiency: 10% achievement

<Reaction Rate (Current Density)>
- CO_2 processing speed 6t/yr/m^2 (Achievement of current density 500mA/cm^2 at ordinary temperature/normal pressure, electrolytic efficiency50%) (Electrochemistry) Note 1)

<Catalysts>
- Further improvement in durability & Reduction in costs

(Others)
- Development of renewable energy combined systems
- Development of hybrid systems (Photo + Electricity, etc.)
- Sector coupling: Demonstrate a case where CO is used as a reducing agent for steelmaking

Target from 2050 Onwards

<Conversion Efficiency (Photochemistry)>
Further improvement of conversion efficiency

<Reaction Rate (Current Density)>
CO_2 processing speed 11 t/yr/m^2 (Achievement of current density 1000mA/cm^2 at ordinary temperature/normal pressure, electrolytic efficiency 50%) (Electrochemistry) Note 1)

(Others)
- Synthesis that utilizes thermal chemistry/photochemistry/ electrochemistry/organisms is the best mix of various reactions/technologies.

Note1) Estimate under the following conditions: 100MW plant, availability factor:16.3%, and JPY 2/kWh.
Source of the available factor: Materials owned by ANRE (Agency for Natural Resources and Energy)

Note2) Supplying inexpensive CO_2 free Hydrogen is important

Basic Substances

- Technologies to produce Methanol, etc.

Thermal Chemistry(catalysts, etc.)

[CO_2 → Methanol]
<Technical Challenges>
- Reaction at low temperature
  Catalyst development/improvement in catalyst's conversion rate/selectivity
- Separation/removal of the water arising from the reaction
- Direct utilization of low quality exhaust gas (at a research stage)
  Measures against deterioration/improvements of durability of catalysts

<Other Challenges>
- Examination & comparison with the current practical process (reaction through syngas)
- Utilization of CO_2 in existing methanol production equipment

[Syngas → Methanol (or DME)]
<Technical Challenges>
- Improvement of yields in methanol production
- A system for concurrent production of methanol and DME where syngas is used as a raw material (production adjustment technique)

Photochemistry (photocatalysts, etc.)

Electrochemistry (electrochemical oxidation/reduction, etc.)

Synthesis utilizing organisms(such as microorganisms)

Implement various types of R&D
<Technical Challenges>
- Direct synthesis of formic acid/methanol(by utilizing the protons in water)
- Improvement in reaction rate & efficiency

<Other Challenges>
- Securing reasonable and stable, large amounts of power derived from renewable energy (in the case of utilizing electricity)

<Specific Practical Example>
- Demonstration of integrated bioethanol production from syngas (derived from waste incineration facilities) using microorganisms (The technology to be established by 2023: Goal 500～1,000kL/y scale demonstration to be implemented)
  ※ some processes require no further hydrogen

Target for 2030

<Common Challenges>
- Reduction in process cost

<Others>
- Development of renewable energy combined systems
- Development of hybrid systems (Photo ＋Electricity, etc.)
- Considering large-scale methanol supply chain
- Apply the technology to existing production systems/secure affinity

<Challenges to be taken up when methanol is utilized as a raw material>
- Demonstrate the technology for methanol to be used in an actual environment
- Expand mixed utilization of existing fuels and methanol as well as the mixed ratio

Target from 2050 Onwards

<Common Challenges>
- Further reduction in process cost

<Expected Cost>
- The expected costs are roughly equal to those incurred for the product synthesized from natural gas-derived methanol

Supplying inexpensive CO_2 free Hydrogen is important

Chemicals

- Technologies to produce commodity Substances (Olefins, BTX, etc.)

<Technical Challenges>
[MTO-olefin] (production plants exist)

- Developing catalysts (improvement in conversion rate/selectivity)
  Eg. Controlling generation ratio of Ethylene, propylene, butane, etc.
- Countermeasures against catalyst poisoning (controlling carbon precipitation)

[MTA-BTX] (R&D projects exist)

- Developing catalysts (improvement in conversion rate/selectivity)
  Eg. Controlling generation ratio of Benzene, toluene, xylene, etc.

Regarding MTO and MTA, methanol derived from coal is implemented or under implemented in China.

[Syngas→olefin, BTX]
Basic research level

- Developing catalysts (improvement in conversion rate/selectivity)
  Eg. Controlling generation ration of Benzene, toluene, xylene, etc.
- Suppression of the generation of CO_2 and methane

Target for 2030

[MTO-olefin]
<Catalyst>
Establish C2-C4 selective synthesis technology

- Further improvement in yield & Control of selectivity
- Establish a small-pilot-scale process

[MTA-BTX]
<Catalyst>

- Further improvement of yield and control of selectivity

[Syngas -> Olefin, BTX]
<Catalyst>

- Further improvement of yield and control of selectivity

<CO_2 Emission Intensity>

- In LCA, the amount of emissions from the current process (crude oil derived) must be equal to or lower than the CO_2 emission intensity

Target from 2050 Onwards

<Expected Cost>

- The costs are similar to those for existing energy/products

<CO_2 Emission Intensity>

- In LCA, the amount of emissions from the current process (crude oil derived) must be equal to or lower than half of the CO_2 emission intensity

Supplying inexpensive CO_2 free Hydrogen is important

Chemicals

• Technologies to produce Oxygenated Compounds

<Technical Challenges>
- Reduce cost in the current process or for commercialization (polycarbonate synthesis, etc.)
- Further reduction of CO_2 emissions
- Reduction in production costs

Basic research level, under low TRL Process (acrylic acid synthesis, etc.)
- Catalyst development (improvement in conversion rate/selectivity)
- Realization of low LCA for reaction partners (such as utilizing biomass/waste plastics, etc.)

<Other Challenges>
- Considering another CO_2 storage technique based on chemicals (such as oxalic acid, etc.)

Target for 2030

<Expected Cost>
- The costs are similar to those for existing energy/products

<CO_2 Emission Intensity>
- In LCA, the amount of emissions from the current process (crude oil derived) must be equal to or lower than the CO_2 emission intensity

Target from 2050 Onwards

<Expected Cost>
- Further reduction in costs

<CO_2 Emission Intensity>
- In LCA, the amount of emissions from the current process (crude oil derived) must be equal to or lower than half of the CO_2 emission intensity

Oxygenated compounds include (in alphabetical order):
acetic acid and acetic acid ester, acrylic acid, ethanol, ethylene glycol, oxalic acid, polyamide, polyester, polycarbonate, salicylic acid, urethane, etc.

Chemicals

- Technologies to produce biomass-derived chemicals

Target for 2030

<Technical Challenges>
(Cellulose-type biomass)
- Low cost, effective pretreatment technique (separation of cellulose, lignin, etc.)
- Establish the related techniques such as dehydration/drying, removal of impurities, etc.
- Production process of high-value added chemicals from non-edible biomass
- Screening & culture techniques for new microorganisms resources
- Utilization of biotechnology (Genome editing/synthesis), establishment of separation/purification/reaction process techniques
- Fermentation technology and catalyst technology that are not susceptible to impurities
- Development of effective materials conversion technologies for biomass materials
- High functionality in biomass-derived chemicals (adding marine biodegradable functions, etc.)

<Other Challenges>
- Establishing integrated production processes (securing production scale, stability in quality, etc.)
- Expanding the scope of target products including derivatives (oxygenated compounds→olefin, etc.)
- Expanding the scope of application of biomass-derived chemicals and verify their economic performance
- Establishing an effective collection system for biomass materials
- Standardization of biomass-derived chemicals/intermediates

<Expected Cost>
- The costs are similar to those for existing energy/products

<CO_2 Emission Intensity>
- In LCA, as compared to alternative petrochemical products (such as oxygenated compounds, etc.), the amount of emissions from the current process (crude oil derived) must be equal to or lower than half of the CO_2 emission intensity

<Others>
- Diversification and high functionality of biomass-derived chemicals (Controlling marine biodegradable functions, etc.)
- Hydrogen is necessary in hydrogenation treatment

Target from 2050 Onwards

- Large-scale production (geographically-distributed chemicals production that utilizes papermaking infrastructure/ agriculture & forestry/wastes, etc.)

