Moonshot International Symposium
December 18, 2019

Working Group 4

Sustainable Resources Circulation for Global Environment

Initiative Report

Contents

EXECUTIVE SUMMARY

This Initiative Report is aimed at discussing Moonshot (MS) Goals in Working Group 4 “Sustainable Resources Circulation for Global Environment” of the International Symposium. It states recovery from global warming and global environmental pollution through circulating resources.

The concept of the MS goal consists of two pillars, “Cool Earth” and “Clean Earth”. In order to clear the goal upon the sense of this concept, this report emphasizes greenhouse gases and various wastes, such as marine plastic litter.

In contrast to the existing resource circulation issues which have been discussed so far in the various fields of science and technology, this report mainly focuses on the circulation of the resources that are released or disposed into the environment, consequently distributed widely in space and thinly in concentration. A typical example is the Direct Air Capture (DAC) of CO_2, a technology for capturing CO_2 directly from the atmosphere, noted as so-called the negative emission technology. Research and Development (R&D) attempts of CO_2 capture from industrial exhaust gas have been already addressed in various places, while few R&D regarding DAC have yet been carried out due to its lower concentration levels of CO_2. In addition to DAC of CO_2 and its utilization, conversion of nitrogen compounds to valuable substances and biodegradable switching plastics are listed as examples.

The timeline mentioned in this report is to develop the circulation technologies to the pilot scale by 2030 and to deploy plants and products globally by 2050.

In conclusion, the MS goal candidate “Realization of sustainable resources circulation to recover the global environment by 2050” is proposed in this Initiative Report.

PREAMBLE

This Initiative Report is aimed at discussing Moonshot (MS) Goals in Working Group 4 “Sustainable Resources Circulation for Global Environment” of the International Symposium.

Since the industrial revolution, the human species has been exploiting natural resources of the earth and built the current affluent material civilization we live in. However, this has led to a steady deterioration of the global environment and if this situation is to continue, the human species may not even able to continue to survive on earth.

According to IPCC (the Intergovernmental Panel on Climate Change), it is warned that there will be a tremendous risk of unusual severe weather such as storms, floods, droughts, heat waves, sea level rise, and etc., unless the increasing the amount of greenhouse gas in the atmosphere begins to slow down and decreases over the next few decades.

Also, when looking at the global environment as a whole, global warming is certainly recognized as the biggest problem. However, global warming is not the only global environmental problem. Environmental pollution caused by various harmful substances released into the environment is another important and real issue affecting the global environment.

Various R&D are underway to solve the above problems. Especially, realizing resources circulation is regarded as an enabling technology for both continuing human activities of production and consumption, and recovery from the on-going issues of global warming and environmental pollution.

This Initiative Report states recovery from global warming and global environmental pollution through circulating resources in the Moonshot R&D program.

I. VISION AND PHILOSOPHY

1. The Moonshot 「Area」「Vision」 for setting MS 「Goals」 candidate

The visionary council, which consists of experts, proposed the 3 Areas, 13 Visions, and examples of 25 MS Goals that Moonshot Research and Development Program should aim for. The aim is to set ambitious targets and concepts for a social agenda that are difficult to tackle but will have profound impact once resolved. (See Fig. 1-1)

Working Group 4 discusses the following Area and Visions for setting MS Goals candidate.

[Area]

Recovery for global environment and growth of civilization.

[Vision]

Sustainable resources circulation.

Significant reduction of resources requirements.

[Examples of MS Goal candidate to be used as reference]

9) Reduction of resources losses to 1/100th.

10) Reduction of energy consumption per calculated unit to 1/1000th.

11) 100% energy self-sufficiency with sustainable energy source.

12) Full recycle system for resources and materials.

14) Elimination of garbage on the earth.

In WG4, it is considered appropriate that ‘12) Full recycle system for resources and materials’ is focused on, associating ‘9) Reduction of resources losses to 1/100th’, ‘10) Reduction of energy consumption per calculated unit to 1/1000th’, ‘11) 100% energy self-sufficiency with sustainable energy source’ and ‘14) Elimination of garbage on the earth’. Specifically, this report will associate them as follows.

Regarding ‘9)’ and ‘10)’, the resources and energy saving, which the industry has been working on, have made a certain contribution to the maintenance of the global environment, and the resources circulation is positioned as the next step.

‘11)’ is an issue regarding with the development of renewable energy. When performing various resources circulations, it is not possible to circulate resources with no energy input. Therefore, resources circulation requires renewable energy in terms of reducing greenhouse gases.

‘14)’ is derived from the resources circulation itself.

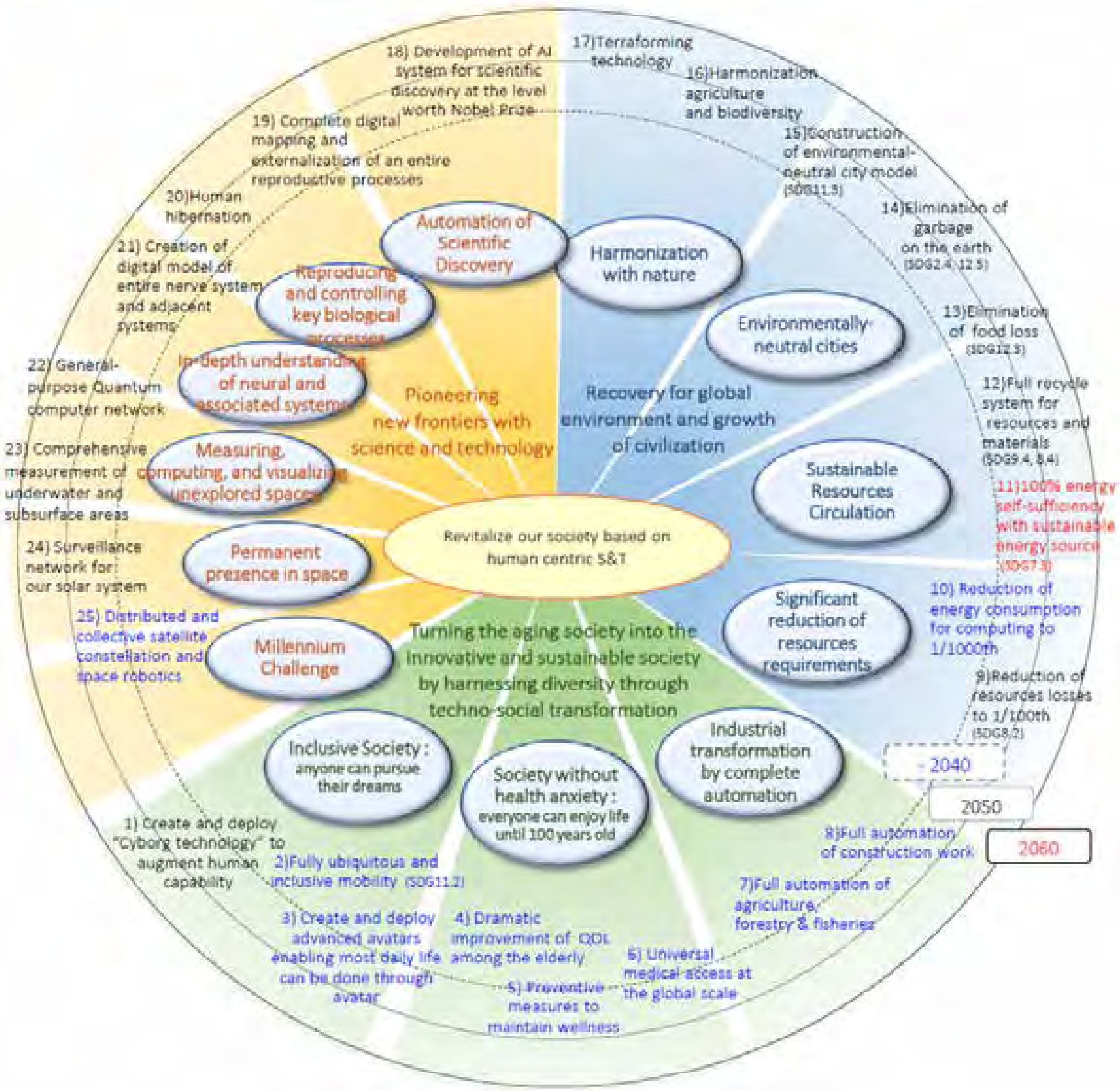


Fig. 1-1. Future visions and 25 MS goal examples

2. Concept of MS Goal candidate

2-1 MS Goal candidate

"Realization of sustainable resources circulation to recover the global environment by 2050"

Realizing resources circulation is regarded as an enabling technology for both continuing human activities of production and consumption, and recovery from the on-going issues of global warming and environmental pollution. In this Initiative Report, the concept consists of two pillars, "Cool Earth" and "Clean Earth".

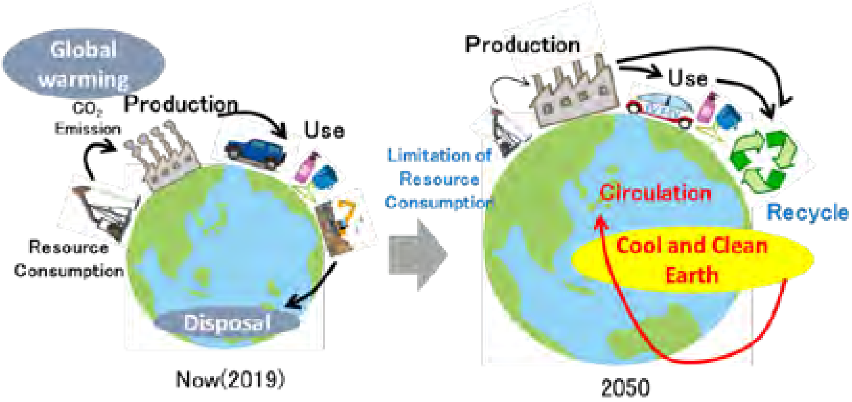


Fig. 1-2. Conceptual schematics of Cool & Clean Earth

2-2 Target

- 2030 (Output target)

  <Cool Earth>

  Development of circulation technology for greenhouse gases, which is effective also in terms of Life Cycle Assessment (LCA) in a pilot scale.

