Beyond Zero Expo

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1. Introduction

As indicated in Prime Minister Suga's policy speech on 26th October, 2020, it is required that our society has net-zero CO_2 emissions by 2050. In order to achieve this, it will be important to reduce energy requirements through higher efficiency, and to maximize the use of energy that does not emit CO_2, such as solar and wind power. In addition, it will also be important to establish systems that realize carbon neutrality by capturing the CO_2 that is unavoidably emitted and using underground storage or fixation and utilization. Through the spread and development of this underground storage technology and fixation and utilization technology, and through the further reduction of CO_2 emissions, it is thought that we will be able to approach the realization of a Beyond Zero state which exceeds neutral (in other words, zero), as described in the Environment Innovation Strategy. At the Osaka, Kansai Expo in 2025 (Fig.1), rather than a simple exhibition of Beyond Zero, we will propose the Beyond Zero Expo as a pioneering system for achievement within the venue during the exhibition period.

Fig.1 Conceptual image of the Osaka, Kansai Expo venue (Courtesy of the Japan Association for the 2025 World Exposition)

To construct this system, it will be necessary to limit the power supplied to the venue during the period to energy that does not emit CO_2. Also, for city gas, the CO_2 emissions from production and consumption will be offset with credits. The hydrogen used will also be either green or blue hydrogen and be carbon neutral. In addition, electric or hydrogen vehicles will be used inside the venue and the CO_2 generated by any gasoline vehicles will be offset with credits in the same way as for city gas. We will achieve carbon neutrality as a starting point through these efforts.

As the next step, in this proposal, we will capture CO_2 from the atmosphere in the venue and either store it underground or fix and utilize it, in order to realize a state Beyond Zero and to promote environmental technology.

The concentration of CO_2 in the atmosphere is about 400 ppm, which is only a few hundredths of the concentration of CO_2 in the current practical applications of capture technology. It is not really possible to say that the technology to capture this efficiently has already been established. However, if we make full use of Japan's cutting-edge technology, then we believe that it will be possible to produce a DAC (Direct Air Capture) device that efficiently captures CO_2 in units of tons (per day) by 2025, and to install and operate it at the venue.

Next, we will also perform underground storage (part of a process called CO_2 Capture and Storage, or CCS) within the venue in order to process the captured CO_2 permanently. The amount stored during the period will only be a few hundred tons, which is actually quite small (as there are proven results of 300,000 tons over three years at Tomakomai). However, the fact that the storage will be in Osaka, which is a large city, will make it a revolutionary attempt unprecedented in the world, so it will have great significance.

In addition, carbon recycling technology will also be realized within the venue as an environmental technology. Specifically, a methanation device for producing methane from CO_2 from the DAC device mentioned above and carbon-free hydrogen will be installed within the venue. The methane produced will then be supplied to the guest house kitchen and elsewhere as city gas. Similarly, CO_2 will be supplied to the plant factory installed in the venue and the vegetables cultivated will be provided to the guest house kitchen on a daily basis. In addition, acrylic resin made using methanol produced from CO_2 fixation as a raw material will be used to manufacture fixtures and fittings for the venue and souvenirs.

Fig.2 shows a summary of these proposals. Furthermore, we want to position the equipment as exhibition displays at the Expo venue. We want to create a Beyond Zero Pavilion of the equipment together with an exhibition of carbon neutral, DAC, underground storage, and other CO_2 fixation and carbon recycling technologies, to promote Japan's environmental technologies to the many visitors.

