Industrial Infrastructure Technologies for the Methane Energy-based Society and the Role of Microwaves

Yoshishige Katori

Abstract

This paper discussed the following.

1. After reaching the final phase of an oil-based society, a resource-saving and -recycling "Methane Energy-based Society" will come about because of limited natural resources.
2. Industrial Infrastructure Technologies which support the Methane Energy-based Society will cause a paradigm shift in the area of industrial, transportation and civilian sectors.
3. The Non-communication application technology of microwaves plays an important role as one of the core element technologies which comprise new industrial infrastructure technologies.

Key words : Methane Energy-based Society, Non-Communication Application Technology of Microwaves, Man Made Photosynthesis, Microwave Iron-Making System, Rapid Pyrolysis and Gasification Process.

Ⅰ. Introduction

In March 2007, the author released the "Apollo & Poseidon Initiative 2025". The origin of America's Apollo program was to fight against threats posed by the Soviet Union's intercontinental ballistic missiles. On the other hand, the origin of the "Apollo & Poseidon Initiative 2025" is to overcome our fears regarding the depletion of oil resources in today's world.

This initiative showed that it is possible for Japan, which has small land and limited natural resources, to get rid of the people's vague fears about the future. Only if we have knowledge to utilize cleverly solar energy and the world's sixth largest exclusive economic zone (EEZ) and if our nation has a strong will to do so, it will come true [1].

The thinking process of R&D for embodying part of the initiative as "Smart Collar Community Program 2021" and outline of the embodied program are discussed in this paper. The program which correspond to the Gemini in the Apollo program, is intended to establish biofuel technology for the seaweeds.

Ⅱ. Thinking Process for the Realization of the Apollo & Poseidon Initiative 2025

2-1 Awareness for the 21st Century

Human beings have been forming "sustainable recycle-oriented society" based on carbohydrates (seasonal biomass) as primary energy sources since the beginning of time. However, human beings have depended on carbon-hydride (fossil fuels such as coal and oil) since the industrial revolution. Due to a huge amount of burning energy from fossil fuel, human beings have wasted the energy resources in the form of exhaust heat. As a result, it produces large volumes of greenhouse gas emissions beyond nature's cleaning ability. It might also cause global warming.

Oil civilization started in the late 19th century and enjoyed prosperity during 20th century. However, there are some specialists in oil resources who state the "2004 peak oil theory". The Gulf of Mexico oil spill in April 2010 has led it to become a reality.

In the 21st century, BRICs and other developing countries continue to achieve economic growth. Therefore, a battle for oil resources and minerals is growing. However it is impossible for the Earth to continue to grow and expand endlessly beyond its "limit of growth".

After the worsening terms of trade that we earn foreign currency by importing low-price raw material and resources and exporting high-value added products, it is difficult for Japan, which doesn't have its own resources, to maintain the economic and industrial structures based on mass production and consumption which formed in the late 20th century.

Those countries as the United States, China, some in Europe and in Asia are trying to use unconventional shale gas as a substitute for oil resources. Our country has no hope to enjoy the same benefit directly. Nevertheless, our country's reviewed energy plan says that fossil fuel will account for 66 to 70 % of primary ener-

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Planning and Administration Office, Mitsubishi Research Institute Inc., Tokyo, Japan.
Corresponding Author : Yoshishige Katori (e-mail : katori@mri.co.jp)

gy as of 2030.

To maintain a certain level of our global competitiveness, we should shift our economic and industrial structures to fit the new era.

2-2 What we should do to create the Non-linear Innovation in the field of the primary energy

We have a history of technology improvement in Japan's technology development. It has gone on since the Meiji Period. Therefore, we often employ a Forecasting-type Technology oriented Approach for the current research and development. This approach is very useful for element technology's improvement, but we tend to follow the concept developed by Europe and the United States without creating our own concept. It clearly reflects our nation's research and development policy that requires results within three to five years.

However, we are now joining in world's top runners. So we should shift our research and development policy to Backcasting-type Concept oriented Approach. A dramatic non-linear innovation can be created only by realizing a smart concept.