  <Clean Earth>

  Development of technology in which environmental harmful substances are converted into valuable or harmless materials in a pilot scale or as a prototype.

- 2040 (Outcome)

  <Cool and Clean Earth>

  Several small markets for the resources circulation technology will be created.

- 2050 (Outcome)

  <Cool and Clean Earth>

  Realization of sustainable resources circulation to recover the global environment by 2050.
  It means commercial plants and products with circulation technology will deploy globally.

For large-scale operations of resource circulation activities in 2050, the deployment period of large-scale facilities is to be ensured, assuming the establishment of demonstration facilities, and pilot facilities, all those necessary for the subsequent technological development in stages. Therefore, as of 2030, the goal is to establish several pilot plants and demonstration facilities with the establishment of the technology.

Fig. 1-3 shows the schematics of timeline in 2030, 2040, 2050, and beyond, for achieving targets through Moonshot projects.

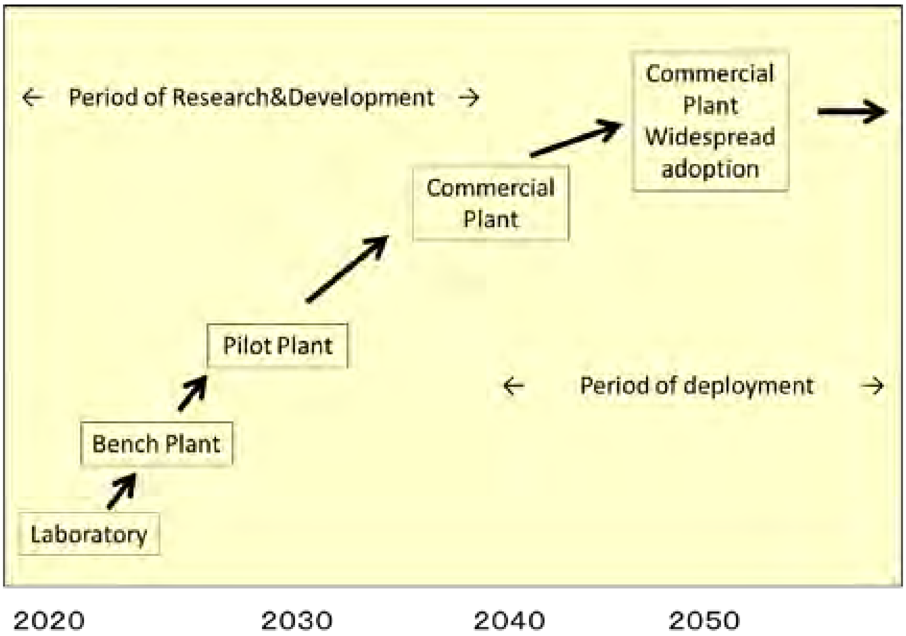


Fig. 1-3. Timeline for realization of the Moonshot Goal

2-3 Concept

(1) Cool Earth

The concept of Cool Earth is to contribute to the achievement of the 2 °C scenario by circulating greenhouse gas resources.

As for Cool Earth, the necessity and value of the efforts are shared globally (Inspiring, Imaginative), and discussions on the countermeasure technology and the preliminary development have begun (Credible). Specifically, feasibility studies of negative emission technologies are being promoted. On the other hand, the efficiency and cost need to be greatly improved. By setting the Moonshot goal proposed in this report, the development of those efficiency improvement technologies and totally new greenhouse gas recovery technologies will be induced.

The appearance in 2050 is considered as follows, on the basis of the IPCC fifth assessment report on climate change, as shown in Fig. 1-4. It is the so-called 2 °C scenario where the greenhouse gas concentration is set from 430 to 480 ppm in 2100. For achieving 2 °C scenario, greenhouse gas emissions in 2050 has to be reduced by about 70% compared to 2010, and negative emissions will be required at the end of this century. This 2 °C scenario is almost consistent with the goal announced by the Japanese government.

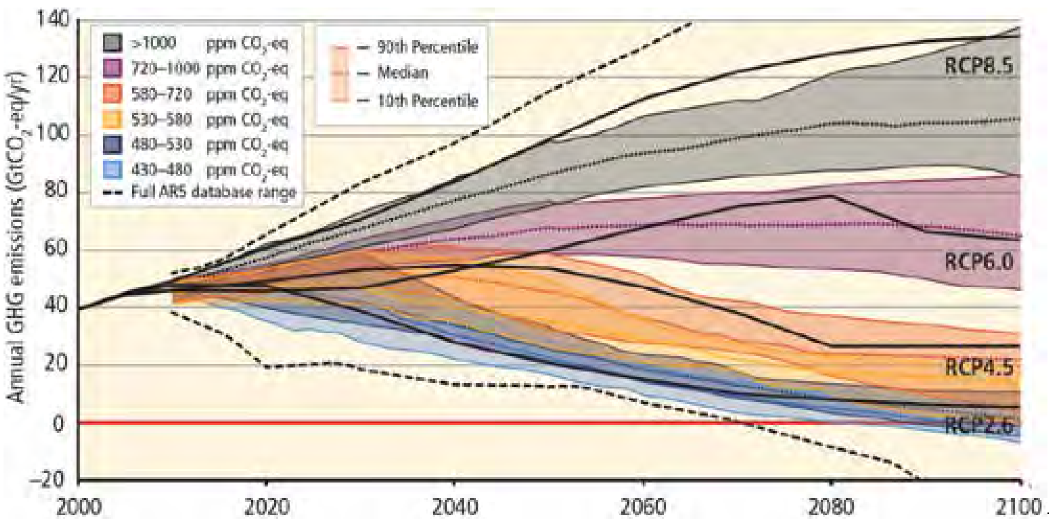


Fig. 1-4. Greenhouse gas emission scenario from IPCC fifth assessment report [1]

(2) Clean Earth

The concept of Clean Earth is to contribute to the recovery of the environment by these resources circulation technologies.

In present, harmful substances for environment existing in various exhaust gases, liquid drainage, and the wastes, are controlled by regulations. However, a certain amount of the harmful substances are leaked out to the environment even if regulated by law. Nitrogen compounds are becoming the subject of emerging debates and marine plastic litter is also the one that has become a hot topic in recent years.

The need and value of Clean Earth are shared globally (Inspiring, Imaginative), and discussions on the countermeasure technology and development of the initial stage have begun (Credible). Based on these current conditions, setting the Moonshot goal proposed in this report will be expected to encourage the development of new and alternative materials such as marine biodegradable plastics, and the recovery technology of diluted NOx that currently cannot be processed.

3. Why Now?

3-1 Cool Earth

If the Paris agreement target of well below 2 °C fails, the prediction line in Fig. 1-5 shifts upward. This means that natural disasters do not only occur more frequently, but also many ecosystems in the global scale are greatly destroyed, making it difficult to secure food supply. The survival of human species with a certain number of populations will be at risk. In order to achieve the target of 2 °C, as described in the previous chapter, a long term action frame will be certainly required. Therefore, this problem should be tackled from now. It might be late now to start it, but no further delay is allowed.

Fig. 1-5 shows the difficulty in achieving the target of 2 °C. The point that each country is currently planning to achieve by reducing greenhouse gases as of 2030 remains to a level in shortage of approximately 13Gt CO_2-eq for achievement to the target of 2 °C, which corresponds roughly to 1/4 of the total global emissions. Thus, the current plan is not enough for 2030, and challenges for the 2030 goal as a milestone that will lead to the achievement of the ultimate 2050 goal are definitely important and to be urgent.

In addition to CO_2, there are other greenhouse gases that have an unignorable effect. Considering the difficulty of developing reduction technologies and the costs such as needed investment for development, CO_2 reduction alone is not an effective matter, therefore R&D challenges for other greenhouse gas reductions should also be addressed. Various efforts have already been undertaken to reduce CO_2, but for greenhouse gases other than CO_2, some basic R&D has just started, and accelerating its development is necessary to catch up with the level of actions for CO_2.

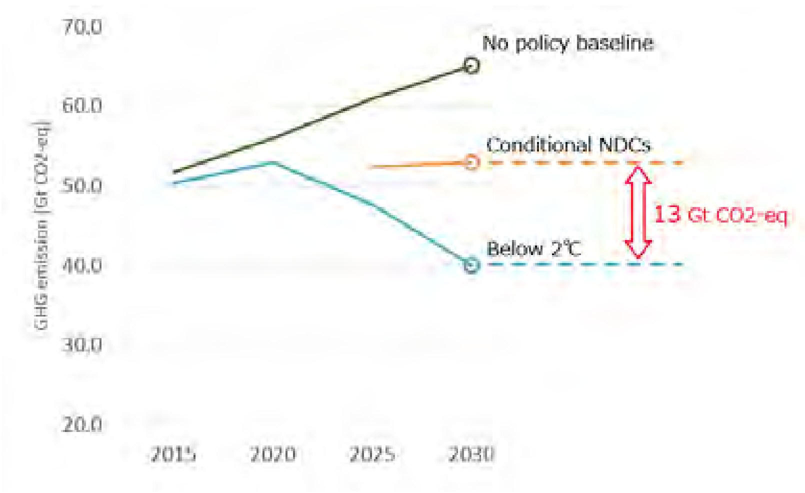


Fig. 1-5. Deviation between 2 °C scenario of greenhouse gas emissions and current plan [2]

3-2 Clean Earth

Scientists at the Stockholm Resilience Center proposed 9 limits for the earth as prerequisites for sustainable development of the earth in 2009. These limit values are called the planetary boundaries (Fig. 1-6). Transgression of the planetary boundaries creates substantial risk of destabilizing the earth system. From the viewpoint of biogeochemistry, the target materials are nitrogen and phosphorus. Especially for nitrogen, it is reported that current value of nitrogen has already exceeded 150 million tons/year, although the value of planetary boundary limits of high risk level is 62 million tons/year [3].

