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ORIGINAL ARTICLE

Toward a Sustainable Civilization through Energy Change

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***Abstract*:** The potential for humankind to change the energy basis that sustains society and civilization is evaluated. Contemporary civilization is not sustainable, because it depends on fossil fuels as its energy basis, which causes serious global warming. Humanity must change its energy basis to stop the global warming that is bringing an irresistible challenge to society and civilization.

The potential of the power generation, industry, transport, and buildings sectors to achieve zero emission of CO_2 is evaluated, and it is concluded that it is possible to achieve it. The most important sector is the power generation sector, because achieving zero emission in the other sectors depends mostly on CO_2-free electric power.

Renewables have the potential to replace fossil fuels in the power generation sector, presuming that innovations for further cost reduction of renewables and power-balancing systems, including batteries and hydrogen systems, will proceed further. Nuclear power can ease the difficulty of achieving zero emission in the power generation sector. Zero emission in the power generation sector can be most realistically achieved by the mix of renewables and nuclear power.

To achieve zero CO_2 emission in the steel industry seems difficult, but one cannot deny a future technological breakthrough in hydrogen steel making. As to the chemical industry, zero CO_2 emission seems possible considering that technologies to make basic chemicals by hydrogen and CO_2 have been put into use. The transport sector seems to have a good outlook. The number of electric vehicles (EVs) in use seems to be increasing. The charging facilities for EVs have advantages over those for fuel cell vehicles (FCVs) that favor their spreading.

Difficulties and suffering bring creation. If global warming creates unbearable difficulty for humanity, energy change will take place, but if it does not cause unbearable suffering for mankind, energy change will probably not take place.

Keywords: sustainable civilization, energy change, fossil fuel, global warming, CO_2 zero emission, renewable energy, potential, balancing/backup, battery, hydrogen, technological innovation

1. Modern civilization on trial

1.1. Rise and decline of civilization and energy

The history of civilization reveals that the rise and decline of civilizations depend on energy.

Development of new energy sources results in the

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rise of new civilizations, and energy exhaustion causes their decline.

At the beginning of the modern age, people overcame the serious shortage of energy (shortage of wood as fuel) by introducing fossil fuels. Coal was first utilized, and then oil and natural gas were made available. Various energy sources, such as energy for heating, salt manufacturing, iron manufacturing, metal processing, and glass manufacturing, were changed from biomass energy sources to fossil fuels.

Important technical inventions, such as iron manufacturing with coke, a steam engine that can change heat energy to power, and an internal-combustion engine, took place. The law of electromagnetic induction was discovered, and people became able to use electric power, which is an excellent source of energy. Humanity has succeeded in acquiring new energy bases. As a result, modern civilization rose and has continued to the present.

Obtaining new energy technologies by innovation has led to new civilizations.

1.2. Modern civilization: not sustainable

Modern civilization rose with the use of fossil fuels. Society is sustained by its energy basis, most of which (82%) is fossil fuel. The modern (contemporary) civilization will be lost if fossil fuels are exhausted.

Fossil fuels are limited. The reserve-production-ratio of oil is 50 years. That of natural gas is 53 years and coal, 134 years. Considering that the technically recoverable resource of oil is 3.6 times its proven reserve, natural gas 3.6 times, and coal 22 times, it is not probable that that the world will become short of fossil fuels soon. However, it is absolutely certain that the fossil fuels are limited, and the contemporary civilization whose energy basis depends heavily on the fossil fuels is not sustainable.

A more serious challenge to contemporary civilization is global warming. The Intergovernmental Panel on Climate Change (IPCC) reports revealed that the world's average temperature rises in proportion to the total amount of CO_2 discharged from the time of industrialization. It has become clear that the discharge of CO_2 must be made substantially zero after 2050 to keep the temperature rise within 2 ℃.

Scientists in the world generally consider that a temperature rise of more than 2 ℃ would cause an irreversible change to the global environment and bring about very serious effects to human living and civilization. Therefore, the contemporary civilization that discharges CO_2 is not sustainable from the viewpoint of global warming.

A sustainable civilization must be one that does not rely on fossil fuels and whose energy basis does not increase CO_2 in the atmosphere.

2. Is it possible to change the energy basis ?

To stop the global warming and make civilization sustainable, it is necessary to eliminate fossil fuels and introduce an energy basis that does not discharge CO_2. However, is it really possible?

At present, 32.6 Gt of CO_2 is discharged by all the human activities in the world (2017). The power generation sector discharges 42% (13.6 Gt), industry 19% (6.1 Gt), transport 24% (7.9 Gt), and buildings 9% (3.0 Gt) [1). In the following, the possibility/potential for energy change to realize zero emissions of CO_2 in each sector is evaluated.