In other words, to envision ideal situation (concept) in the future, not to dream the future as extension of the past achievement and then to decide what must be done now for realizing the smart concept are important.

As we do so, it is important to identify differences between function and technology. For example, the future of the Non-communication application technology of microwaves isn't seen as an extension of microwave signal transmission technology. Both of them generate microwaves, but microwave signal transmission technology reduces heat generation, and the Non-communication application technology of microwaves effectively induces heat generation of an object. If we can reverse our way of thinking, we may earn our place in history (See Fig. 1).

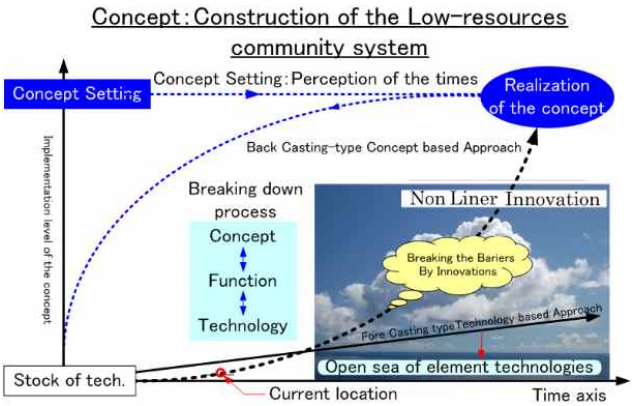

Fig. 1. The pass way to the non-linear innovation.

Efforts to understand an object are also needed. As for signal transmission, it is possible to advance research and development only with the expertise of electronics which can consider oscillation, transmission and reception. However, to advance research and development on the Non-communication application technology of microwaves, it is necessary to have not only expertise of electronics but also fundamental knowledge to communicate with experts in thermal dynamics, chemical engineering, life sciences, etc. It means that we must acquire an ability to produce a simple mathematical model of the total system for any purpose and also must develop an ability to understand the essence of things.

Ⅲ. What is the Methane Energy-based Society?

3-1 After "the Petroleum Century" and skipping over "the pure hydrogen energy-based Society", what is coming?

The Methane Energy-based Society is a society where the methane gas is used as the major raw material of primary energy. The major raw materials of primary energy have shifted from biomass to coal and petroleum. And, a "Natural Gas Century" will come after the end of the "Petroleum Century" skipping over Pure Hydrogen Energy-based Society (See Fig. 2).

The technology which generates hydrogen by reforming methane gas on site and then utilizes it will advance furthermore. However, the time when pure hydrogen is produced and supplied under high pressure will not come. That is because two largest demands(Fuel cell cars, Iron-making process with hydrogen reduction) to supply pure oxygen under high pressure will disappear in the Methane Energy-based Society.

In our country, we pursued the Pure Hydrogen Energy-

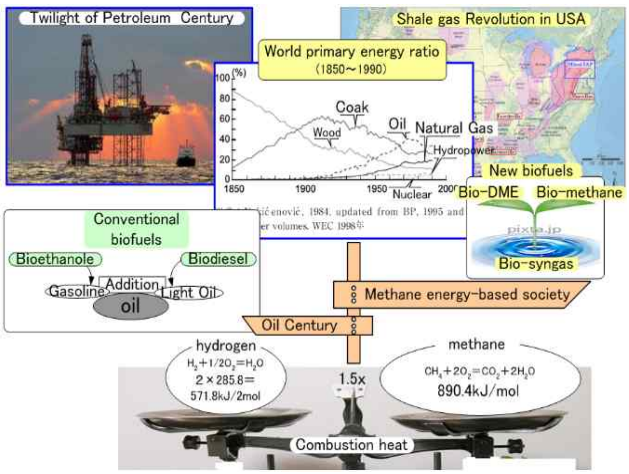

Fig. 2. Methane Energy-based Society is coming.

based Society in the past and conducted demonstration experiment of a hydrogen fuel gas supply station. However, after that, hybrid cars have become popular and the development of PEFC fuel-cell car has slowed down.