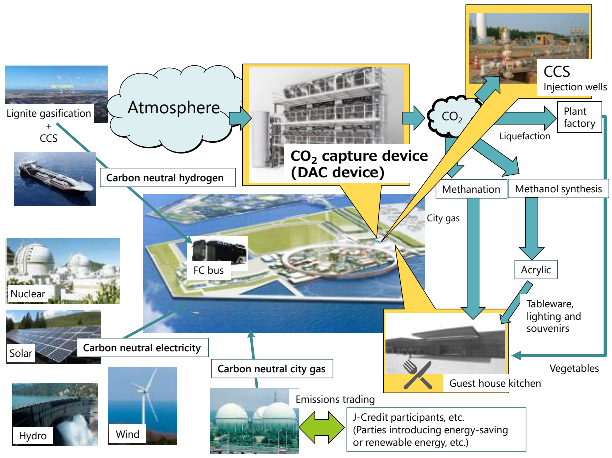

Fig.2 Conceptual image of the Beyond Zero Expo proposal

This special issue gives a detailed introduction to each technology for the realization of the Beyond Zero Expo. First, Chapter 2 discusses the need to achieve carbon neutrality and the prospect of achieving Beyond Zero. Chapter 3 then introduces DAC, underground storage, and other technologies. As a summary, Chapter 4 discusses the relationship between this proposal and the basic policy of the Osaka, Kansai Expo.

2. For the achievement of carbon neutrality

As described in the previous chapter, on 26th October, 2020, Prime Minister Suga declared the intention to "Aim for carbon neutrality and decarbonization by 2050". Here we discuss what measures are required to achieve carbon neutrality.

2.1. Multiple possibilities for carbon neutrality achievement

The Special Report on Global Warming of 1.5°C (SR15) by the Intergovernmental Panel on Climate Change (IPCC) noted that to limit the increase to 1.5°C, it will be necessary to achieve a net near-zero level of global CO_2 emissions in around 2050[1)]. Carbon neutral in 2050 is in line with this.

In SR15, four typical pathways are presented. Of these four, the two extreme pathways are as follows. The first is a scenario of exhaustive energy conservation, known as the Low Energy Demand (LED) scenario. On the energy demand side, the amount of energy currently being used greatly exceeds the level that is originally necessary. There is a possibility that the use can be greatly reduced by changes such as advances in digitization technology. The scenario shows that if social changes also occur, then a society with low energy demand and low CO_2 emissions can be realized. (The RITE Systems Analysis Group launched the research project, EDITS (Energy Demand changes Induced by Technological and Social innovations) research project in FY2020 and started detailed international studies on low-energy demand scenarios.) The LED scenario described in SR15 does not assume the use of CDR (Carbon Dioxide Removal) technology. Another model scenario is the achievement of carbon neutrality during the time when fossil fuels continue to be cheap, by using fossil fuels whilst also using a large amount of CDR technology. In addition to CCUS, the CDR also includes biomass with CCS (BECCS), which produces negative emissions, and the direct capture and storage of atmospheric CO_2 (DACCS). It will be desirable to have multiple scenarios as we go on to enhance the feasibility of carbon neutrality so that it can be achieved at an early stage.

2.2. Image of carbon neutrality achievement

Fig.3 shows a conceptual image of measures for net zero emissions (= carbon neutral) in terms of greenhouse gas emissions. Broadly speaking, there is energy conservation and there is the reduction of CO_2 emissions per unit of power. Firstly, what is fundamentally important is the conservation of energy, including through the reduction of materials and energy services through digitization. For the reduction of CO_2 emissions per unit of power, it tends to be easier to reduce these for electricity than for non-electric power, so the IPCC also emphasizes the importance of promoting electrification whilst simultaneously promoting the decarbonization of power sources[2)]. On the other hand, for both energy conservation and the reduction of CO_2 emissions per unit of power, when the effort for a large reduction is increased, in other words, when the effort to bring the figures to close to zero is increased, the costs increase rapidly. Furthermore, there are some sectors where the reductions are more difficult than those for CO_2, such as methane from livestock production. One major direction for achieving carbon neutrality will be to cancel out those remaining emissions by using negative emission technologies (NETs). However, as mentioned in the previous section, there are several different prospects for the level of contribution of each. We should aim for carbon neutrality with a wide range of options.