<CO_2 Emission Intensity>
- In LCA, as compared to alternative petrochemical products (such as olefin, etc.), the amount of emissions from the current process (crude oil derived) must be equal to or lower than half of the CO_2 emission intensity

- Introduction into global markets (Marine biodegradable plastics : JPY 850 billion (Global market share of Japan: 25%))

Image of expansion

- Utilize edible biomass (mainly, ethanol and amino acid)
- Utilize oils and fats
- Bio and waste power generation
- Synthesize high-value added chemicals (functional chemicals)

- Utilize non-edible biomass/microalgae
- Bio power generation (ultimately, BECCS)
- Diversification of biomass chemicals/fuels

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※ Such technological development is also common to that in fuel sector (bioethanol, etc.)
※ Cultivation and capturing biomass technologies include marine use as well (fuel sector as well)

Fuels

- Technologies to produce liquid fuel (1) *Microalgae Biofuel (Jet Fuel/Diesel)

<Technical Challenges>
(Microalgae→Biojet fuel/Biodiesel)

- Improve productivity (culture system/ gene recombination)
- Low cost, effective pretreatment technique
- Establish the related techniques such as dehydration/drying, oil extraction, removal of impurities, etc.
- Develop the technology for utilizing oils/fats residues
- Scale-up (from bench-scale to pilot-scale, followed by demonstration level)
- Large-scale technological demonstration
- Pursuit of cost reduction

<Other Challenges>

- Expanding the scope of application and verify economic performance
- Establishing an effective collection system for raw materials

Target for 2030

<Expected Cost>

- Bio-jet Fuel: costs: similar to those for existing energy/products, JPY 100-200/L (Currently, JPY1600/L)

<Production Rate>

- 75 L-oil/day・ha (Currently, 35 L-oil/day·ha)

<CO_2 Emission Intensity>

- With regard to biojet fuels, in LCA, as compared to existing jet fuels, the amount of emissions from the current process (crude oil derived) must be equal to or lower than half of the CO_2 emission intensity

<Others>

- Compliance with fuel standards
- Scale up to the demonstration level and establish the supply chain
- Expand mixed utilization of the liquid fuel and an existing fuel as well as the mixed ratio
- Since hydrogen is used in relatively small amounts for oil reforming, the presence of CO_2 free hydrogen increases the GHG reduction impact

Target from 2050 Onwards

<Expected Cost>

- Further reductions in costs

<CO_2 Reduction Amount>

- Must contribute to 50% CO_2 reduction relative to that for 2005 in aviation sectors

(FYI) If a biojet fuel with a greenhouse gas emission reduction rate of 50% continues to be introduced at 100 thousand kL/yr, a CO_2 reduction of 123 thousand t/yr will be achieved.

*Such technological development is also common to that in the chemicals sector
(High value added products, such as cosmetics and supplements derived from microalgae are partially commercialized)

Fuels

- Technologies to produce liquid Fuel (2)
  *CO_2-derived Fuel or Biofuel (excluding microalgae-derived fuels) (such as methanol, ethanol, diesel, jet, DMC, OME, etc.)

Target for 2030

<Technical Challenges>
- Improvement in FT Synthesis (current process) (Improvement in conversion rate/selectivity)
- Improvement in other synthetic reaction (current process)

<Other Challenges>
- System's optimization (Renewable energy introduction (E-Fuel))

<Specific Practical Example>
- Demonstration of integrated bioethanol production from syngas (derived from waste incineration facilities) using microorganisms (The technology to be established by 2023: Goal 500-1,000kL/y scale demonstration to be implemented)

※ some processes require no further hydrogen

<CO_2 Emission Intensity>
- In LCA, the amount of emissions from the current process (crude oil derived) must be equal to or lower than the CO_2 emission intensity

<Other Challenges>
- Wondering what impact a CO_2-derived fuel may have on the regulations/ device/equipment on which naphtha- /crude oil-derived fuels had no effect
- Demonstrate the technology in an actual environment
- Expand mixed utilization of the liquid fuel and existing fuels as well as the mixed ratio

Target from 2050 Onwards

<Expected Cost>
- The costs are similar to those for existing energy/products

<CO_2 Emission Intensity>
- In LCA, the amount of emissions from the current process (crude oil derived) must be equal to or lower than half of the CO_2 emission intensity

Supplying inexpensive CO_2 free Hydrogen is important

Costs for biofuels and target for CO2 emissions, the same as biomass derived chemicals and microalgae biofuels attempt to reduce the cost equivalent to those existing energy/products in 2030 as well as in LCA the amount of emissions from the current process (crude oil derived) must be lower than half of the CO2 emissions intensity.

Fuels

- Technologies to produce gas fuel (Methane)

<Technical Challenges>
Existing Techniques (Sabatier Reaction)
- Long lasting of catalysts
- Thermal management (utilizing the generation of heat)
- Activity management
- Considering scale-up

R&D of Innovative Technology (co-electrolysis, etc.)

[Power to Methane]
- Production of electrolytic methane through co-electrolysis (utilizing city gas, etc.)
- Integrate the synthesis/power generation of electrolytic methane that utilizes CO2
- Improvement of efficiency

<Other Challenges>
- System's optimization (introducing renewable energy)
- Upsizing/cost reduction
- Equipment cost

<Specific Practical Example>
- Commercial scale (125Nm^3/h) demonstration that utilizes CO_2 contained in exhaust gas from a cleaning plant
- Development of basic technology towards practical-scale (60 thousand Nm^3/h) demonstration of city gas introduction that utilizes coal fire exhaust gas CO_2 contained in coal-fired exhaust gas

Target for 2030

<Expected Cost>
- Reduction in costs for CO_2 derived CH_4

<CO_2 Emission Intensity>
- In LCA, the amount of emissions from the current process must be equal to or lower than the CO_2 emission intensity

<Others>
- Demonstrate insertion into gas introduction pipes
- Develop sales channel/use application
- Expand mixed utilization of the gas fuel and an existing fuel as well as the mixed ratio

Target from 2050 Onwards

<Expected Cost>
- The costs are similar to those for existing energy/products

<CO_2 Emission Intensity>
- In LCA, the amount of emissions from the current process (crude oil derived) must be equal to or lower than half of the CO_2 emission intensity

Supplying inexpensive CO_2 free Hydrogen is important

Minerals

- Carbonates, Concrete Products, etc.

<Technical Challenges>
- Separation of effective components (Ca or Mg compounds) from industrial byproducts (such as iron& steel slag, waste concrete, coal ash, etc.) and/or waste minerals, saltwater (lye water) etc. (including the treatment of byproducts arising from the separation process)
- Energy-saving of the pretreatment (for example, pulverization of effective components) that helps to enhance the reactivity with CO_2 (dry process)
- Energy-saving in wet process (inexpensive treatment for waste water containing heavy metals, etc.)
- Development of inexpensive aggregates, admixtures, etc.
- Scale up

<Energy required to fix 1 ton of CO_2 >
- 500 kWh/t-CO_2 (utilizing blast furnace slag, dry process)

<Other Challenges>
- Establish a system from CO_2 emission sources through to production/supply (to optimize CO_2-fixiation amount and economic performance)
- Expand the scope of application and verify economic performance (development & demonstration of the technologies designed to utilize carbonates – verify the scope of application to concrete products, develop high-value added articles such as fluorescent materials, etc.)
- Long-term evaluate the performance as a civil-engineering/ building material as well as organize standards/guidelines

<Specific Practical Example>
- Development of a technology that is used to convert unused industrial byproducts carbonates (coal ash, etc. in which energy-saving of the pretreatment can be relied on)

※ Even now, iron and steel slags and coal ash are used as materials for concrete but not in the form of carbonates

Target for 2030

<Expected Cost>
- Road curb blocks: costs are similar to those for existing energy/products

<Energy required to fix 1 ton of CO_2>
- 200 kWh/t-CO_2 (regardless of a raw material and reaction process)

<CO_2 Utilization>
- Approx. 10% of Iron & steel slag and coal ash must be converted into carbonates

<Others>
- Large-scale demonstration
- Pursuit of cost reduction
- Survey on appropriate sites within/outside the country
- Promotion of demands by providing some incentive (such as procurement for a public work project, etc.)

<Specific Practical Example>
- Expand raw materials (Coal ash, biomass mixed combustion ash, waste concrete, etc. → Iron & steel slag, waste minerals, saltwater utilization (lye water), etc.)

Target from 2050 Onwards

<Expected Cost>
- Other products: The costs are similar to those for existing energy/products

<CO_2 Utilization>
- Approx. 50% of Iron and steel slag and coal ash

Important points for Carbon Recycling Technologies

- In order to progress R&D for Carbon Recycling technologies effectively, following points need to be considered for the solving climate change issues and security for natural resources.

✓ Inexpensive CO_2 free Hydrogen is important for many technologies

  ✓ Under the Hydrogen and fuel cells strategy roadmap in Hydrogen Basic Strategy, the target for 2050 is JPY 20/Nm3 at the plant delivery costs

  ✓ Even supplying hydrogen problems exist, 1) R&D for biomass or any other no hydrogen requested technologies need to progress, as well as 2) without waiting for the establishment for hydrogen supply, start any FS or other transitional activities using CH_4 (methane).