On the other hand, the SOFC fuel-cell is under development by TOKYO GAS Co., Ltd. and KYOCERA Corporation for practical use. Hydrogen and carbon monoxide obtained by reforming methane gas on site can be used as direct fuel. Moreover, if reduction of operating temperature and speeding-up of start-up characteristics become possible, the SOFC can be used for fuel-cell cars. Recently, Toyota Motor Corporation has announced its participation in technology development of SOFC fuel-cell.

It is said that Steelmaking Process with hydrogen reduction isn't realized in principle because internal temperature of the shaft furnace drops extremely as long as shaft furnace is used for iron-making process.

Now we are shifting from the "Petroleum Century" to the "Natural Gas Century". This transition involves an innovative change in energy use, from mass production and consumption to resource saving and recycling. With this transition to the Natural Gas Century, technologies for energy conversion and usage have to change considerably.

The "Petroleum Century" wasting energy resources will end and the "Natural Gas Century" which have to use primary energy resources economically will be coming.

3-2 Industrial Infrastructure Technologies for the Methane Energy-based Society

Our country, where shale gas is not produced, should begin the following four technology developments immediately to maintain a quality of people's life in rural areas and a certain international competitiveness (See Fig. 3).

1) CH_4 recycling technology at SOFC
2) CO_2 recycling technology in large urban Gas fields
3) Technology for rapid pyrolysis and gasification of seasonal biomass and water-rich organic matters
4) Developing technologies for GTL and FT synthesis

These are based on the "man-made photosynthesis" technology.

Many researchers are promoting research and development of artificial photosynthesis, but it is the technology which produces carbohydrate by using sunlight, water, and CO_2. On the other hand, the "man-made photosynthesis" is the technology which produces hydrocarbon by using exhaust heat energy, steam, and CO_2. Carbohydrates have been transformed to hydrocarbons in nature over the several hundred million years.

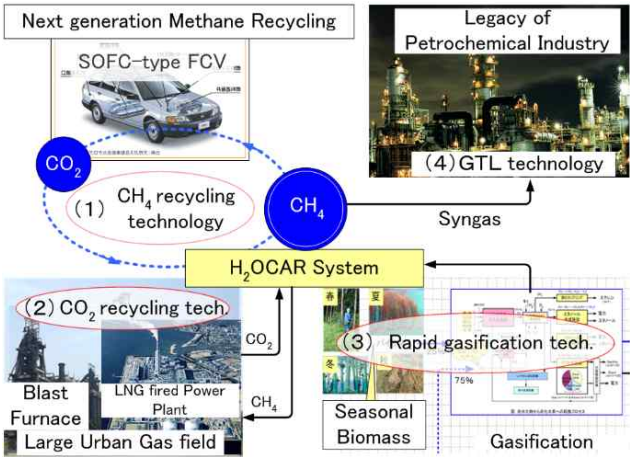

Fig. 3. Industrial Infrastructure Technologies for the Methane Energy-based Society.

The author is working on research and development of "man-made photosynthesis" technology which allows us to obtain hydrocarbon (CH_4) for short time. We have named the technology the "H_2OCAR (Hybrid Hydrogen Oxygen & CARbon) System".

Ⅳ. The Role of Microwaves

4-1 Microwave Features for Energy Field Applications

Recently, microwave and millimeter-waves are getting a lot of attention as a third heating means. Heating method using microwave and millimeter-wave is the internal-heated method which is characterized in between a classic heat conduction/convection heating and infrared thermal radiation [2].

Microwave heating arises from converting the oscillating electromagnetic field produced by microwave into heat energy, interacting with dipole, space-charge, and vibration and rotation of ion which consist of dielectric material.

Macroscopically, internal heating arises having no relation with heat conduction/convection heating due to characteristics of electromagnetic wave heat transforming process by interacting with materials.

Microscopically, a chemical reaction is accelerated, because "electromagnetic wave-excited/non-equilibrium reaction field" in high-temperature is formed without being locally constrained by Le Chatelie's law.

Moreover, not only polarization, but electricity-conducting joule loss and eddy-current loss also arise in solid phase.