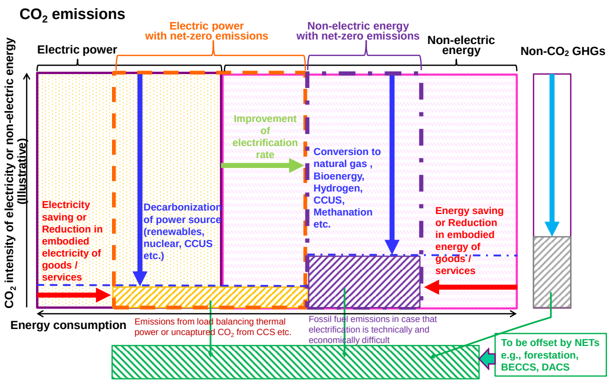

Fig.3 Conceptual image of measures for net zero emissions in terms of greenhouse gas emissions

In the same way, Fig.4 shows an image of measures for net-zero from the viewpoint of primary energy supply in Japan. In principle, it is necessary that primary energy only consists of renewable energy, nuclear energy, and fossil fuels with CCS. However, it is also important to consider the utilization of overseas resources for renewable energy and CCS, and in doing so, conversion to hydrogen is important. Hydrogen is also called green hydrogen when it originates from renewable energy and blue hydrogen when it originates from fossil fuel + CCS. To improve convenience, it may also become important to convert hydrogen to ammonia or synthetic fuel for transportation and utilization. However, there is a high possibility that fossil fuel use without CCS will also remain. It will be necessary to cancel this out with measures such as afforestation, BECCS, and CO_2 mineralization (CO_2 fixation in concrete sector, etc.). However, due to volume constraints, the use of DACCS is also considered important. There is a limit to the storage capacity of CCS, which includes BECCS and DACCS, so it is important to secure CO_2 storage sites and also it is very important to consider the utilization of CO_2 storage sites overseas.

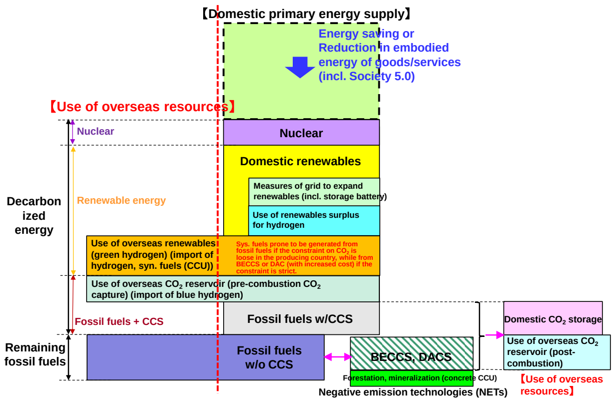

Fig.4 Conceptual image of measures for net zero emissions in terms of primary energy supply in Japan

2.3. Example of comprehensive analysis using the global energy and climate change mitigation assessment model: The role of DACCS

Next is an example analysis of the total global measures for carbon neutrality by using the global energy and climate change mitigation assessment model, DNE21+. In the emissions scenarios, in the scenarios for less than 2°C and for less than 1.5°C, the CO_2 emissions reach net zero in around 2060 and 2050 respectively, and then become negative (Beyond Zero). For greenhouse gas emissions, the scenarios have net zero reached in around 2100 and 2065, respectively, and then a negative figure after that. For the 1.5°C scenario, in the assumptions for this model, there were no feasible solutions without the assumption of DAC (Table 1).

Table 1 DAC-related model analysis scenarios

	Emission scenarios	DAC costs	Feasibility
2℃(No DAC)	<2℃ (>66%)	No DAC	○
2℃(DAC, High cost)		High cost	○
2℃(DAC, Low cost)		Low cost	○
1.5℃(No DAC)	<1.5℃ in 2100 (>66%), Overshoot of temperature	No DAC	×
1.5℃(DAC, High cost)		High cost	○
1.5℃(DAC, Low cost)		Low cost	○

Note) The assumptions for DAC are based on Ref. 4). The required energies in 2050 are 5.5-7.2 GJ/tCO_2 and 4.7 GJ/tCO_2 for the high and low cost scenarios, respectively.