This amount of nitrogen circulation is the sum of the nitrogen taken up from the atmosphere, shown in the following.

- Taken up by animals and plants for survival and growth.
- Industrial conversion to nitrogen fertilizer and chemical products, etc.
- By-produced NOx with combustion.

If this amount of nitrogen is increased, the environment will be destroyed due to the eutrophication of water and atmosphere pollution. Reduction measures must be taken to bring them back to be under the planetary boundary limits of high risk level.

It is also reported that the global environment is polluted by nitrogen [4] [5] [6].

Fig. 1-6. Planetary boundaries [7]

Regarding the recent topic of marine plastic litter, there have been reports of cases where a considerable amount of plastic already exists in the sea, and some adverse effects on fish have become apparent. There are recent global efforts to solve the problems as followings:

- A European Strategy for Plastics in a Circular Economy [8].
- At the G20 in June 2019, the "Osaka Blue Ocean Vision", which aims to make new marine plastic litter zero by 2050, was shared [9].

It must be recognized that marine plastic litter is the issue that should be started immediately.

4. Changes in industry and society

If the Cool Earth and Clean Earth are realized, the following environmental improvement can be expected.

- Abnormal weather such as heavy rain, drought, and cold waves that are increasing (in frequency) around the world will decrease.
- Reduced food yield reduction and uneven distribution of plants, animals and marine products that are triggered by rising temperatures and seawater temperatures will be resolved.
- Sea level rise will stop at a certain level, and the disappearance of submerged lowland will be avoided.
- There will be no harmful substances that hinder the growth and the breeding of marine organisms, and it will be possible to secure seafood.

In order to recover the global environment and maintain a sustainable society, the social implementation that will be addressed toward 2050 must continue also after that. Thus, it is expected to bring changes in society, such as creation of new industries and new jobs.

II. STATISTICAL ANALYSIS

1. Structuring of MS Goal

1-1 Existing approach

Both global warming and environmental pollution began after the industrial revolution, while human species has not taken no measures until now. There are still a lot of research and development in this field as shown in the CRDS overview report [10].

In Japan, the resource and energy saving have been worked by the industries since the high economic growth period of the 1970s as shown in Fig. 2-1. This energy-efficient driving force was originally triggered by the oil shock in the early 1970s, but it has continued to improve efficiency even after the oil market has stabilized. Fig. 2-2 shows that Japan is leading the world with energy efficiency. It can be said that as resource saving progressed, waste emissions also decreased, which contribute to reducing the burden on the global environment.

In addition to the resource and energy saving, the development and introduction of renewable energy have increased significantly not only in Japan but also globally in recent years. The widespread use of renewable energy has greatly contributed as global warming countermeasures, which should continue to expand in the future.

However, at present, global warming and environmental pollution have not stopped. Therefore, further efforts are necessary for Cool Earth and Clean Earth.

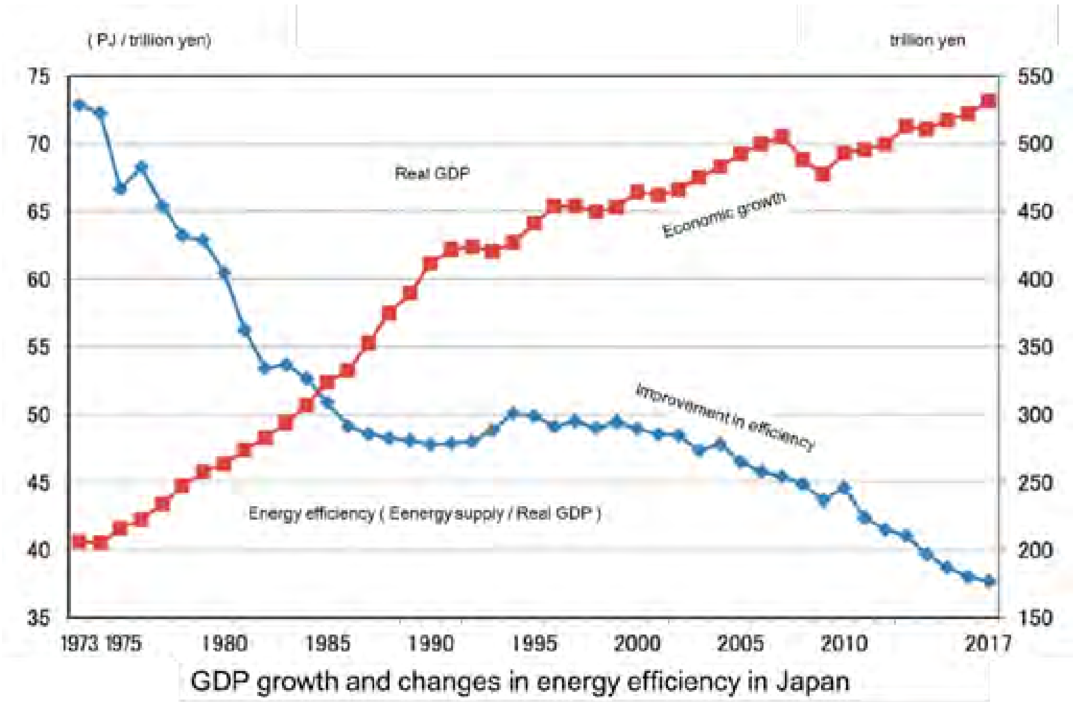


Fig. 2-1. Trend graph of GDP and energy efficiency in Japan [11]

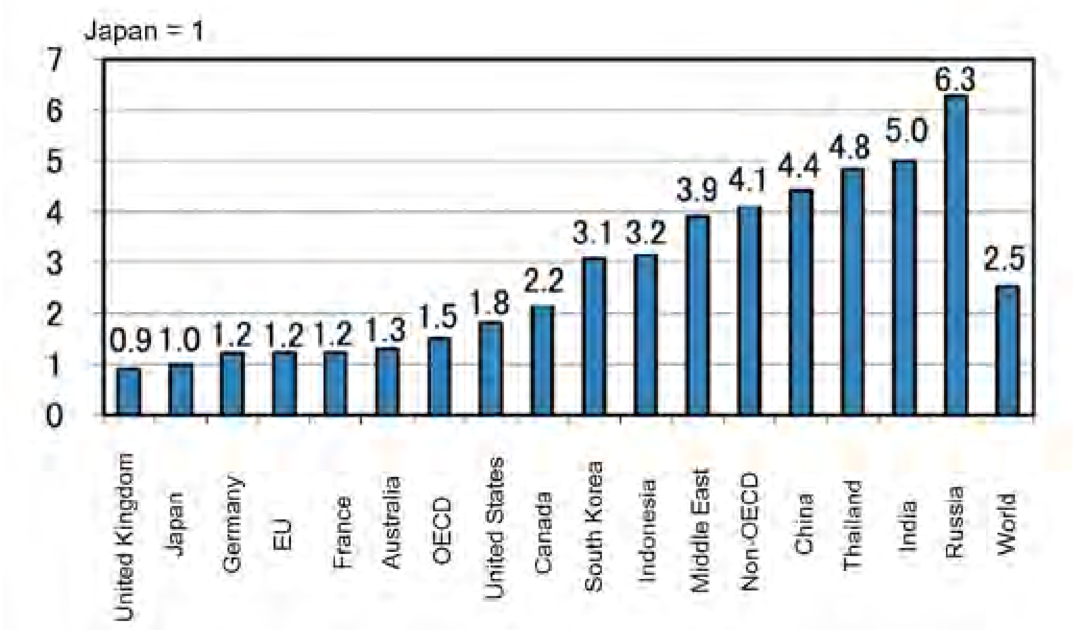


Fig. 2-2. Comparison chart of energy efficiency by country [11]

1-2 Cool Earth

(1) Current status

Regarding global warming, there are many gases called greenhouse gases. Characteristics of 7 major greenhouse gases, which are subject to be reported, are described in Table 2-1.

As is well known, CO_2 has an overwhelming influence, but CH_4 and N_2O also have a certain influence.

Table. 2-1. List on the characteristics of 7 major greenhouse gases ([1] for GWP)

		Emission : V 100 million tons / year	Global Warming Potential : K (CO_2=1)	Impact on Global Warming =V × K
①CO_2		350	1	350
②CH_4		3	28	63
③N_2O		0.1	265	31
④Fluorine compounds	HFCs	0.1>	12,400>	-
	PFCs	0.1>	11,100>	-
	SF_6	0.1>	23,500	-
	NF_3	0.1>	16,100	-

Fig. 2-3, 2-4, 2-5 show that increase of the annual greenhouse gas emissions and concentration, and increase of atmosphere temperature respectively. The temperature continues to rise consistently, and its speed is about (a little under) 0.1 °C by 10 years.