Therefore, by replacing the traditional thermal equilibrium reaction process which needs high temperature and a long time with non-equilibrium reaction process in

electromagnetic wave energy, it becomes possible to shift to low-temperature short-time operation. It allows energy conversion facilities to be small and resource saving. As a result, it is possible to reduce the plant construction cost and running cost. In conventional energy conversion plant, the "economy of scale" has been pursued. Now we need to change the design concept and the economic assessment methodology.

In other words, we can get away from "scale merit" if we adopt the microwave heating method for thermal processing. Therefore, we can reduce the plant size of heating furnaces and also develop a system to ensure break-even point in the relatively low-volume and unprofitable production.

4-2 Applications for the Industrial Sector

A reduction of large volume of CO_2 from thermal power station and blast furnace is a big issue in the area of industry to address global warming. As one of the countermeasures, research and development of CCS (Carbon Capture & Storage) is actively being promoted. However, in Japan, distance between CO_2 generation point and its reservoir point has led to cost rises. In addition, the Australian government has been careful about providing their national land for ground burial of CCS since the Gulf of Mexico oil spill. This is a looming issue for technology development of CCS.

In the area of iron-making, research and development of iron-making process with hydrogen reduction is being promoted internationally. In Japan, the Japan Iron and Steel Federation has led research and development of COURSE50 (CO_2 Ultimate Reduction in Steelmaking Process Innovative technology for Cool Earth 50) for New Energy and Industrial Technology Development Organization (NEDO). The research and development theme can be classified roughly into three categories: Iron-making Process with hydrogen reduction, hydrogen amplification technology and CCS.

As for conventional blast furnace, technology development is required for feeding pellet of sintered mixture of milled iron-ore and carbon material into the blast furnace. However, considering the principle of blast furnace, the limit of mixing is about 10 %.

A steel plant's blast furnace is a very delicate reactor but it is the largest structure in the field of chemical engineering. It takes 8 hours to feed iron ore and tap hot metal. 500 kg of coke is used to produce one ton of pig iron, which results in two tons of CO_2 emission.

A half of the 500 kg of coke is used for iron-oxide reduction and the remaining half is used as heat source for maintaining reduction reaction. Efforts to reduce CO_2 emission by half by heating iron ore with microwave instead of using the heat source is the origin of the microwave iron-making system [3].

It cuts processing time from 8 hours to 15 minutes. But 120 kW of electricity is needed for producing one ton of pig iron a day. A major reduction of power consumption has become one of the research and development issues.

So the author invented an "Iron reduction system using microwave-heated water gas reaction". The system incorporates not only the iron-making process which recycles the reactor exhaust gas into the methane gas used as heating fuel by the H_2OCAR System, but also the steelmaking process which employs high-frequency induction heating method. The theoretical power consumption is 12 kW. Compared with the existing micro-wave iron-making system, it allows us to reduce power consumption by one-tenth.

In addition, if the H_2OCAR System is applied to LNG-fired power generation system, we can significantly improve the LNG turbine thermal efficiency.

4-3 Applications for the Transportation Sector

Transportation sector pays much attention to bioethanol, biodiesel and biooil as global warming countermeasures because these are carbon neutral.

However, for the sustainability criterion, bioethanol made from sugarcane of existing fields in Brazil and sugar beet in Japan only meet LCA condition. If emissions regulations get stricter, an exhaust gas purification system has to become larger in size. But passenger cars and specialized vehicles (earth moving vehicle, agricultural vehicle, fishing vessel, etc.) have no space for equipping an exhaust gas purification system. It is difficult for these vehicles to use biodiesel and biooil.

Much attention is being paid to electric cars as the next generation environmentally-friendly car. However, the use of it will be limited due to power-supply problems and restrictions on securing rare metal for the battery.

In the future, it is expected that natural gas for heavy trucks, methane fuel SOFC for passenger cars and DME for specialized vehicles become popular. The Non-communication application technology of microwaves will be used for an exhaust gas purification system for natural gas- and DME-driven vehicles.