Fig.5 shows the balance between global CO_2 capture and storage/use in the results from this model analysis. (For details of the analysis, see reference 3.) Even under the scenario where the cost of DAC is assumed to be high (a maintenance of the current technology level), the cost of the energy inputs will be reduced by utilizing surplus renewable energy, so when aiming for carbon neutrality, it is evaluated as a cost-efficient option in around 2050. In the scenario where it is low cost, there is even more extensive use. As the use of DACCS makes negative emissions possible, it will still be possible to use fossil fuels without CCS at an appropriate level. There is still a long way to go in DAC technology development, but it will contribute to the achievement of cost-effective carbon neutrality as a whole, and also bring achieving Beyond Zero into view.

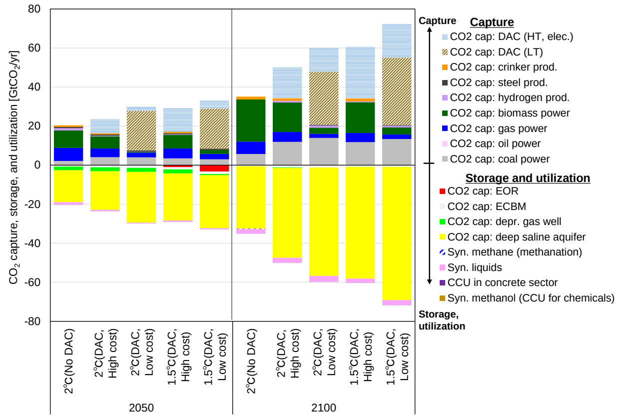

Fig.5 Balance between global CO_2 capture and storage/use

3. Technology introduction

3.1. DAC

Since the concept to capture CO_2 from the atmosphere was proposed as a feasible option for climate mitigation technology, development of direct air capture (DAC) technologies have attracted much attention. According to the Energy Technology Perspectives 2020, for the achievement of sustainable development scenarios, BECCS (Bio-energy with CCS) and DACCS (Direct Air CO_2 Capture and Storage) are expected to achieve negative emissions of 3 Gt-CO_2/y by 2070. The utilization of captured CO_2 by DAC is also be considered, however, the effect of removing the CO_2 from the atmosphere by CCU is small. DAC can be used as a negative emission technology by combining it with storage as DACCS.

DAC is considered to be energy intensive and costly, but it does use less land area and water than BECCS, afforestation, or reforestation, so it is possible to suppress the problem of competition with land use for food production, and the adverse impacts on biodiversity.

As shown in Table 2, some researches are being carried out in the United States and Northern Europe. However, the capture cost is currently high. Therefore, based on a detailed cost estimation, the reduction of both costs (CAPEX) and thermal and electric energy (OPEX) are required.

Table 2 Status of DAC technology development overseas [5)]

Company name	Materials	Energy /Cost of CO_2 separation and capture	Remarks
Climeworks (Swiss)	Amine modified filter (Solid sorbent material and resin filter)	9.0 GJ/t-CO_2, 600 \$/t-CO_2(Target cost around 2025: 100 \$/t-CO_2)	Launched the world's first commercial plant(900t-CO_2/y), which has already been installed in eight locations. Energy and costs are high.
Carbon Engineering (Canada)	Aqueous solution containing KOH/$Ca(OH)_2$	5.3 GJ/t-CO_2, 94-232 \$/t-CO_2	Plan to put two 500,000 t-CO_2/y DAC plants into operation in 2022 with Occidental Petroleum. The only company using alkaline aqueous solution.
Global Thermostat (USA)	Amine-containing ceramics(Solid sorbent material)	4.4 GJ/t-CO_2, 150 \$/t-CO_2 (Target cost: 50\$/t-CO_2)	Working in cooperation with Georgia Institute of Technology. Has already installed six units and constructed 4,000 t-CO_2/y pilot plant.
Center for Negative Carbon Emissions (USA)	Ion-exchange resin	220 \$/t-CO_2 (Target cost: 30 \$/t-CO_2)	Adsorption/desorption using dehumidification/humidification swing. Proposing installation of AT along expressways.
The VTT Technical Research Center (Finland)	Ion-exchange resin	8.9GJ/t-CO_2	1～2kg-CO_2/d on Day/night capture cycle

The target CO_2 concentration of DAC is only 400 ppm. This is two to three orders of magnitude lower than that of exhaust gas from coal- and natural gas-fired power plants. This is a main reason that the DAC cost will be high. The amount of air that contains one ton of CO_2 is approximately 1.27 million m^3. What this means is that even if the capture rate is 100%, it would take the air of one Tokyo Dome to capture 1 ton of CO_2 from the air.