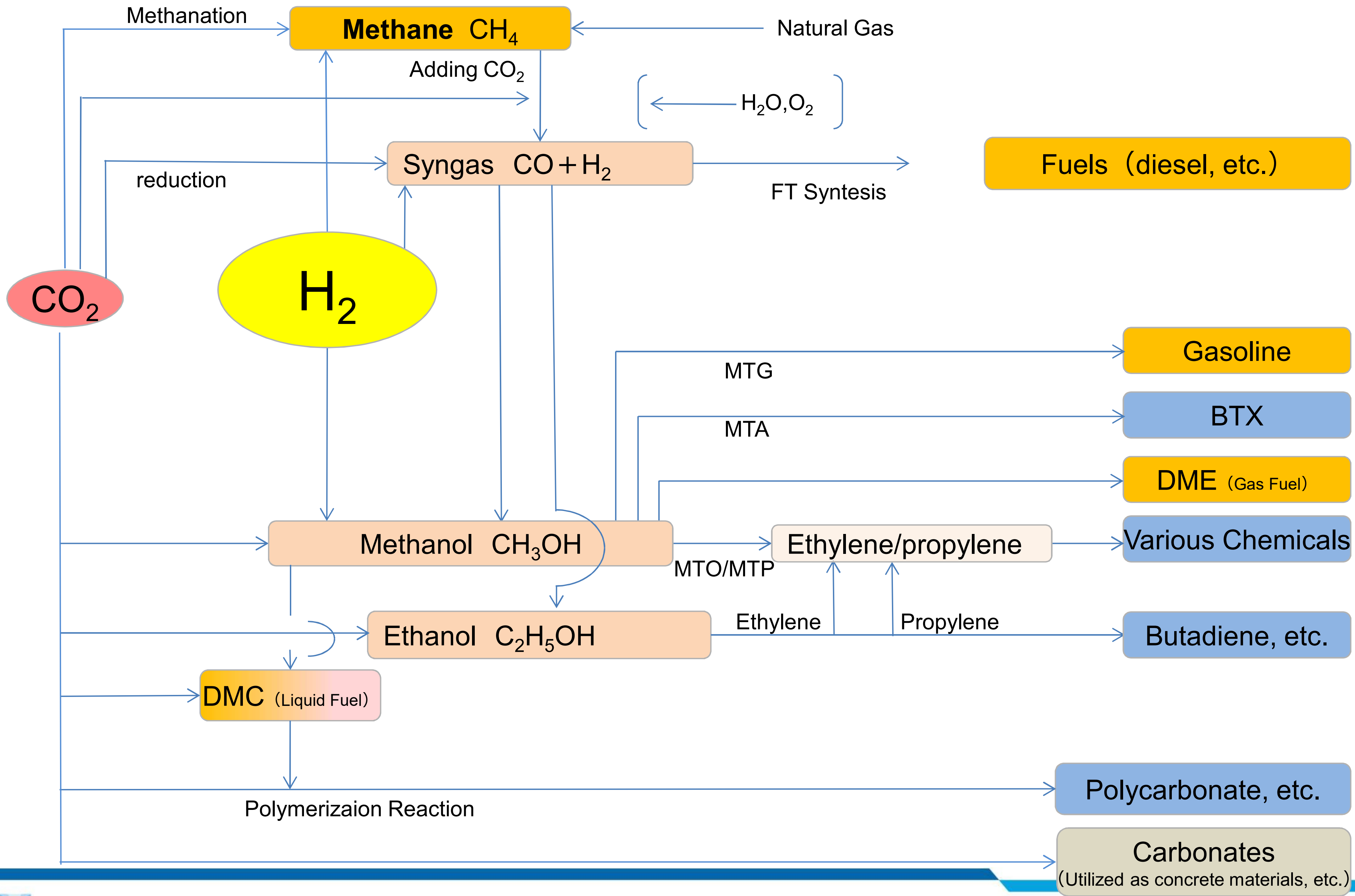
✓ Using zero emission power supply is important for Carbon Recycling

  ✓ Conversion of a stable substance, CO_2, into other useful substance will require enormous energy inputs.

✓ Life Cycle Analysis (LCA) and its valuation are needed, in order to evaluate Carbon Recycling technologies.

✓ Furthermore, reduce the costs for capturing CO_2.

Flowchart for CO_2 Utilization (for chemicals/fuels/carbonates)



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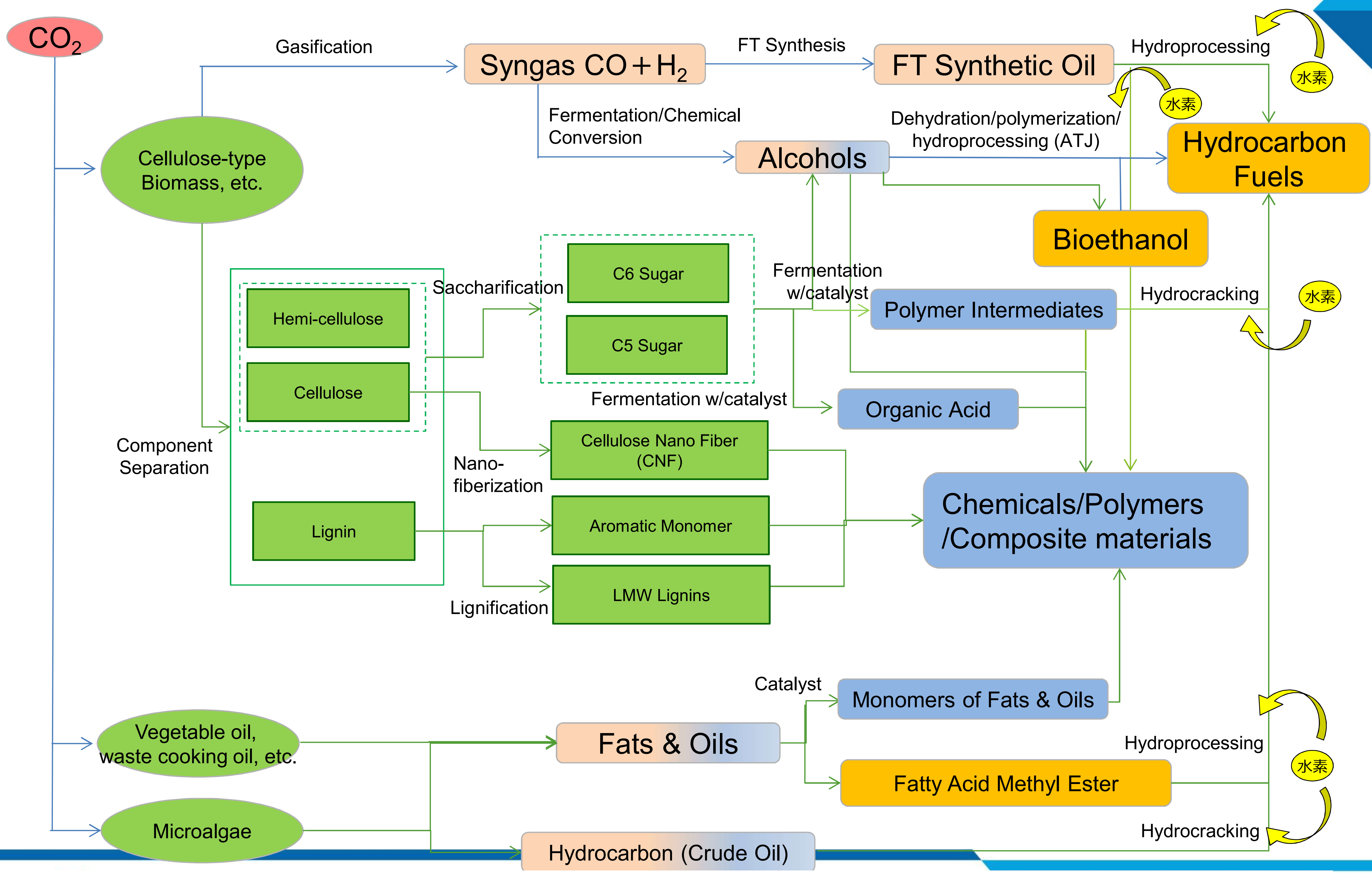
Confidential: (Dr.Koji Saito): 25of Sep 2019: (CSE2019)

Flowchart: CO_2 Utilization (for Bio-derived fuels/chemicals)



※Reduction reaction or hydrocracking during the process to produce "chemicals, polymer products or composite materials", may require hydrogen.

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2. Activities in Nippon Steel Corporation
3. Blue Carbon Technology
4. Conclusions

Direct synthesis of Carbonate ester from CO_2

Nippon Steel Corporation
Mitsubishi Gas Chemical Co. Inc.
Nippon Steel Engineering Co. Ltd.

1. Background/Objective/Abstract

The carbonic ester which is used for the raw materials of plastics (e.g. polycarbonates) and lithium batteries electrolytes, etc. has been produced using phosgene of deadly poison up to now.