Currently, PEFC is the mainstream of fuel-cell, but research and development on SOFC is being promoted actively. With the reduction of operating temperature (from 900 ℃ to 550~600 ℃), the start-up characteristics is improving by several tens of seconds. Bloom

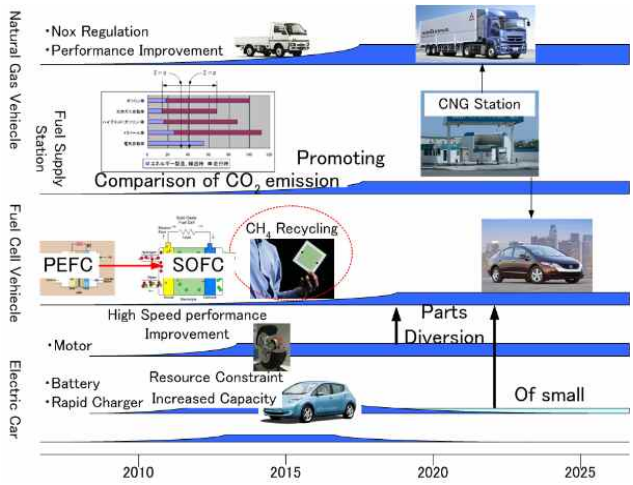

Fig. 4. One of the future prospects of the eco-car.

Energy Company in USA, is prompting research on methane gas recycling. The SOFC exhaust heat energy can be used for methane gas recycling. At that time, the Non-communication application technology of microwaves is expected to play an important role (See Fig. 4).

4-4 Applications for the Civilian Sector

Saccharification and fermentation currently predominate in Japan as technology for producing bioethanol from woody biomass. Microwave utilization technology for preprocessing has been developed.

However, imports of biomass from Southeast Asia are under consideration in Japan despite our having a lot of biomass for all four seasons. Japan's nature has not only supplied primary energy, but also reproduces biomass for all seasons. But now, it is too desolate to see what it used to be. The reason why we have to rely on overseas for biomass is application of saccharification and fermentation to a bio-fuel manufacturing technology.

The author therefore developed the "Electromagnetic heated rapid pyrolysis and gasification system". Biomass, agriculture waste, raw garbage, sewage sludge cake, etc. can be used as raw materials for the system. In addition, large seaweed, which is raw material for the system, plays an important role because alginic acid and a metal element enrichment capability, which are major structural components of the seaweed, can be used as binder and thermal catalyst for the other raw materials.

A rapid pyrolysis and gasification of seasonal biomass will be possible at low power consumption by combining with frequency matching type microwave heating technology, in-line heater type high frequency induction heating technology and tar reforming technology successfully.

As a result, biooil and syngas are produced. High-value added raw materials for medical services and chemistry can be extracted from the biooil. The syngas is used not only as materials for FT synthesis, but also to synthesize methane gas (CH_4), DME (CH_3OCH_3), and ethanol (C_2H_5OH), etc.

Ⅴ. The Smart Collar Community Program 2021

The integrated total system design of 1) Raw materials procurement, 2) Energy conversion technology, and 3) Usage technology is essential to provide the bio-fuel that is a produced sustainably for regional consumption fuel with regional community.

It is necessary to equip with the following three points in order to establish the bio-fuel manufacturing system as a social system.

1) Sustainable quantitative securement of raw materials
2) Economical energy conversion technology
3) Steady demand for biofuel

The above 1) and 3) are issues not of technology but of regional community system design. We used to pay for our regional economies by setting up leading companies' plants there and doing revenue share. However, it is getting difficult to make money enough to support life of people in rural areas because of decline in tax revenues in urban areas caused by overseas transfer of the plants and extremely worsening balance of trade. Therefore, one of the measures for reviving the local economies, in Japan is to create "the Regional energy self-sufficiency Industry" in order to provide their energy bill and fuel by their own.

The author is preparing to conduct a demonstration experiment for "Smart Collar Community Program 2021" in Kagoshima, Japan (See Fig. 5).