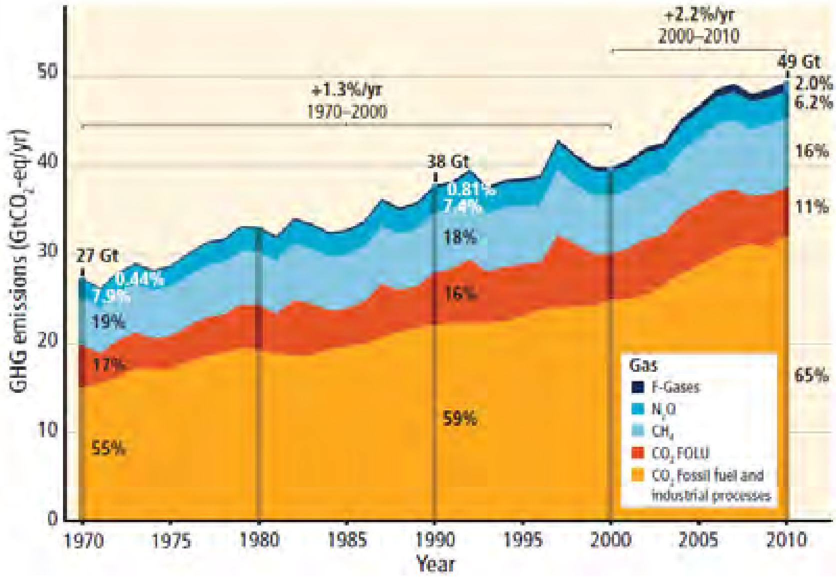


Fig. 2-3. Greenhouse gas emission trend [1]

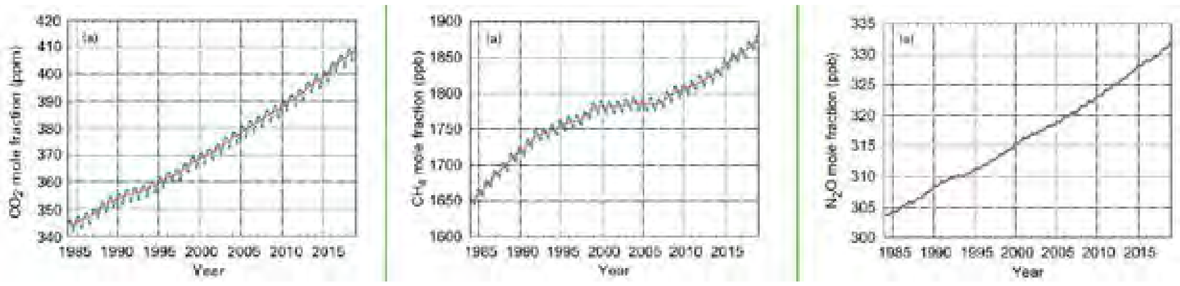


Fig. 2-4. Greenhouse gas atmospheric concentration trend [12]

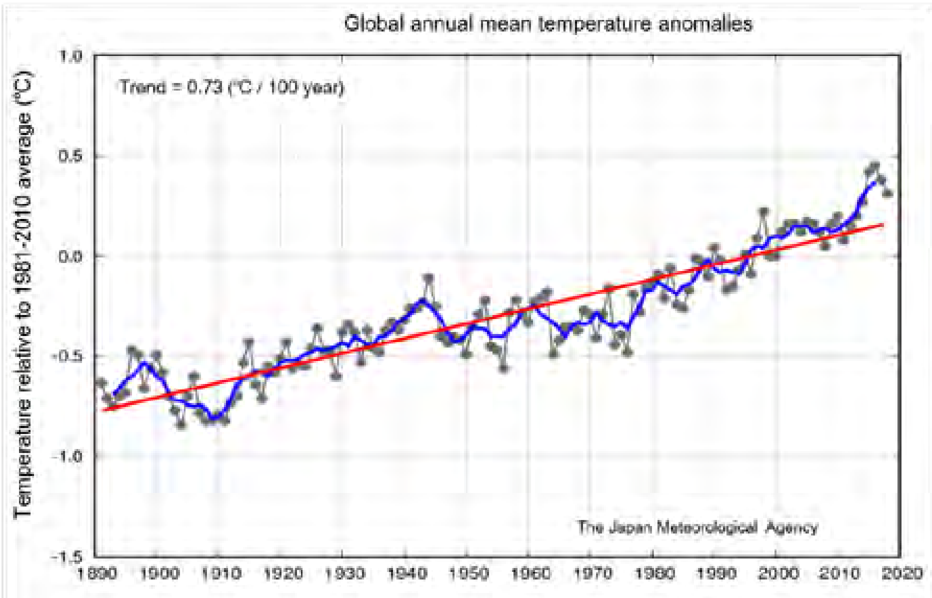


Fig. 2-5. Atmospheric temperature rise trend [13]

(2) Approach

The countermeasures for each greenhouse gas are described below.

① CO_2

The CO_2 utilization flow chart that is the biggest issue in global warming is shown in Fig. 2-6.

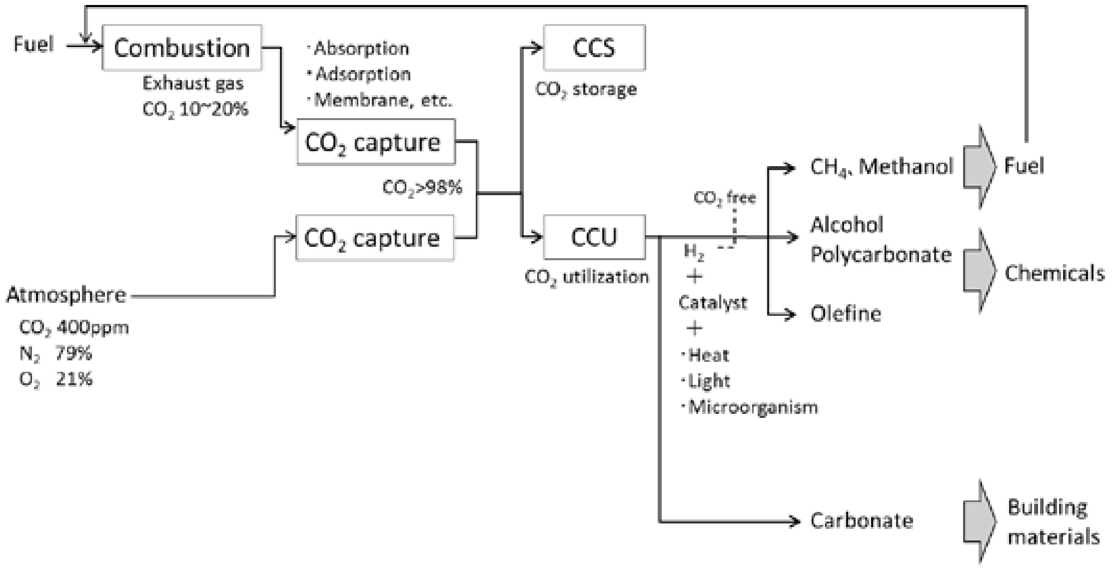


Fig. 2-6. CO_2 utilization flow chart

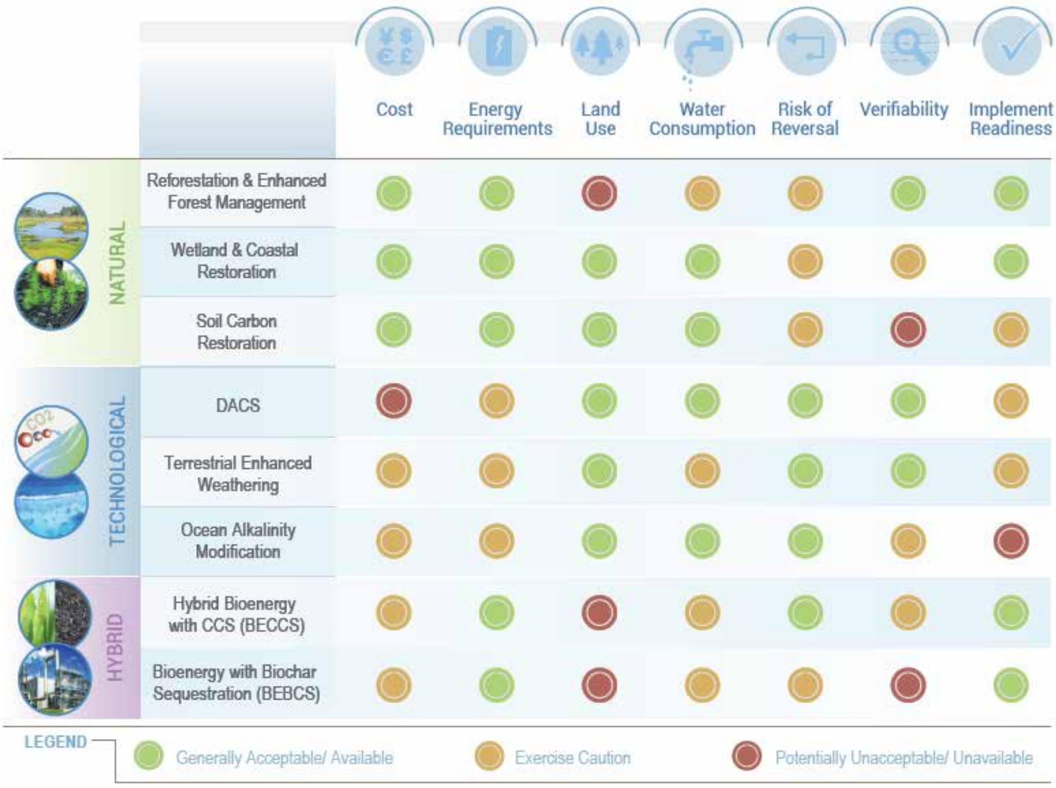
There are already some implementations of CO_2 recovery from the exhaust gas from combustion, which contains high concentration of CO2, by absorption, adsorption and membrane.