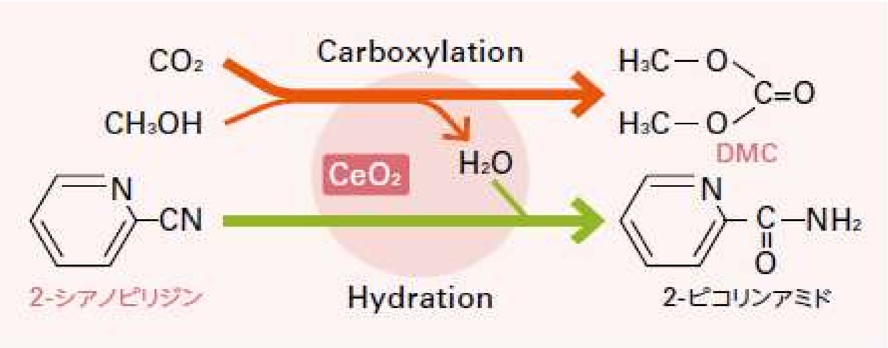
We found that carbonic ester can be directly produced by CO_2 and alcohol under the catalyst and the existence of dehydration agents. It leads to so-called green process, which means production gently with the environment as well as CO_2 emission reduction.

$CO_2 + 2ROH \rightarrow (RO)_2CO$ (Eq.)

2. Technical Target

- Reaction validation by pilot test equipment
- Feasibility study and commercialization judgement based on engineering data

【Schematic figure of this reaction】



3. Impact (CO_2 reduction effect, etc.)

- CO_2 reduction potential which is about 1 Million tons by substituting of the present process for the world amount of propylene carbonate completely.

Thermal conversion to CO from CO_2 for iron ore reduction Nippon Steel Corporation

1. Background/Objective/Abstract

In the steel manufacturing process, iron ore must be reduced by carbon-based reductant in the blast furnace (Eq.1), it' inevitable to exhaust a great deal of CO_2.

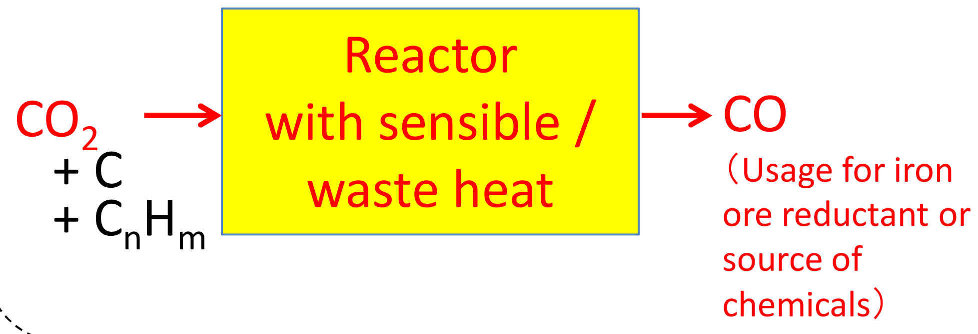
$FeOx + H_2, CO \rightarrow Fe + CO_2 + H_2O$ (Eq.1)

Utilizing hot sensible heat and waste heat in the ironworks, CO_2 in the blast furnace gas can be reacted and converted to CO through CO_2 and carbon (Eq.2) or CO_2 and some hydro carbons (Eq. 3) . We aim at CO_2 reduction by carbon-recycling to return CO into blast furnace as reductant of iron ore.

$CO_2 + C \rightarrow 2CO$ (Eq.2)

$nCO_2 + CnHm \rightarrow 2nCO + 1/2mH_2$ (Eq.3)

【Schematic figure of this reaction】



2. Technical Target

- CO conversion ratio from CO_2: Over 30%
- Reaction validation using real gas from the ironworks

3. Impact (CO_2 reduction effect, etc.)

- CO_2 reduction potential which is about 2 to 3 Million tons by apply for this process in Japan in 2050' s.

Hydrogen manufacture using photosynthesis

Nippon Steel Corporation
National Institute of Advanced Industrial science and Technology

1. Background/Objective/Abstract

Although large amount of CO2 emission is inevitable when iron ore usually be reduced by coal, 'zero-carbon steel' will be realized if iron ore can be reduced by hydrogen.

In the past, hydrogen is produced from fossil fuel accompanying with CO2 emission. We aim at less CO2 type hydrogen production due to comparable low electrolysis voltage using photosynthesis.

<photocatalyst>

$$2H_2O + 4Fe^{3+} \rightarrow O_2 + 4Fe^{2+} + 4H^+$$

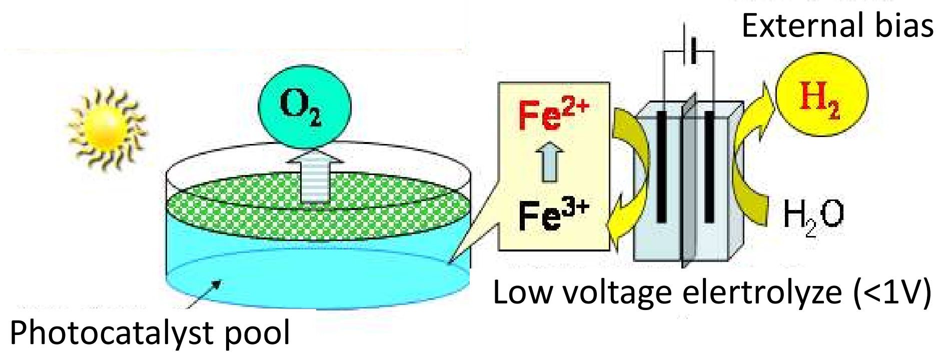
<electrolysis>

$$4Fe^{2+} + 4H^+ \rightarrow 4Fe^{3+} + 2H_2$$

2. Technical Target

- Sunlight energy transform efficiency > 3%
- Production cost < ¥30/Nm^3-H_2
- Certification using bench scale test equipment combined photosynthesis and water electrolysis

【Schematic figure of this system】



3. Impact (CO_2 reduction effect, etc.)

- CO_2 reduction potential which is about 3 Million tons by apply for this system in 2050's.

Direct synthesis of olefins from CO_2

Nippon Steel Corporation
Toyama University

1. Background/Objective/Abstract

Olefins such as ethylene and propylene as starting materials of chemicals are produced by thermal decomposition of naphtha at higher temp. up to now.

We found that olefins can be directly synthesized by one-pass from CO2 at low/middle temp. instead of two-pass comprised of CO2 to methanol and methanol to olefins., which leads to eco-friendly green process.

$CO_2 + H_2 \rightarrow 2ROH$, $ROH \rightarrow C_2=, C_3=, \cdots$

$CO_2 + H_2 \rightarrow C_2=, C_3, \cdots$

2. Technical Target

- CO2 conversion＞60%
- Optimum process design
- Reaction certification and engineering data acquisition using bench scale equipment

【Schematic figure of this technology】

CO_2+H_2 → FT catalysis / Methanol catalysis / Hybrid catalysis → olefins

3. Impact（CO_2 reduction effect, etc.）

- CO_2 reduction potential which is about 28 Million tons by substituting of the present process for the domestic amount of ethylene and propylene completely.

Photocatalytic conversion to CO from CO_2 for iron

Nippon Steel Corporation
Kyushu Institute of Technology

1. Background/Objective/Abstract

In the past, CO is produced from fossil fuel accompanying with CO2 emission. We aim at no CO2 type CO production using photosynthesis, which will lead to green process.

＜Photocatalytic electrode＞

$H_2O \rightarrow O_2$

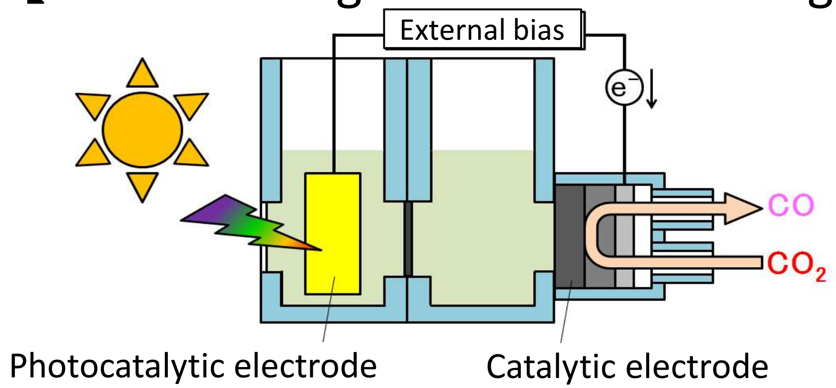
＜CO_2 catalytic reduction electrode＞

$CO_2 \rightarrow$ CO、HCOOH

2. Technical Target

- CO_2 conversion＞2%
- Reaction certification and engineering data acquisition using bench scale equipment comprised of flow–type photocatalytic electrolyzed cell.

【 Schematic figure of this technology 】



3. Impact (CO_2 reduction effect, etc.)

- CO_2 reduction potential which is about 2 to 3 Million tons by apply for this system in Japan in 2050’s.