2.1. Power generation sector

Of the total power generation of the world of 24,919 TWh (2016), thermal power using fossil fuels has a share of 65% (coal 38%, oil 4%, and natural gas 23%), nuclear 10%, and renewable energy 24% (hydro 17%, wind 4%, solar photovoltaic (PV) 1%, biomass 2%, and geothermal 0.3%). Is it possible to change all the power generation to renewables that do not emit CO_2?

2.1.1 Potential of renewables

Hydropower has 8,800 TWh as economically developable potential and technically developable potential of 14,600 TWh [2]. The former amounts to 35% of the total electric consumption in the world, and the latter is 59%. Hydropower potential is unevenly distributed in the world. It seems difficult to provide all the electric demand of the world with hydropower.

Geothermal is regarded to have not much more than 116 GW as a recoverable resource [3]. Considering that the world total power generation capacity is 6.7 TW, the potential of geothermal power is small.

The International Energy Agency (IEA) estimates that the potential of biomass energy will be 200~500 EJ in 2050. The world's total primary energy consumption now is 573 EJ, so it seems that biomass energy has considerable potential. However, historically, humans began to use fossil fuels facing a critical shortage of biomass energy. Because of this history, one cannot expect much of biomass energy.

Solar PV and wind power have a large potential. According to one estimate, solar PV has as much potential as 286,438 TWh, which is 12 times the total electric consumption in the world, and wind power has 50,000 to 60,000 TWh as a technically developable resource [4]. Solar PV and wind power have the potential to provide all the electric power in the world.

2.1.2 Cost of solar PV and wind power

The high prices of solar PV and wind power have been a big problem for their widespread use. However, because of the improvement of efficiency resulting from technology innovation and mass production of solar PV and wind power, recently, their costs have fallen rapidly. The generation cost of solar PV fell to 9.1 yen/kWh, onshore wind power to 7.4 yen/kWh, and offshore wind to 13.6 yen/kWh by 2017. Solar PV reduced its cost by 73% since 2010, and offshore wind by 50% since 2013.

These costs are already competitive compared with those of thermal power. The costs of solar PV and wind power will continue to decrease.

2.1.3 Storage and balancing ability

Solar PV and wind power have an important fault, which is that their power generation is unstable and intermittent, and it is impossible to generate power just in response to demand. This type of renewable energy, which is called variable renewable energy (VRE), needs backup power to balance demand and supply. If thermal power produced by fossil fuels is used as the backup, CO_2 emission from the sector of power generation will not be reduced. The backup measures that can reduce CO_2 emission by introducing VRE are (1) pumped-storage hydropower, (2) battery storage, and (3) CO_2-free hydrogen (gas to power, power to gas).

Pumped-storage hydropower

Many pumped-storage hydropower stations have been introduced as balancing power. This technology is mature, and its introduction cost is the lowest among the three. In Japan, its introduction cost is approximately 23,000 yen/kWh [5]. There seem to be enough places to construct pumped-storage stations in the world, although it depends on the natural features of the country.

Whether people construct more pumped-storage hydropower stations depends on the comparison of its cost with those of other backup/storage systems (battery and hydrogen systems).

Batteries

Cost

The biggest problem of battery storage systems is cost. Lithium ion batteries have high potential to reduce the cost. They have room for technological development, such as raising their energy density, and cost reduction is expected when demand increases. Lithium ion batteries for automobiles have reduced in cost to one quarter during the time from 2010 to 2016.

IEA forecasts that the capital cost of utility-scale battery storage systems will decline to 20,000 yen/kWh in 2040 from 40,000 yen/kWh in 2017 [1]. The International Renewable Energy Agency (IRENA) forecasts that stationary storage batteries will lower their cost by 60% not later than 2030. The Ministry of Economy, Trade and Industry (METI) of Japan has the target to realize 23,000 yen/kWh as the introduction cost of utility-scale battery systems, which is equal to the cost of pumped-storage hydropower.

Outlook for batteries

The IEA estimates that the installed capacity of utility-scale battery systems will reach 200 GW in 2040, most of which are paired with renewables. This is remarkable growth considering the present capacity (3.5 GW, 2017), meaning that it will grow 50 times in 20 years.

IRENA estimates that, although pumped-storage hydropower has the most storage capacity now, it will be rapidly replaced by battery systems, such as lithium ion batteries, owing to cost reduction through technological innovation and economies of scale.

The energy density of batteries is far smaller than that of oil or hydrogen. Many scientists are not optimistic about the cost of batteries falling sufficiently through technological innovations, considering that the low energy density of batteries comes from the fundamentals of accumulating electricity in batteries. However, solar PV and wind power have shown remarkable cost reduction through the effects of mass production and improvement of production technology, although there have not been fundamental theoretical changes in those fields. Battery storage systems, the demand for which is rapidly expanding, may reduce their cost and become the main backup power systems by 2050.