On the other hand, few R&D regarding CO_2 recovery from atmosphere have yet been carried out, because the CO_2 concentration is as low as 400 ppm.

The recovered CO_2 can be stored underground and contained (Storage; CCS), or can be converted into fuel and/or various chemicals as a raw material (CCU). If CO_2 is converted to fuel and burned, fuel consumption can be reduced by the circulation. If the various chemicals converted from CO_2 are distributed in the market, the consumption of conventional fossil resources can also be reduced. At present, although there are some commercial implementation, most of CCU activities are at the R&D stage and further development should be encouraged.

Regarding CO_2 removal from the atmosphere (negative emission technologies), there are some examples shown in Table 2-2. In these examples, DAC (Direct Air Capture) is the only purely-technological pathway which doesn't affect the natural environment. All the other pathways are likely to become unstable, or could cause unexpected results. Therefore, DAC is selected as a subject of challenging technological development.

Table 2-2. Summary table of pathways in the carbon dioxide removal portfolio, highlighting strengths, weaknesses and indicative technical potential [14]



In 2050, CO_2 emissions must be reduced considerably, but not all the emissions can be stopped due to technology and cost constraints, and thus a certain amount of emissions is inevitable. In order to realize net zero emissions of greenhouse gases in the second half of this century as mentioned in the 2 °C scenario, negative emissions with the equivalent amount to the remaining emissions are necessary. Therefore, a considerable amount of capacity is expected for the DAC.

DAC is now underway with some technologies and efforts as shown in Table 2-3, 2-4. Various R&D have been carried out for conversion and utilization, and some are already implemented [15]. But these technologies are with low efficiency and high energy consumption. By significantly improving these issues, DAC and CO_2 utilization should be realized with feasible cost for deployment, and should be effective also in terms of LCA.

Table 2-3. Examples of technology currently used in DAC [16] [17] [18]

Target	**Current status**	**Examples of technology**
DAC	Laboratory ～ Pilot plant	ü Absorb CO_2 in alkaline solution → Immobilize in carbonate → Firing and release CO_2 ü Adsorb and desorb CO_2 with honeycomb ceramic adsorbent containing amine ü Adsorb and desorb CO_2 with activated carbon and K_2CO_3 adsorbent

Table 2-4. List of major characteristics on DAC pilot plant [14] [17] [20] [21]

Company	Thermal energy/ tCO₂ (GJ)	Power/ tCO₂ (kWh)	Heat: Power ratio	Reference
Climeworks	9.0	450	5.6	Ishimoto 2017
Carbon Engineering	5.3	366	4.0	Keith 2018
Global Thermostat	4.4	160	7.6	Ishimoto 2017
APS 2011 NaOH case	6.1	194	8.7	APS 2011

Up to this point, this report has focused on CO_2. However, in order to achieve the IPCC 2 °C scenario, it is also necessary to take the measures against the greenhouse gases other than CO_2, which account for approximately 24% of the total.

② CH_4

CH_4 has subsequent impact following CO_2. The main sources of CH_4 emissions are associated with fossil fuel production, livestock, landfills, waste and agriculture [22]. In fossil fuel production, some efforts have been made against the gas accompanying the natural gas mining. In livestock, the gas discharged from the cow's stomach occupies the certain amount. There is a possibility of using biotechnology as a countermeasure against the emission from livestock. In landfills, waste and agriculture, although there is also a possibility of using biotechnology, no effective solution has been found.

③ N_2O

For N_2O, major artificial emissions are originated from the nitrogen chemical fertilizer used in agriculture (Fig. 2-7). In response to the global population increase, the fertilizer has been used for efficient food productions and sprayed over the farmland with excess amounts of the levels capable to be absorbed by the plants. The excess fertilizer remained in the farmland flows out sooner or later, through the rainwater and groundwater, from farmland into rivers and then into lakes and sea widely. Thus, the target area against the N_2O emissions seems to be widespread. However, it is actually not a large area on a global scale as for the case in CH_4. Therefore, it seems sufficiently possible to circulate N_2 from N_2O by controlling the behavior of N_2O emissions in the environment such as lake bottoms, far originated from the fertilizer in the farmland. Although it has not been implemented yet, some R&D have been conducted as shown in Table 2-5.

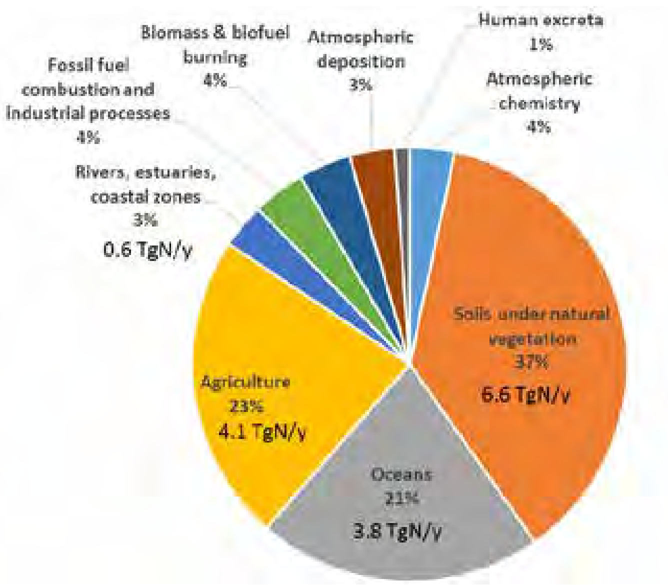


Fig.2-7. Breakdown of N_2O sources [22]

Table 2-5. Examples of technology for the circulation of N_2O [23] [24] [25] [26]

Target	Current status	Examples of technology
N_2O	Laboratory	ü Reduce N_2O to N_2 with natural or artificially modified enzymes ü Reduce N_2O to N_2 by chemical reaction through a catalyst ü Reduce N_2O to N_2 using microorganisms ü Suppress the generation of N_2O by NH_3 and NO_3 adsorbent

④ Fluorine compounds

Out of the 7 major greenhouse gases, four gases are fluorine compound gases. These have a large global warming potential, but the impact on global warming is small. These fluorine compound gases are not naturally derived nor generated from a wide range, and the emission source is almost limited to refrigerant gas or the likes. Because of these characteristics, an appropriate recovery process before being released to the atmosphere is reasonable. Therefore, regulatory management is appropriate.

1-3 Clean Earth

(1) Current status

Looking at the current status in Japan, harmful substances include various exhaust gases (NOx, SOx, dust (PM2.5) and etc.), liquid drainage (oil, nitrogen, phosphorus, etc.), and the soil wastes (metals, organic pollutants, etc.) are regulated by lows. However, nitrogen compounds are partially leaked to the environment even under regulations. This is one of the reasons why nitrogen has already exceeded the planetary boundary limits of high risk level. As shown in Fig. 2-8, the nitrogen compounds are leaked to the environment, including N_2O derived from chemical fertilizers, NOx in exhaust gas and nitrogen compounds contained in industrial wastewater.

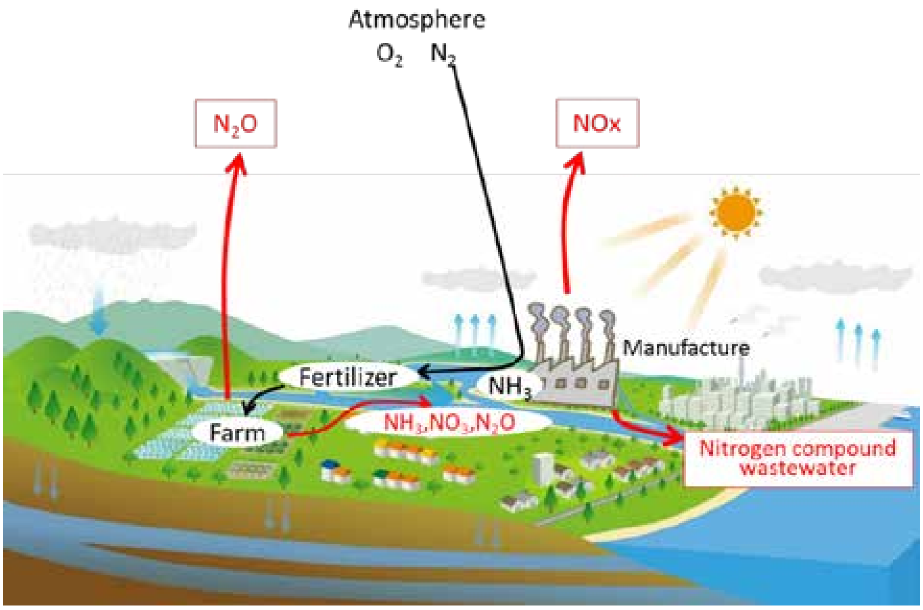


Fig. 2-8. Conceptual diagram of nitrogen circulation

Another substance currently leaked to the environment is marine plastic litter. Fig. 2-9 shows the amount of waste plastic and its treatment status in Japan. Environmental impact of waste has become reduced, as the rate of material recycling and chemical recycling increase.

However, waste plastic which outflows from land to sea has become a global problem. The United Nations Environment Programme (UNEP) estimates that 9 million tons of plastic flow into the sea annually (Table 2-6). It is said that as many as 700 species in the sea, including endangered species, have been damaged by plastic tangles or accidental ingestion of plastic. Preventing marine pollution is one of the targets of the Sustainable Development Goals (SDGs) because of concerns about the adverse impacts on food chains and ecosystems. So technology development for solving this problem should be addressed. For reducing marine plastic litter, waste management including recycling system is necessary. In addition, it is effective to introduce biodegradable plastic. In May 2019, Japanese government has set a goal to introduce 2 million tons of bioplastics by 2030 [27].