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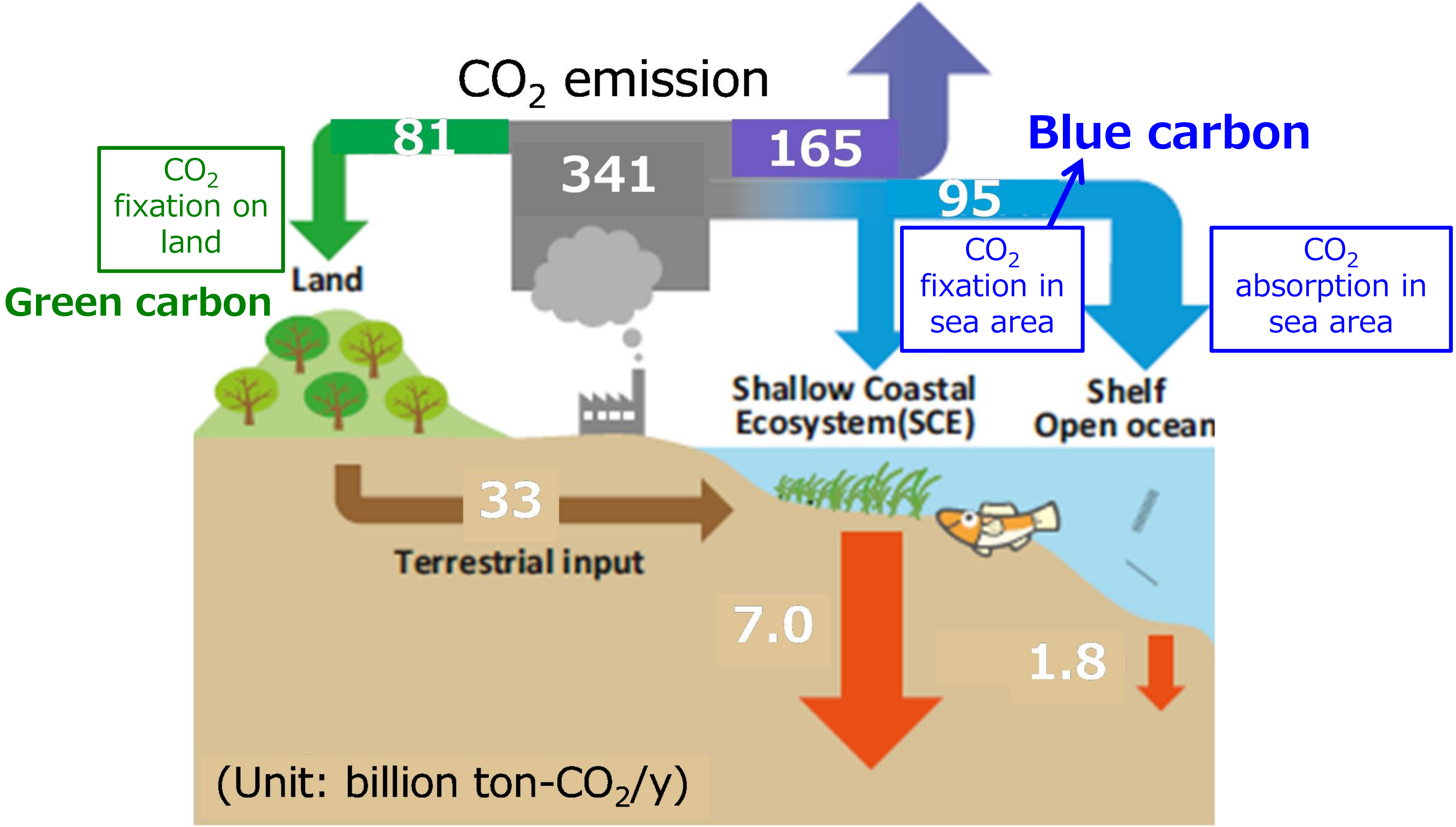
CO_2 circulation

Global CO_2 annual emissions: 34.1 billon tons of which steel industry: 0.32 billion tons (2015)



Kuwae and Hori eds. (2019) partial revision

CO_2 reduction target using natural ecosystem

Land	Sea

Green carbon
by plants
Forests, Peatlands

Slow

National land : 0.38Mkm^2
(61st in the world)

Forests : 2,7.8Mt/y
Cropland : 7.93Mt/y

Fixation speed

Domestic potential

Area

CO_2 fixed amount
(2030 forecast)

Blue carbon
by marine organisms
Mangrove forests, Seagrass beds

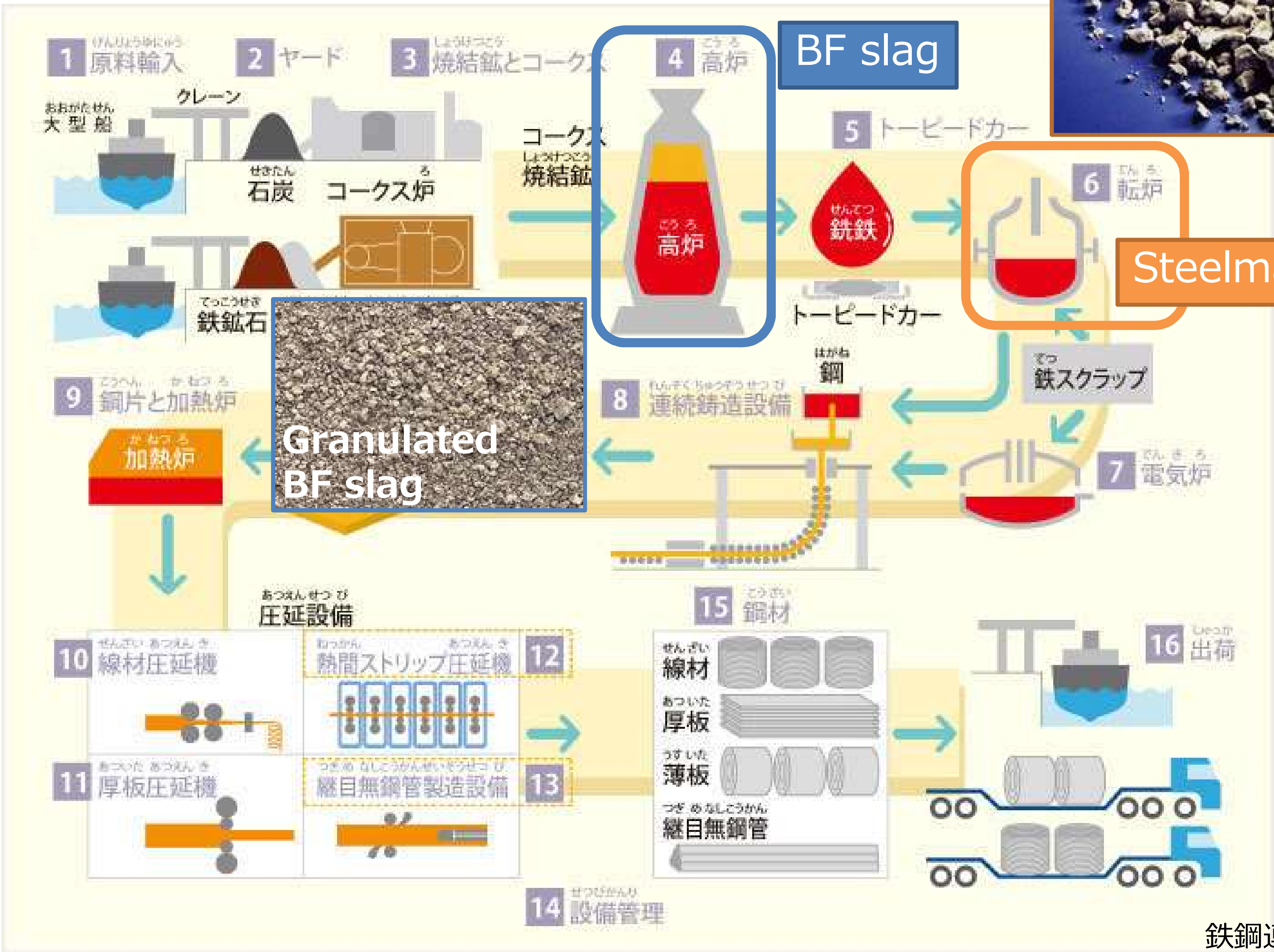
Fast

EEZ : 4.48Mkm^2
(8st in the world)
Coastline : 0.03Mkm
(6st in the world)