In order to make DAC realistic, it will be necessary to develop CO_2 separation materials with unprecedented high performance, and to construct a process that makes it possible to absorb and desorb large amounts of air efficiently. Now, RITE is working on the development of new materials based on our experience in the development of solid sorbents and amine compounds and a highly efficient DAC system with the cooperation of private companies and universities (Fig.6).

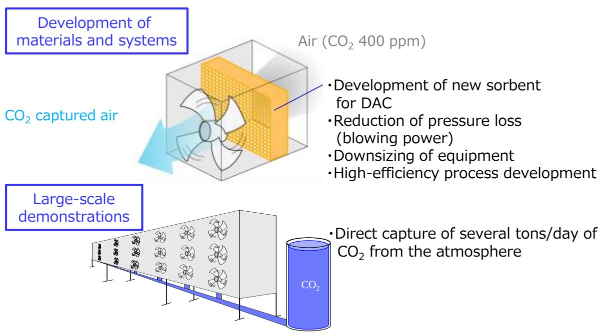

Fig.6 Development of technology to capture CO_2 from the atmosphere

In this proposal, we want to make full use of Japan's cutting-edge technology to produce a DAC device that efficiently captures CO_2 in units of tons (per day), and to install and operate it at the venue.

3.2. Underground storage of CO_2

Methods for CO_2 injection and storage in the ground include EOR (Enhanced Oil Recovery), where CO_2 is injected into oil fields to perform enhanced oil recovery, ECBM (Enhanced Coal Bed Methane), where CO_2 is injected into coal seams to recover methane, and CO_2 geological storage in deep saline aquifers.

The geological structures necessary for the storage of CO_2 underground include a "reservoir" and a "seal layer". Sedimentary layers such as porous sandstone are suitable for the "reservoir", and saline aquifers with large permeability correspond to this.

Saline aquifer storage is a method of storage that targets sandstone layers at depths of 800 m or more below ground. The sandstone layers are geological strata formed by the accumulation of sand grains. Salt water which is not used for groundwater utilization fills the gaps between the sand grains. Fig.7 shows a conceptual image of saline aquifer storage. CO_2 is injected into the sandstone layer via a well that is drilled from the ground surface. CO2 pushes away the part of salt water and accumulates in the gaps, and also some of it is dissolved in the salt water. It is possible to store the CO_2 stably over a long period of time if there is a seal layer such as mudstone above the sandstone layer. Mudstone has strong sealing properties and allows hardly any gas or liquid to pass through.

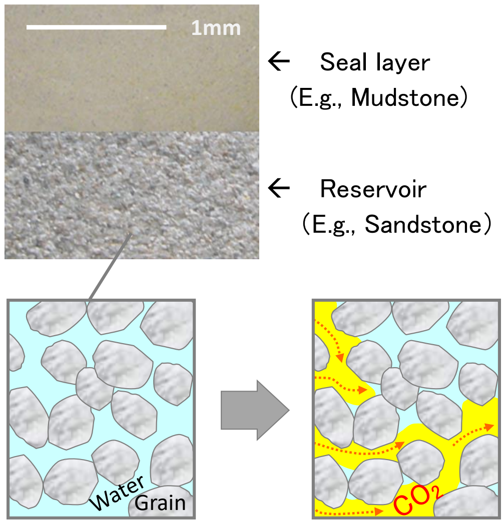

Fig.7 Schematic diagram of underground CO_2 storage

Fig.8 shows a general outline of a CO_2 storage site. The CO_2 is captured from the source generating it and then either stored directly below ground from facilities on the surface, below the seabed from ground facilities, or below the seabed from offshore facilities.