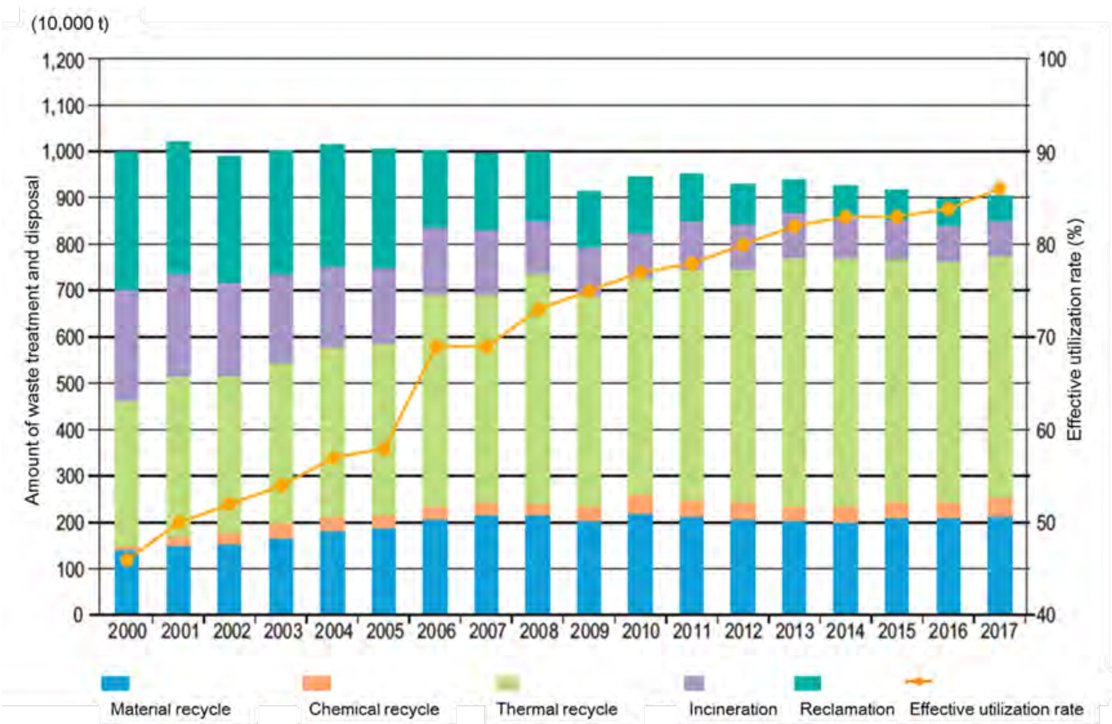


Fig.2-9. Treatment status of waste plastic in Japan [28]

Table. 2-6. Sources of plastic pollution reaching the marine ecosystem [29]

(thousand metric tones per annum)

Source	Tonnage plastics estimated to be entering the ecosystem
Rivers/land run off-land based	9,000
Direct dumping	1,500
Fishing gear	640
Lost cargo	600
Vehicle tire dust	270
Industrial pellet spills	230
Road and building paint	210
Textiles	190
Cosmetics	35
Marine paint	16

(2) Approach

① NOx and nitrogen compounds

Conventionally, NOx in exhaust gas is denitrated by ammonia. The remaining NOx has been released into the environment with its low concentration.

Nitrogen compounds in waste water from industry have also been released into the environment with their low concentration.

The circulation technology regarding NOx and nitrogen compounds, which is effective even for very low concentrations, is expected. Since it is still a laboratory level, there is not any example of social implementation. Examples of possible circulation technology are shown in Table 2-7.

Table 2-7. Examples of technology for the circulation of nitrogen compounds [30] [31] [32] [33] [34]

Target	Current status	Examples of technology
NOx in exhaust gas (after conventional denitration)	Laboratory	ü Convert NOx to ammonia by chemical reaction using a catalyst ü Convert NOx to nitric acid by chemical reaction
Nitrogen compounds in waste water	Laboratory	ü Convert nitrogen-containing organic to ammonia by catalytic reaction ü Convert nitrogen-containing organic to ammonia using microorganisms

② Marine plastic litter

Regarding the actions for marine plastic litter, Fig. 2-10 shows the resource flow using biodegradable plastics. It is not necessary to replace all conventional hard-to-decompose plastics with biodegradable plastics. This is because even if it is difficult to decompose, it does not necessarily flow into the sea if being properly managed and processed. On the other hand, replacement is necessary for applications where spillover concerns remain.

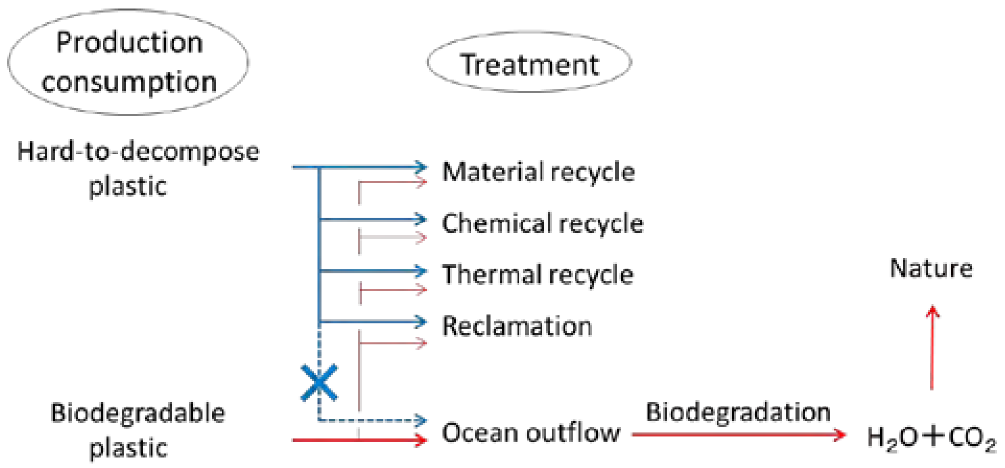


Fig.2-10. Plastic resource flow with biodegradable plastics

With biodegradable plastics for marine plastic litter issue, if the plastics decompose in the sea, they can be returned into the environment by becoming CO_2, nitrogen, and oxygen that lead to large resource circulation of ground, sea and air.

Compared to the amount and type of microorganisms and enzymes in the soil, those in the sea are overwhelmingly small. Especially, as the depth increases, the microorganisms and enzymes which decompose the plastic become fewer. Therefore, the development of the plastics which decompose in the sea is more difficult than the one in the soil. Even under such circumstances, R&D on biodegradable and detoxifying plastics has already started, and some products have been commercialized and marketed as shown below.

- Polylactic acid
- Fatty acid polyester
- Polyvinyl alcohol

In addition, the state-of-the-art efforts to add the switch function, by which the starting point of biodegradation and the rate of biodegradation can be designed in manufacturing stage, have recently started.

Here, there is the application for which a biodegradable plastic having a so-called switch function capable of purposely. For example, fishing gear is forced to be used mechanically severely, such as rewinding, so that it easily flows out into the sea when the net breaks. It is very beneficial that it does not decompose and maintains a predetermined performance while used as a fishing gear, and it starts to decompose when it flows into the sea.

Since it is still a laboratory level, there are no examples of social implementation. Examples of possible biodegradable plastic technology to add switch function are shown in Table 2-8.

Table 2-8. Examples of biodegradable plastic technology to add switch function [35] [36] [37] [38]

Target	**Current status**	**Examples of technology**
Biodegradable plastic with switch function	Laboratory	ü Technology to control the starting point of biodegradation • Biodegradation appears when the chemical structure changes in pH, salt concentration, etc. • Biodegradation appears when the enzyme in the material is activated by the physical stimulus due to outflow ü Technology to control the rate of biodegradation • Controlling biodegradation rate by changing crystallinity and crystal thickness • Controlling biodegradation rate by using microbiomes such as biofilm

2. Science and Technology Map

The resources circulation technologies that contribute to Cool Earth and Clean Earth are mapped in a matrix in Fig. 2-11. The horizontal axis shows whether the target resource is high concentration (rich) /low concentration (lean) or recoverable / unrecoverable. The vertical axis shows where the degree of perfection of the technology toward implementation is at present. This map shows that, as it goes to the lower left, they are in initial stage and the road to social implementation is far away, that is, challenging R&D.

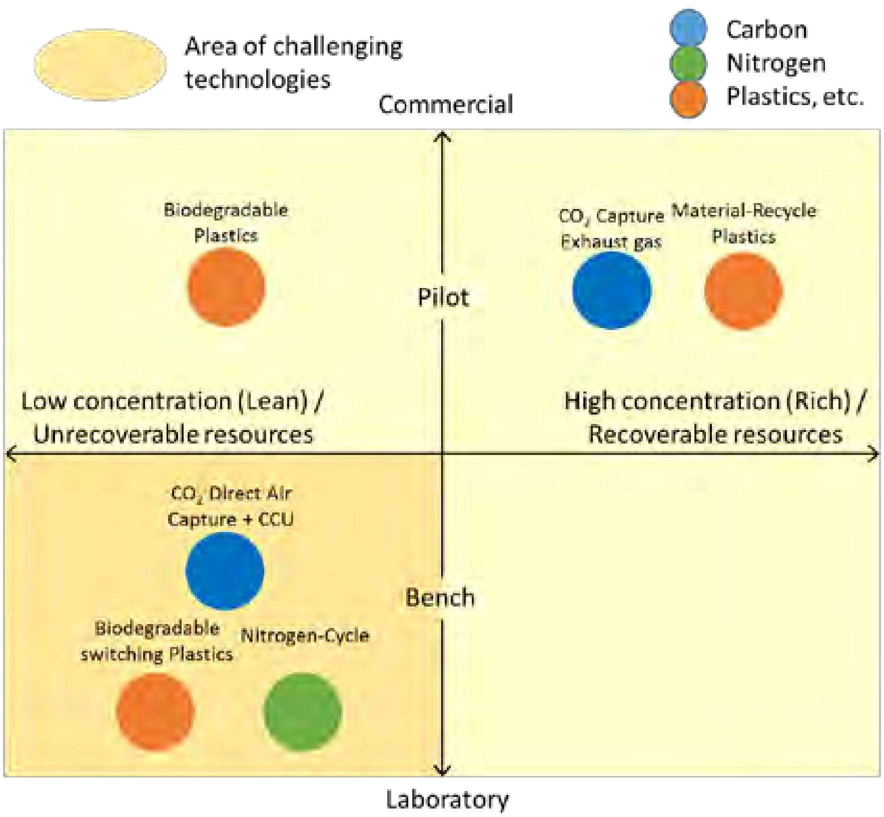


Fig. 2-11. Science and technology map for Cool and Clean Earth

III. SCENARIO FOR REALIZATION

1. Realization of Goals

1-1 Essential pathway to resource circulation

The timeline for achieving the MS goal candidate is given in I. VISION AND PHILOSOPHY / 2. Concept of MS Goal candidate.