The "Electromagnetic heated rapid pyrolysis and gasification system" will play an important role for the experiment. In addition, the experiment will cover the "Low-resources community system" which envisions the regional economic society where self-efficiency in primary energy and urban tax revenues-independent will be realized. And the "Smart Collar House" is minimum structural unit of the "Low-resources community system". The "House" is a self-contained all-electric system.

HUMS (House Utility Management System) is installed to control utilities (SOFC, heat pump equipment, and recycled wastewater, etc.) in order to minimize energy consumption of the "House". If each "House" adopts this HUMS, we will be able to reduce energy consumption throughout the region (See Fig. 6).

The Non-communication application technology of

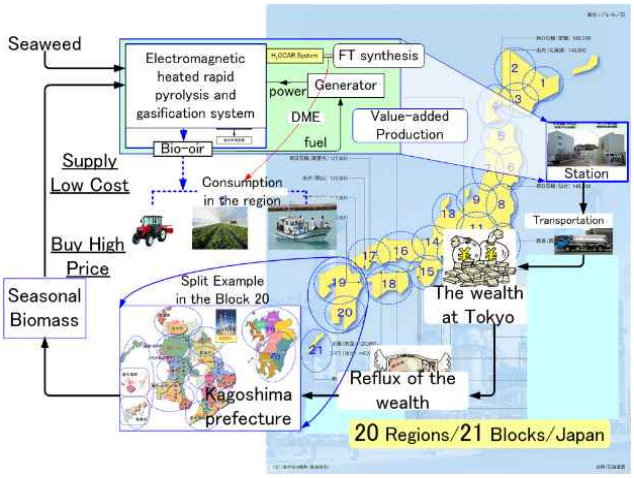

Fig. 5. Configuraion of the Smart Collar Community Program 2021 in Kagoshima.

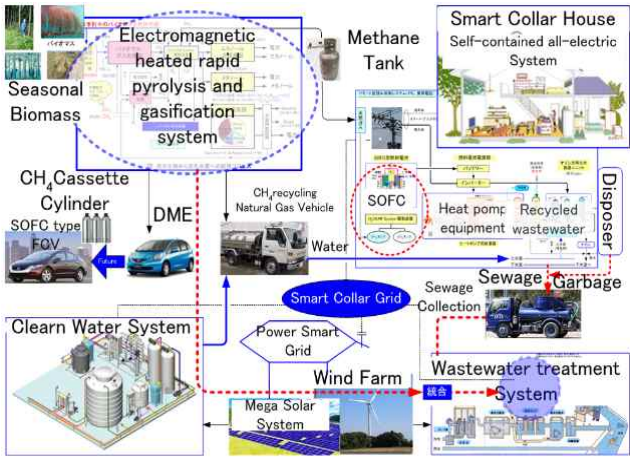

Fig. 6. Configuration of the Low-resources Community System.

microwaves is expected to play an important role in the H_2OCAR System which is a core component of the SOFC power supply for the "House".

Ⅵ. Conclusion

We do not need to be pessimistic, even if the communication means is replaced from microwaves to optics. In the coming Methane Energy-based Society, the Non-communication application technology of microwaves is expected to play an important role as one of the key components that make up the new industrial infrastructure technologies.

As important points when designing the total system, the first is to understand the overall picture of the target system, the second is to extract subsystems that can take advantage of microwaves in the target system. And, considering that it generates thermal energy using electrical energy, the third is to devise as much as possible to suppress the power input into microwave oscillators. Without trying to design the total system using only microwaves, we need to design the target total system by integration with other technologies.

In order to achieve this, we can not live only in the microwave's community, it is important to actively collaborate with different field's experts (for example, sociologists, life scientists, seaweed scholars, marine engineers, chemical engineers, plant engineers, power engineers, automotive engineers, metal engineers, etc.) by efforts to understand the nature of the different fields.