1.57～5.18Mt/y

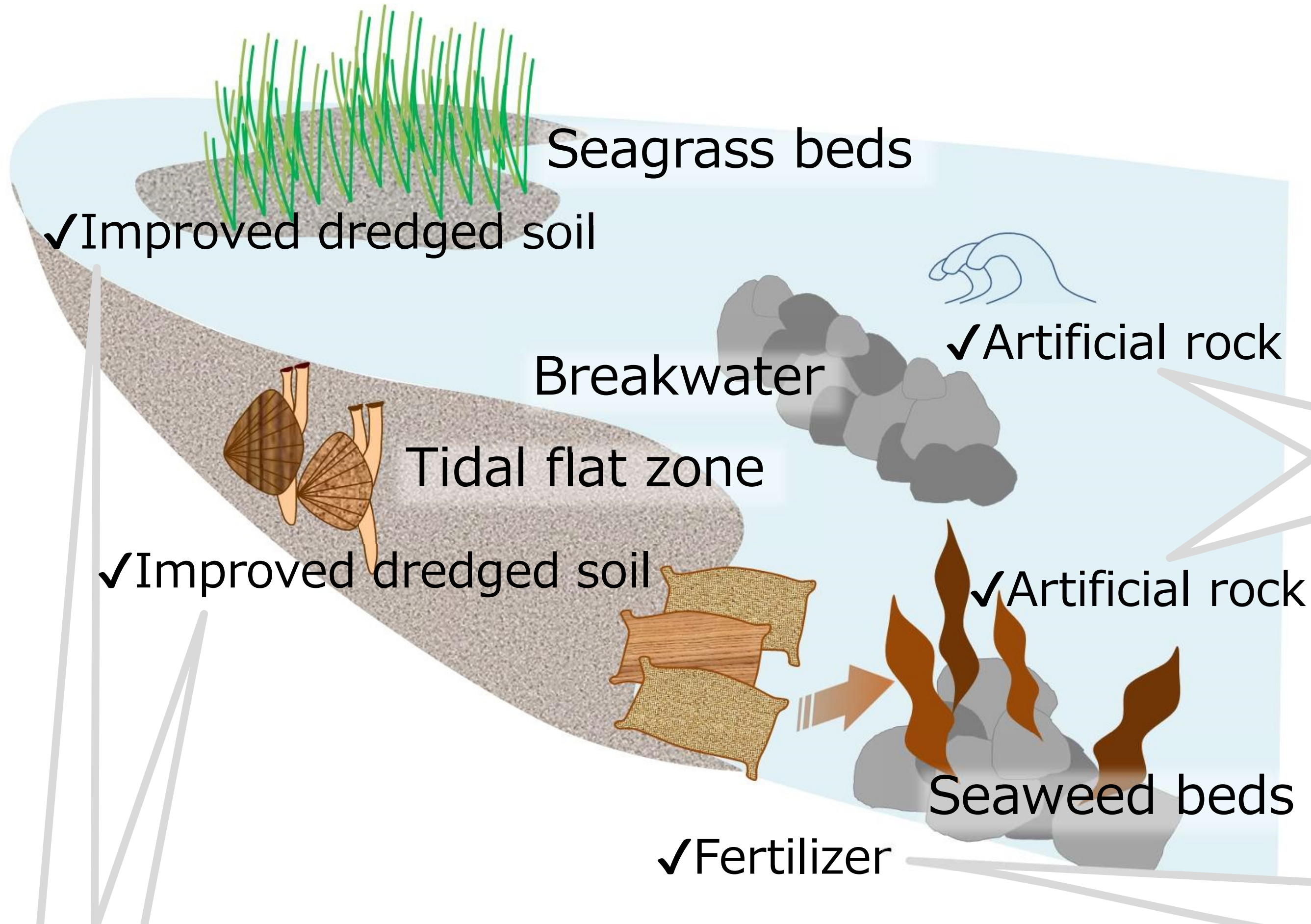
Blue carbon is effective CO_2 reduction target for Japan having long coastline.

By-product iron process, steel slag



鉄鋼連盟HPより転載

Steel slag utilization to marine environmental restoration



Artificial rock

The artificial rocks are made from steelmaking slag for aggregates and granulated BF slag for binder. Their CO_2 emission is reduced about 80% than concrete rocks.

Fertilizer

The fertilizer is composed of steelmaking slag containing about 20% iron, and artificial humic soil. It elutes the organic-chelated iron in marine environment.

Improving dredged soil using steelmaking slag

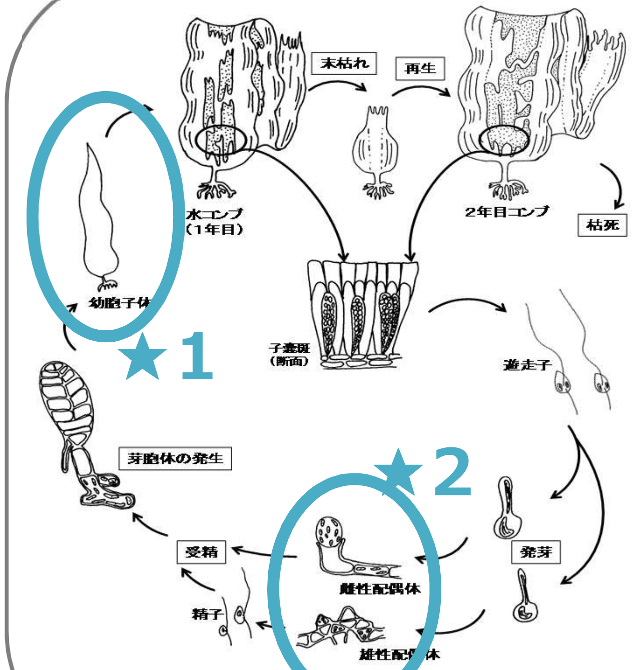
The utilization of soft dredged soil is improved by hydration reaction with steelmaking slag.

Creation of blue carbon ecosystem using steel slag will contribute to CO_2 reduction

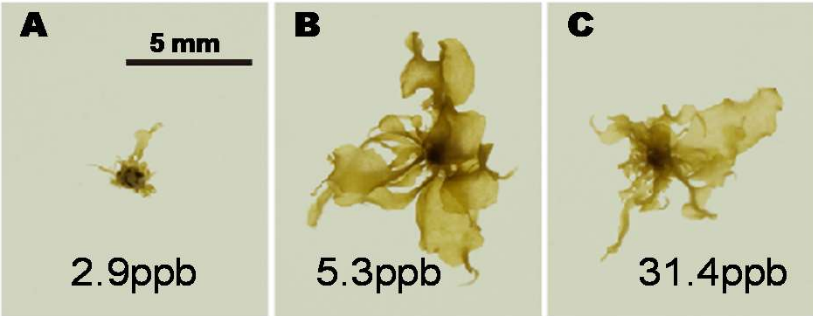
Seaweed bed restoration by steelmaking slag

Fertilizer

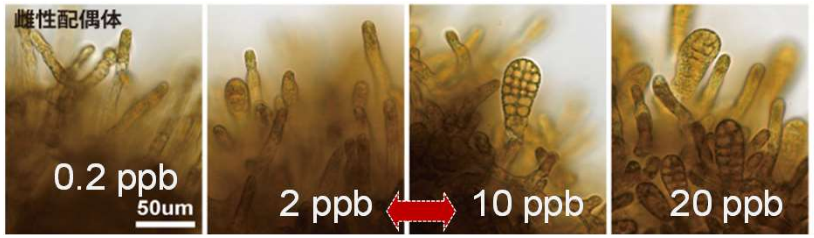
We have tested
at more than 30 points.



Life cycle of Kelp



★1 Growth of juvenile thalli



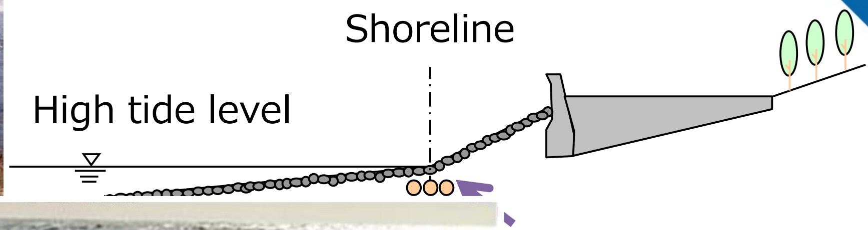
★2 Maturation of gametophyte
(Egg and sperm formation)

The fertilizer had been developed based on the iron necessity in the life cycle of kelp.