For realization of the goal, circulation of the resources that are released or disposed into the environment widely in space and thinly in concentration should be addressed as an essential pathway. As specific circulation methods, there are the following two methods. One is to capture thin and widespread resources and circulate them artificially, and the other is to detoxify or decompose them to be circulated by nature.

1-2 Moonshot project example

Based on this pathway, assessing each technology in Fig 2-11, the technologies located in the lower left require radical solution and technical breakthrough inspired from truly disruptive and extreme ideas, therefore they will be suitable as the Moonshot project. The Table 3-1 are examples of the Moonshot project.

Here, although several specific examples are presented, the project to be adopted in the future is not limited to these examples. If Cool Earth and Clean Earth can be realized by resources circulation that matches the basic idea described above, e.g. the possibility of the project that is on a metal resource or a carbon resource other than CO_2 is not excluded.

Fig. 3-1～3-4 show the schematic diagrams of circulation realized by each example.

Table 3-1. Moonshot project example

	Target	Background	Moonshot project examples
Cool Earth	CO_2	・Paris agreement ・IPCC 2°C scenario by United Nations	① DAC related to CCU
	N_2O		② Detoxify N_2O or suppress N_2O generation
Clean Earth	Nitrogen compounds	・Planetary boundary	③ Convert nitrogen compounds in exhaust gas and wastewater to chemicals
	Marine plastic litter	・G20 Osaka Blue Ocean Vision ・EU plastic regulation	④ Biodegradation plastic including switch function

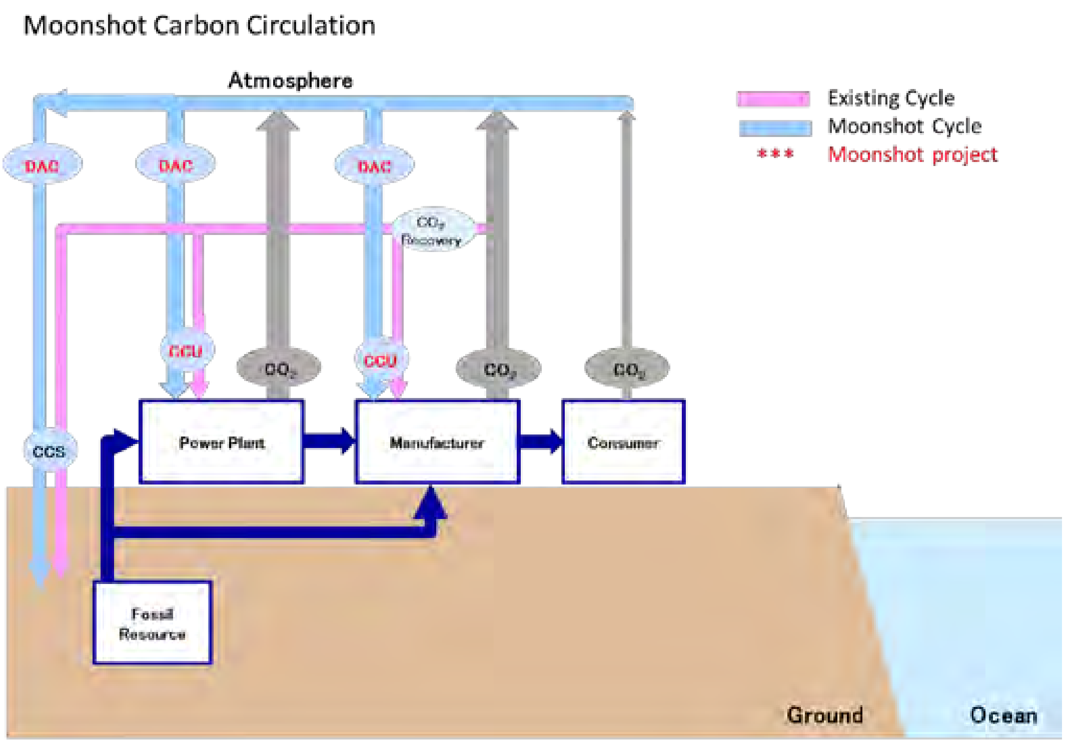


Fig.3-1. ①Schematic diagram and the target area on carbon circulation

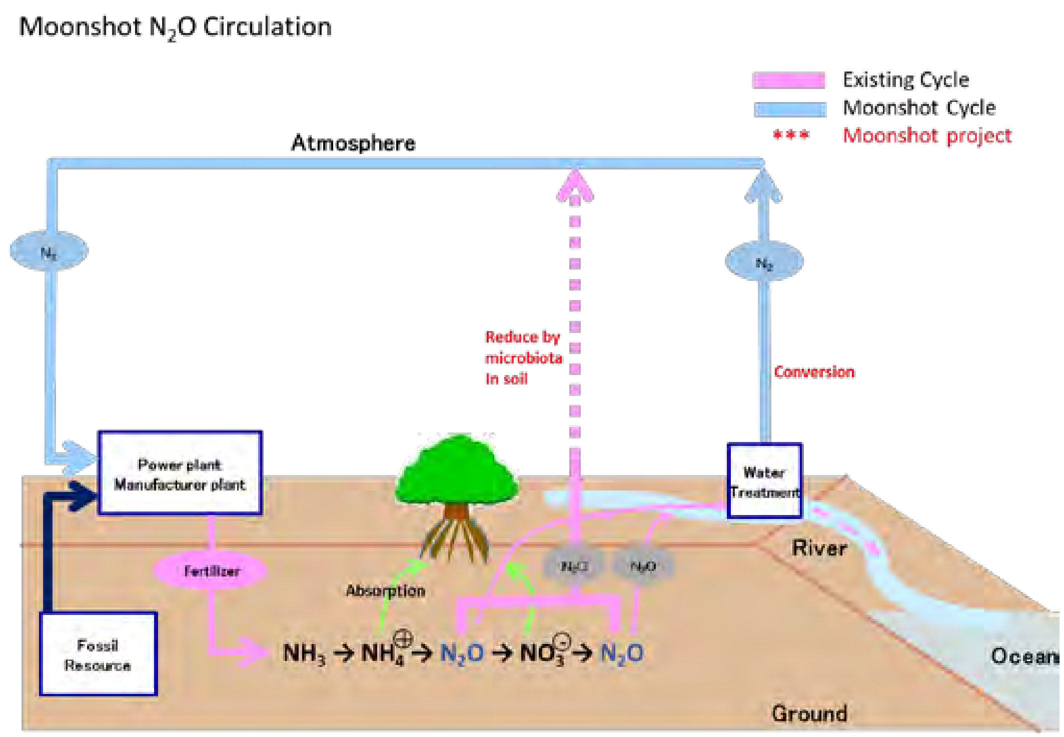


Fig.3-2. ②Schematic diagram and the target area on N_2O circulation

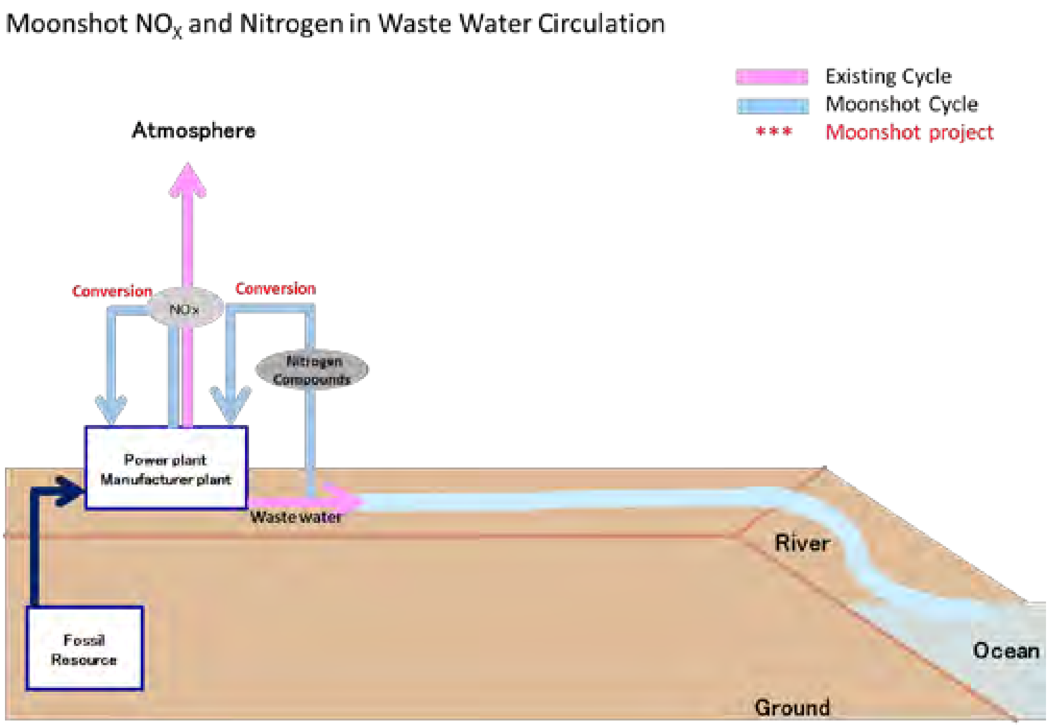


Fig.3-3. ③Schematic diagram and the target area on NOx and nitrogen in waste water circulation