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Yoshishige Katori

In March 1973: graduated from Dept. of Control Engineering, Tokyo Institute of Technology. From April 1973 until March 1979: worked for Kawasaki Heavy Industries, Ltd. and engaged in research and development of control systems for blast furnace top pressure power generation system at steel plants and the black liquor recovery turbine & power generation system at paper plants. July 1979: joined Mitsubishi Research Institute, Inc. From 1985 until 1991 : worked in research and development on the image reconstruction technique of the synthetic aperture radar mounted in the J-ERS-1 in order to study the off-nadir angle. From 1992 until September 2002: engaged in research and development on the Space Solar Power Satellite systems (SSPS). From October 2006 until now: has continued research and development on the "Apollo & Poseidon Initiative 2025".

ACRONYMS

2021	20 Regions/ 21 Blocks/ Japan
2025	2025 AD (Long-range goals)
BRICs	Brazil Russia India Chinas
CCS	Carbon Capture & Storage
CH_4	Methane (≒Natural Gas)
CO_2	Carbon dioxide
COURSE 50	CO_2 Ultimate Reduction in Steelmaking process by innovative technology for cool Earth 50
DME	Dimethyl ether (CH_3OCH_3)
EEZ	Exclusive Economic Zone
FCV	Fuel Cell Vehicle
FT synthesis	Fischer Tropsch synthesis
GTL	Gas To Liquid
H_2OCAR	Hybrid Hydrogen Oxygen & CARbon
HUMS	House Utility Management System
J-ERS-1	Japan Earth Resources Satellite 1
LCA	Life Cycle Assessment
NEDO	New Energy and Industrial Technology Development Organization
PEFC	Proton-Exchange membrane Fuel Cell
SAR	Synthetic Aperture Radar
SOFC	Solid Oxide Fuel Cell
SSPS	Space Solar Power Satellite

GROSSARY

Apollo & Poseidon Initiative 2025
: showed that it is possible for Japan, which has small land and limited natural resources, to get rid of the people's vague fears about the future. Only if we have knowledge to utilize cleverly solar energy and the world's sixth largest exclusive economic zone (EEZ).

Smart Collar Community Program 2021
: is a part of the Apollo & Poseidon Initiative 2025. And the program is intended to establish bio-fuel technology for the seaweeds.

Low Resources Community System
: envisions the regional economic society where self-efficiency in primary energy and urban tax revenues-independent.

Smart Collar House
: is minimum structural unit of the "Low-resources community system". And the "House" is a self-contained all-electric system.

House Utility Management System
: is installed to control utilities (SOFC, heat pump equipment, and recycled wastewater, etc.) in order to minimize energy consumption of the Smart Collar House.

Methane (CH_4) Energy-based Society
: is a society where the methane gas is used as the major raw material of primary energy.

Pure Hydrogen Energy-based Society
: is a society where pure hydrogen is produced and pure hydrogen is supplied under high pressure.

Natural Gas Century
: will come after the end of the "petroleum century".

Petroleum Century
: Human beings have depended on carbon hydride (fossil fuels such as coal and oil) since the industrial revolution.

Shale Gas Revolution in USA
: The United States is trying to use unconventional shale gas as a substitute for oil resources.

Man-made Photosynthesis
: is the technology which produces hydrocarbon (CH_4) by using exhaust heat energy, steam, and CO_2. On the other hand, many researchers are promoting R&D of the artificial photosynthesis which produces carbohydrate by using sunlight, water, and CO_2.

H_2OCAR System
: The author is working on research and development of "man-made photosynthesis" technology which allows us to obtain hydrocarbon (CH_4) for short time. We have named the technology "H_2OCAR System". On the other hand, many researchers are promoting R&D of methane fermentation technology using various bacteria, but the technology needs a lot of time to get CH_4.

Large Urban Gas fields
: Blast furnaces and LNG(Liquid Natural Gas) fired Power plants are the source of large amount of CO_2 emissions. By using H_2OCAR System, we have developed the technology which converts the CO_2 to CH_4 for short time.

Electromagnetic Heated Rapid Pyrolysis and Gasification System
: A rapid pyrolysis and gasification of seasonal biomass and water-rich organic matters will be possible at low power consumption by combining with frequency matching type microwave heating technology, in-line heater type high frequency induction heating technology and tar reforming technology successfully.