Field demonstration of the fertilizer

● Mashike-cho, Hokkaido

●Embedding the fertilizer along the shoreline



tilizer (6 t)

●Changing

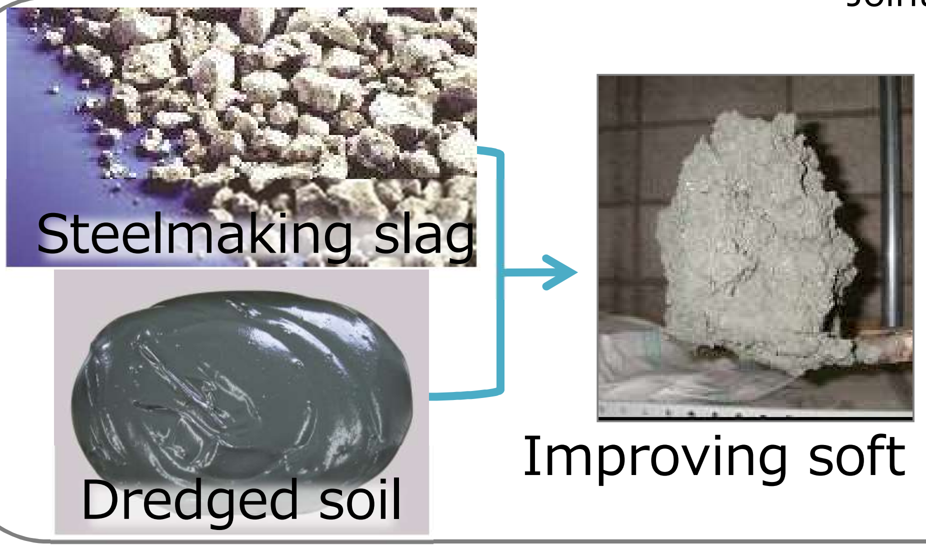
(2005. 7)

About 1 ha seaweed bed were restored by the fertilizer for 10 years.

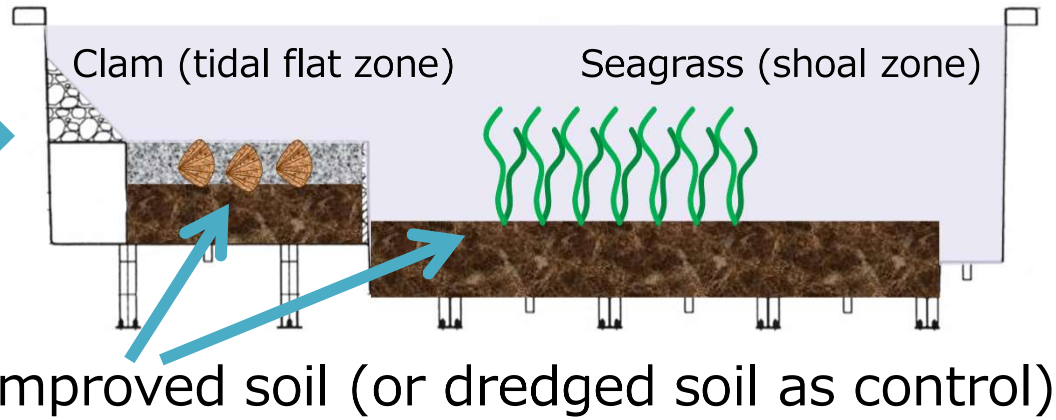
Mesocosm for the calculating CO_2 fixed amount

Creating a blue carbon ecosystem using steelmaking slag

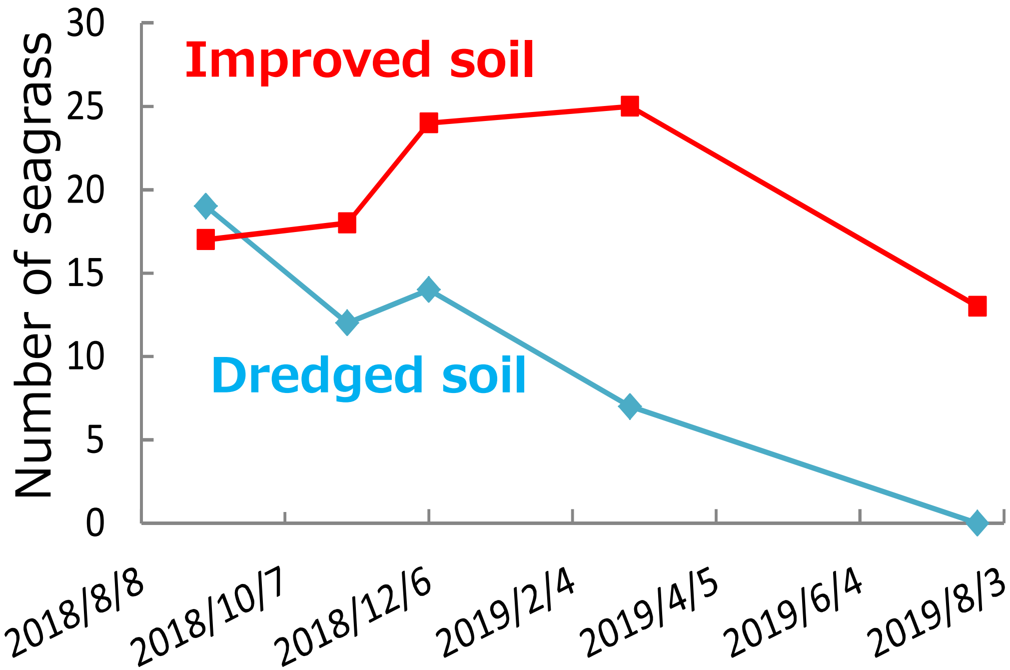
Joint research with Professor Nakamura at Yokohama National University

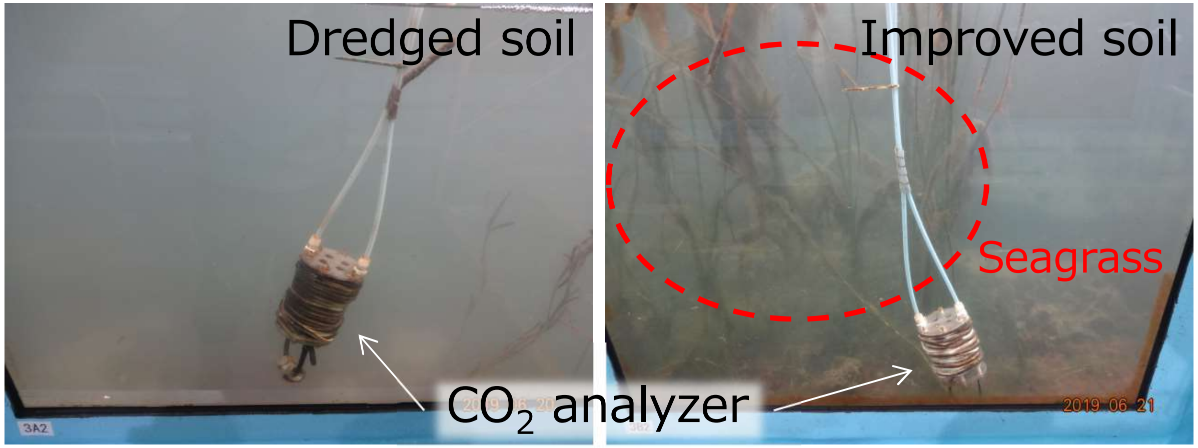


Improved soil used as the sediments in mesocosm



- Cultivation of seagrass in mesocosm





Improved soil can restrict the turbidity.

→Accelerating photosynthesis (CO_2 fixation)

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Introduction

- Over 1.8 billion tons of worldwide steel production
  population/economic growth … steel demand increase
- Carbon-reduction … large amount of CO2 emission
- Steel production from iron ore is still needed in 2100
- Nov. 2014 : JISF
  Commitment to a Low Carbon Society Phase II
  2030 target … JPN’s NDC (medium-term target)
- Nov. 2018 : JISF
  Long-term vision for climate change mitigation
  “A challenge towards Zero-carbon STEEL”
  beyond 2030 … JPN’s long-term strategy
  Hydrogen … a vital measure

Pathways towards Zero-carbon STEEL

Pathway 1: Carbon usage and treatment

$$1/2Fe_2O_3 + 3/4C \rightarrow Fe + \underline{3/4CO_2 \cdot\cdot\cdot GHG}$$

Proven
Existing
Experienced
Exothermic reaction

CCS/CCU is needed

Pathway 2: Carbon avoidance by hydrogen

$$1/2Fe_2O_3 + \underline{3/2H_2} \rightarrow Fe + 3/2H_2O \cdot\cdot\cdot \text{water}$$

Unproven
Unexisting
Inexperienced
Endothermic reaction

A huge amount of carbon-free hydrogen supply with rational cost is needed

Roadmap for Zero-carbon STEEL

- ✓ **JISF has decided to develop super innovative technologies to realize zero-carbon STEEL.**
- ✓ **Hydrogen replacing carbon and CO_2 capture are main measures.**
- ✓ **COURSE50 is the first step to the future.**
- ✓ **For hydrogen-reduction, massive and stable supply of carbon-free hydrogen with rational cost is essential.**