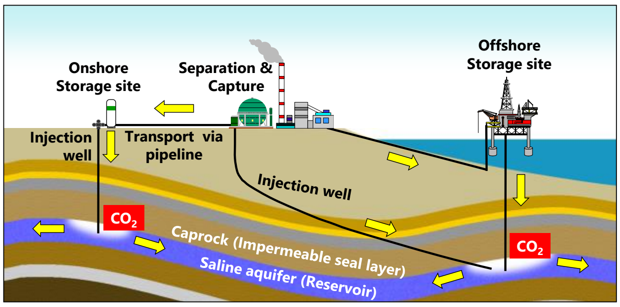

Fig.8 General outline of an underground CO_2 storage site

As discussed in the previous chapter, the underground storage of CO_2 is one of the important options for sequestering the CO_2 that is captured.

A large number of CO_2 injection wells would be required for CCS at a level that would suppress global warming. However, the number is only a small fraction of the number of oil production wells that have been drilled to date around the world. It is expected that the underground storage of CO_2 will be utilized in earnest and become one of the measures against global warming. An introduction to this kind of underground CO_2

storage at the Osaka, Kansai Expo will be very meaningful for spreading knowledge of CCS to a wide audience.

In this proposal, underground storage will be carried out within the venue. The amount stored during the period of the event will only be a few hundred tons, which is actually quite small (as there are proven results of 300,000 tons over three years at Tomakomai). However, the fact that the storage will be in Osaka, which is a large city, will make it a revolutionary attempt unprecedented in the world, so it will have great significance.

3.3. Other

3.3.1. Methanation

Methanation is a technology to synthesize methane from CO_2 and hydrogen. The synthesis requires energy, but unlike hydrogen, it has the major advantage that it is possible to utilize the existing city gas infrastructure, so it is attracting much attention.

The technology itself is an existing technology that was discovered in 1911 by the French chemist Sabatier. In Japan, as part of a NEDO project to develop effective CO_2 utilization technologies, INPEX and Hitachi Zosen constructed a test facility with a methane synthesis capacity of 8 Nm^3/h in 2019 and have conducted demonstration testing such as continuous operation. On the other hand, there have not yet been any examples of utilization as city gas. The issues for this are scaling up and the improvement of the conversion efficiency and economic efficiency. The synthesis requires four times as much hydrogen as CO_2, but if the hydrogen is produced using the surplus electricity from renewable energy sources, then the use of synthetic methane can reduce the amount of natural gas used as a fossil fuel and contribute to decarbonization. In addition, if a large amount of renewable energy power is introduced as a measure to achieve net-zero carbon, then one issue will be the storage of the large amount of surplus electricity. There are also expectations for methanation as a technology for that storage and for the stabilization of the power system.

The reason for converting hydrogen to methane is that the storage, transportation, and use of hydrogen would require new capital investment and the development of new equipment technology. However, methane has almost the same composition as natural gas, so if it is connected to a gas pipeline, then it can be used without building new equipment. In addition, the possibilities for methane as an energy carrier are attracting attention from the viewpoint of low carbonization for the utilization of heat from primary energy.

In Europe, where decarbonization is in progress, Audi is operating a demonstration plant with a methanation capacity of 315 Nm^3/h, which makes it the largest demonstration plant in the world. It performs the methanation using electricity derived from renewable energy and CO_2 separated from biogas, with the assumption that the price for renewable energy will fall when a large amount of it is placed on the market. Also, in China, which aims to achieve net zero CO_2 emissions by 2060, Hitachi Zosen announced in December 2020 that it would conduct a feasibility study for methanation technology, and plans to evaluate the supply chain and business profitability for social implementation.

In this proposal, we are considering the installation of a methanation device within the venue. The device will use CO_2 from the DAC device mentioned above and supply the methane to the guest house kitchen and elsewhere as city gas.