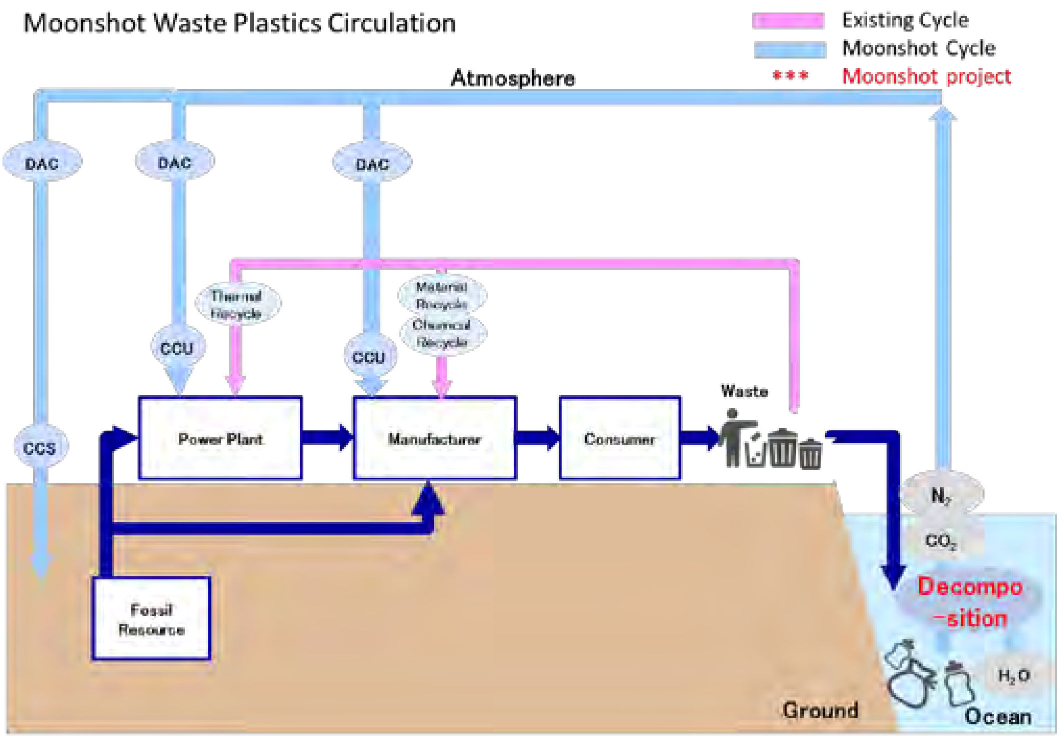


Fig.3-4. ④Schematic diagram and the target area on marine plastic litter

2. International Collaboration

In order to realize Cool Earth and Clean Earth, it is important to work globally, not just in Japan. For this reason, international cooperation will be discussed, utilizing international frameworks such as ICEF (Innovation for Cool Earth Forum).

3. Corporation with other WG

As for developing resources circulation technologies, WG4 intends to collaborate with other working groups related to technologies and approaches. For an example, reduction of GHG emission will be cooperated with WG5.

4. ELSI

Technologies of resources circulation for Cool Earth and Clean Earth will affect the natural environment. It is necessary to promote social implementation of the technologies while avoiding unexpected negative effects. Therefore, it is important to discuss ELSI (Ethical, Legal, and Social Issues).

5. Remarks

This report have focused on the point of technology. However, in 2050, it will be certainly necessary to establish an appropriate framework to accelerate the introduction of indispensable investment for Cool Earth and Clean Earth. For this objective, economic and social argument should be arranged simultaneously with this R&D program.

IV. CONCLUSION

It is recognized that global warming and environmental pollution are entering an unacceptable area as social issues. Therefore, in this Initiative Report, the countermeasures for these problems are discussed through the statistical analysis.

In the examples of 25 MS Goals proposed by the visionary council, ‘Full recycle system for resources and materials’ is focused on, associating the following examples. Regarding ‘Reduction of resources losses to 1/100th’ and ‘Reduction of energy consumption per calculated unit to 1/1000th’, the resources and energy saving have made a certain contribution to the maintenance of the global environment, and the resources circulation is positioned as the next step. Regarding ‘100% energy self-sufficiency with sustainable energy source’, resources circulation requires renewable energy in terms of reducing greenhouse gases. ‘Elimination of garbage on the earth’ is derived from the resources circulation itself.

As a result of the above discussion, circulation of the resources that are released or disposed into the environment widely in space and thinly in concentration is clarified as an essential pathway for realizing of Cool Earth and Clean Earth. As specific circulation methods, there are the following two methods. One is to capture thin and widespread resources and circulate them artificially, and the other is to detoxify or decompose them to be circulated by nature.

In conclusion, “Realization of sustainable resources circulation to recover the global environment by 2050” is proposed as MS Goal candidate in this Initiative Report.

REFERENCES

[1] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[2] Created by NEDO based on “Emissions Gap Report 2018” (United Nations Environment Programme, 2018)

[3] W. Steffen et al., Science 347, 1259855 (2015).

[4] The Ministry of the Environment “Annual Report on the Environment (2019)"

[5] https:// www.unenvironment.org/resources/frontiers-201819-emerging-issues-environmental-concern

[6] https://www.unenvironment.org/news-and-stories/press-release/colombo-declaration-calls-tackling-global-nitrogen-challenge

[7] J. Lokrantz/Azote based on Steffen et al. 2015.

[8] A European Strategy for Plastics in a Circular Economy (January 2018)

[9] G20 Osaka Leaders' Declaration (2019)

[10] Center for Research and Development Strategy, Japan Science and Technology Agency (CRDS), Overview Report on R&D/Environment and Energy Field (2019)

[11] Agency for Natural Resources and Energy, “FY2018 Annual Report on Energy (Energy White Paper 2019)”

[12] WMO Greenhouse Gas Bulletin No 15

[13] The Japan Meteorological Agency (https://www.data.jma.go.jp/cpdinfo/temp/an_wld.html)

[14] Innovation for Cool Earth Forum (2018)

[15] Direct Air Capture of Carbon Dioxide. David Sandalow, Julio Friedmann, Colin McCormick, and Sean McCoy (2019)

[16] Sanz-Pe´rez et al., Chem. rev., 116, 19, 11840-11876, 2016

[17] Keith et al., Joule 2, 1573–1594, (August 15, 2018)

[18] Li et al., ChemSusChem, 399-903, 2010

[19] Antecy------“CO2the Uber Resource”-Direct CO2Capture from Air for E-Fuels & more -

[20] Yuki Ishimoto et al. (2017) PUTTING COSTS OF DIRECT AIR CAPTURE IN CONTEXT

[21] APS & POPA (2011) Direct Air Capture of CO_2 with Chemicals - A Technology Assessment for the APS Panel on Public Affairs

[22] Climate Change 2013: The Physical Science Basis, IPCC(2013)

[23] Zhang et al., Proc. Natl. Acad. Sci. USA, 116(26), 12822-12827, 2019

[24] Hinokuma et al., Chem. Lett., 45, 179-181, 2016

[25] Akiyama et al., Scientific Reports 6:32869, 2016

[26] Jiang et al., RSC Adv., 60, 34573-34581, 2018

[27] Japanese government “Resource Circulation Policy for Plastics”

[28] Plastic Waste Management Institute “Production, disposal, recycling, and disposal of plastic products -material flow diagram-(2017)”

[29] Jenna R. Jambeck, Roland Geyer, Chris Wilcox, Theodore R. Siegler, Miriam Perryman, Anthony Andrady, Ramani Narayan, and Kara Lavender Law, “Plastic waste inputs from land into the ocean”, Science, vol. 347 Issue 6223, pp. 768-771, February 2015.

[30] Nanba et al., Chem. Lett.,37(2008)710

[31] Nanba et al., Catalysis Science & Technology., 9(2019)2898

[32] Japan Science and Technology Agency, New technology presentation meetings, “Proposal of new denitration method by adsorption and concentration of NOx and nitric acid production by water absorption of concentrated NOx” (2014) (in Japanese)

[33] Yuichi Kamiya laboratory HP (Department of Functional Materials Chemistry, Department of Materials Science, Graduate School of Global Environmental Sciences, Hokkaido University) https://www.ees.hokudai.ac.jp/ems/stuff/kamiya/index_En.html
[34] CHUTIVISUT et al., Journal of Water and Environment Technology, Vol.12,No.4,2014
[35] Nduko et al., BIOBASED MONOMERS, POLYMERS, AND MATERIALS, 1105, 213-235(2012)
[36] Iwasaki et al., Biomacromolecules,17, 2466（2016）
[37] Gan et al., Polymer, 172, p7-12(2019)
[38] Morohoshi et al., Microbes and Environments, 33, 332-335 (2018)