Challenges specific in iron & steel sector

		2020 2030 2040 2050 2100
COURSE50	Raising ratio of H2-reduction in blast furnace using internal H2 (COG) Capturing CO2 from blast furnace gas for storage	R&D → Implementation
Super COURSE50	Further H2-reduction in blast furnace by adding H2 from outside (assuming massive carbon-free H2 supply becomes available)	Stepping up → R&D
H2-reduction ironmaking	H2-reduction ironmaking without using coal	Stepping up → R&D → Implementation

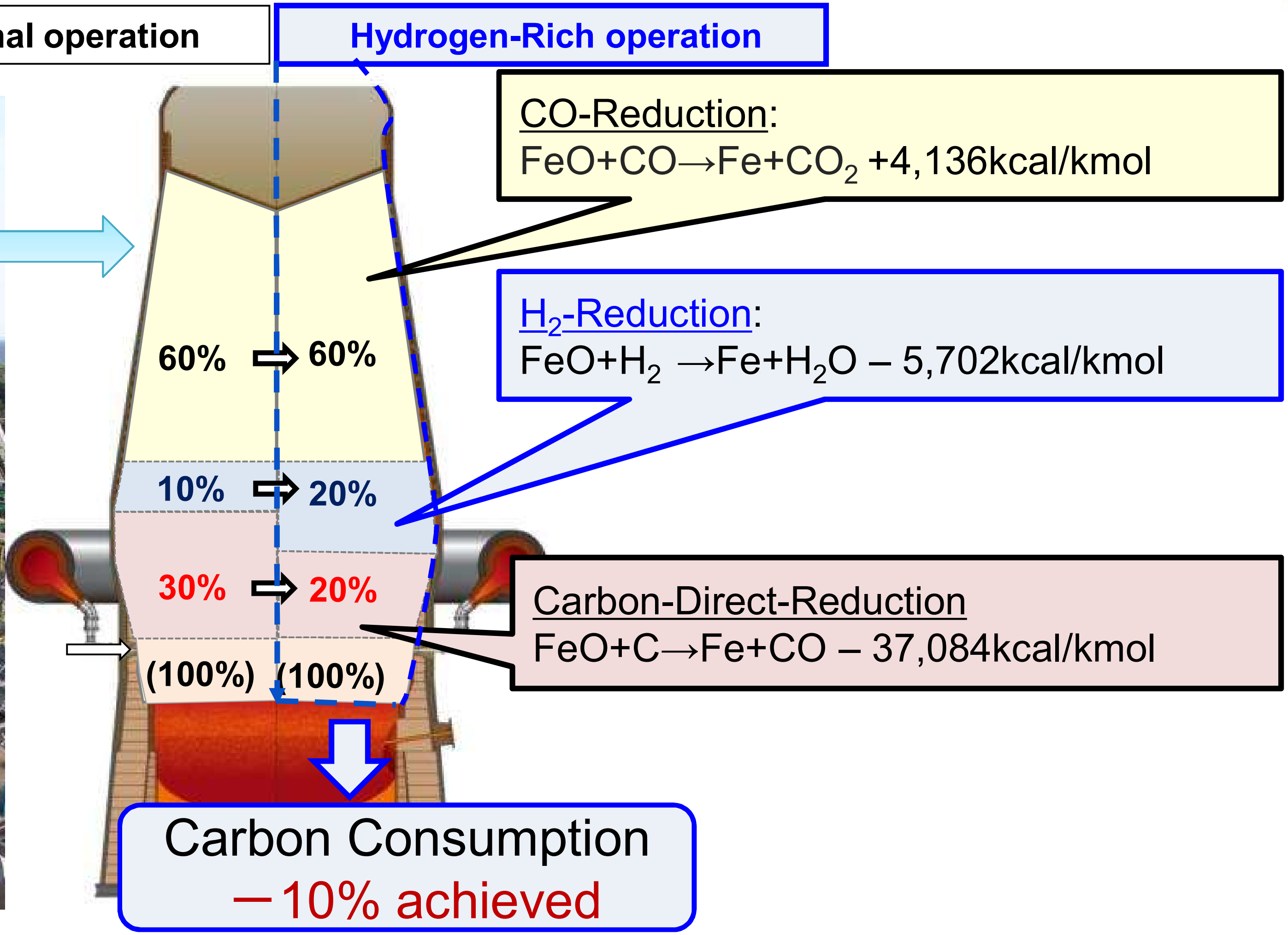
Challenges common in social fundamental

		2020 2030 2040 2050 2100
Carbon-free H2	Technical development of low cost and massive amount of hydrogen production, transfer and storage	R&D → Implementati
CCS/CCU	Technical development on CO2 capture and strage/usage Solving social issues (location, PA, etc.)	R&D → Implementatio

COURSE50:The First Step to the Future

CO2 Ultimate Reduction in Steelmaking process by innovative technology for cool Earth 50

Ratio of reducing reaction in the experimental blast furnace



In the experimental blast furnace, 10% reduction in carbon consumption has been achieved by hydrogen-rich operation.

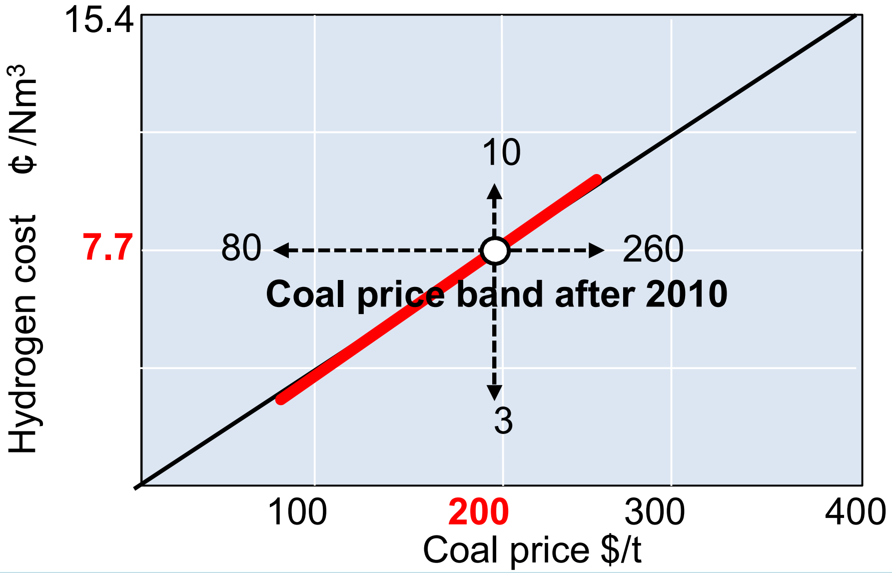
Requirements for Hydrogen Supply

<u>Volume</u> for $1/2Fe_2O_3 + 3/2H_2 + 48kJ \rightarrow Fe + 3/2H_2O$

reduction + compensation of endothermic reaction… **<u>1000 Nm^3-H_2/t-hot metal = 1.3 trillion Nm^3-H_2/year</u>**

for worldwide iron production

<u>Cost</u> equivalent for carbon reduction ironmaking:



A trial calculation : Assuming **$200/t-coal** and **700kg-coal/t-hot metal**, coal cost is **140$/t-hot metal.**

55% of thermic value of coal is consumed for reduction (another 45% changes to byproduct gases), and then the cost of reducing agent is **$77/t-hot metal.**

The equivalent cost of hydrogen **($77/t-hot metal / 1000$Nm^3$-$H_2$/t-hot metal)** becomes **¢ 7.7/Nm^3-H_2**

NIPPON STEEL

Conclusions

- ✓ **"A challenge towards Zero-carbon STEEL"**

  Direction towards achieving the long-term goal of the Paris Agreement

- ✓ Clear but very tough technical challenges

  Technical issues to overcome in hydrogen-reduction ironmaking

  Huge and stable supply of carbon-free hydrogen with rational cost

- ✓ COURSE50 : the first step to realize Zero-carbon STEEL

  Challenge super innovative technologies for realizing Zero-carbon STEEL using the technologies gained from COURSE50

Conclusions

・Carbon Recycling technology, recognizing carbon dioxide as a source of carbon, capturing and recycling it as raw materials and fuels by mineralization, artificial photosynthetic or Methanation as well as controlling the CO2 emissions to the air.

・Carbon Recycling technology focuses upon the research and development of CO2 Utilization in collaboration among industries, academia and governments around the world and promotes disruptive innovation.

・Carbon Recycling is one of key technology for the world together with energy saving, renewable energy and CCS.

・Nippon Steel Corporation have several trails about CCU, for example, direct synthesis of Carbonate ester from CO2, thermal conversion to CO from CO2 for iron ore reduction, hydrogen manufacture using photosynthesis etc.

・Big challenge theme is establishing of CO2 reduction target using natural ecosystem which means creating a blue carbon ecosystem using steelmaking slag.

・We will tackle various problems surrounding ironmaking through the maximum use of the most advanced technologies and will increase Japan's world-leading energy efficiency.

Thank you very much for your kind attention