3.3.2. Methanol synthesis

Methanol is used widely as a raw material to produce lower olefins such as ethylene and propylene. It is also a basic raw material for chemicals such as synthetic resins, adhesives, chemicals, and paints. The annual demand for it globally is about 80 million tons. It is produced under high temperatures and high pressures through multiple manufacturing processes, and the main raw materials currently used are fossil resources such as natural gas, liquefied petroleum gas, and coal.

Instead of using fossil resources as the raw materials to obtain methanol, it can be synthesized by using hydrogen derived from renewable energy and CO_2 obtained by capturing it from the atmosphere or from the combustion exhaust gas from facilities such as coal combustion power plants and blast furnaces. Doing this makes it possible to simultaneously reduce greenhouse gas emissions while producing the useful industrial product methanol.

The methanol that is obtained from these raw materials of CO_2 obtained from capture and hydrogen derived from renewable energy can then be reacted with methacrylic acid to synthesize an acrylic resin (PMMA). Acrylic resins have high transparency and impact resistance and are easy to process and color, so they are used in various applications such as window materials for buildings and vehicles, covers for lighting fixtures, and signboards.

In this proposal, we would like to show examples of the realization of a carbon recycling society by using this acrylic resin at the venue. This includes use in exhibits and souvenirs, and in transparent boards surrounding the DAC (Direct Air Capture) equipment displayed at the Expo venue as equipment to capture CO_2 from the atmosphere (Fig.9).

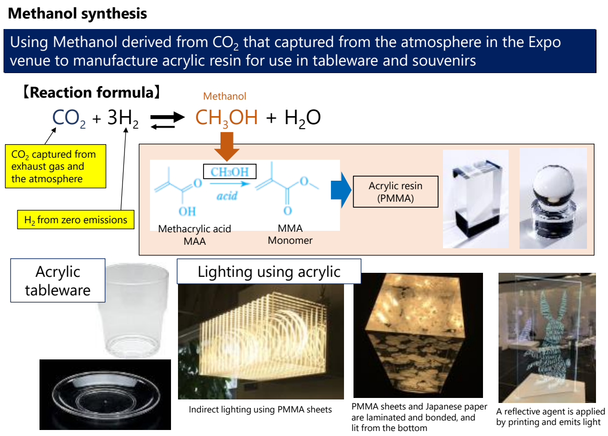

Fig.9 Methanol utilization at the Expo

3.3.3. Plant factory

Plant factories are a facility that could utilize CO_2 on a global scale in the future. Plant factories can be either the artificial light type or the solar light type. Of these, an artificial light type plant factory (Fig.10) uses artificial light as the light source and has air conditioning and liquid nutrient cultivation to control the environmental elements necessary for plant growth (light, temperature, humidity, CO_2 gas concentration, and airflow). These can stably cultivate high-quality plants throughout the year[6].

For example, for leaf lettuces, for which the technology has already been applied, it is necessary to add 22 kg of CO_2 in order to produce 3,000 leaf lettuces (of 100 g each), and this greatly contributes to productivity[6]. In addition, further development and advances can be expected, such as through the research and development currently being carried out for strawberry production.

In this proposal, carbon recycling and the latest technology for plant factories will be promoted by setting up a small factory to produce the latest vegetables for which the technology has been applied. The factory will use CO_2 captured by the DAC within the venue and will supply the vegetables to the guest house kitchen.

Fig.10 Example of an artificial light type plant factory
(Source: Techno Farm™ Website)

4. Conclusion

At the 2025 Osaka, Kansai Expo, rather than just exhibiting about Beyond Zero, we are proposing a pioneering system that uses technologies such as those described above to achieve Beyond Zero within the venue during the period of the Expo.

The outline of this proposal was already presented on September 24, 2020 at a symposium hosted by RITE, and it was also reported on October 14 as an article in the Chemical Daily.

Also, in the basic policy for the Osaka, Kansai Expo that was decided by the Cabinet on December 21, 2020, the third of the twelve basic concepts is active efforts for radical innovation toward carbon neutrality. We will make further efforts to refine and actualize our proposal for the realization of this basic policy.

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