Scientists and engineers are performing intensive research and development in the area of batteries. Battery technology is not as mature as that of pumped-storage hydropower. It cannot be denied that technological breakthroughs will take place in the field of batteries.

CO_2-free hydrogen (gas to power, power to gas)

Hydrogen technology for storing power and responding to power load already exists. One can produce hydrogen by electrolysis of water. It is possible to generate power by fuel cells using hydrogen. Power used to produce hydrogen by electrolysis must be CO_2-free, such as renewable energy or nuclear power.

The largest problem of hydrogen systems is also their cost.

Cost

When hydrogen is produced by electrolysis of water using a renewable whose cost is 13.6 yen/kWh, the electricity cost occupies 68 yen to produce 1 m^3 of hydrogen. The fixed cost of an electrolysis device is estimated to be 103 yen/Nm^3 when the equipment utilization rate is 10%, and 11 yen/Nm^3 in the case of an equipment utilization rate of 90%. Therefore, the cost to produce hydrogen is 171 yen/Nm^3 when the equipment utilization rate is 10%, and 79 yen/Nm^3 when the equipment utilization rate is 90% [6].

When electricity is generated by hydrogen, one obtains a comparable generation cost to that of coal-fired or liquefied-natural-gas-fired thermal power plants, if hydrogen whose price is at the 30 yen/Nm^3 level is used.

It appears difficult to reach the cost level of 30 yen/Nm^3 for hydrogen from renewables without further cost reduction, considering that the storage cost and transport cost are added. However, METI has the target in its "Hydrogen Strategy" to attain the 20-yen/Nm^3 cost level of CO_2-free hydrogen from 2030 on.

The National Institute for Material Science (NIMS) of Japan reported a research result in which it predicts that a cost level of 17 to 37 yen/Nm^3 for hydrogen can be realized around 2030. Scientists at NIMS have created a comprehensive design to adjust the amount of hydrogen produced in electrolysis devices and adjust the charging and discharging of batteries in responding to solar PV. They examined the economy of this system and showed the potential to realize competitive CO_2-free hydrogen produced by renewables [7)].

2.1.4 Outlook of power generation sector

The costs of solar PV and wind power have recently fallen remarkably. In 2018, the cost of solar PV reached 4.3U.S.cent/kWh and onshore wind power 4.2U.S.cent/kWh. The cost will continue to fall [8)].

Besides the cost of renewables, the cost to produce hydrogen by electrolysis is dominated by the utilization rate of electrolysis devices. It seems difficult to raise the utilization rate of devices, because generation from Solar PV and wind power is unstable and intermittent. However, it is possible to raise it by combining battery systems and hydrogen systems.

Further innovation to lower the cost of battery and hydrogen systems will take place. A large amount of balancing/backup power with reasonable costs obtained by combining all the systems, including pumped-storage hydro, will be introduced, and zero emission of CO_2 in the power generation sector will be realized.

2.2. Industry sector

The main parts of the industry sector that emit CO_2 are the steel industry, cement industry, and chemical industry. Those sectors emit 2.6, 2.0, and 1.2 Gt, respectively [9)].

2.2.1 Steel industry

Iron manufacturing by blast furnaces is a process in which iron ore (iron oxide) is deoxidized by coal coke. Thus, it is indispensable to use coal for iron making in blast furnaces. However, there exists technology to use hydrogen instead of coke to deoxidize iron ore. There also exists the technology to make steel by electrolysis from melted iron ore.

（1）Hydrogen steel making

Technology to replace part of coke with hydrogen in the furnace and eliminate 20% of CO_2 emissions has been realized [10)].

The deoxidization of iron ore by hydrogen is an endothermic reaction. When much hydrogen is put into the furnace, the temperature in the furnace goes down. This creates a fundamentally difficult problem. In addition, deoxidizing iron ore causes powdered ore and closes pathways in the furnace. Measures to solve these problems are needed.

At present, it is difficult to realize hydrogen steel making in existing furnaces. The Japan Iron and Steel Federation has formulated a road map to reduce CO_2 emissions from the steel industry [11)]. The road map prepares a "Super Innovation Technology Development Scenario" as a long-term scenario that assumes zero CO_2 emission from the steel industry in 2100. In this scenario, hydrogen reduction steel making and zero emission from all the electric supply are assumed to be realized.

Primetals Technologies Limited announced that it has developed a direct reduction method for steel making using hydrogen as a deoxidizing material, and it can reduce CO_2 emissions nearly to zero. It plans to construct a pilot plant for testing at

Voestalpine Stahl Donawitz GmbH in Austria and start test operation in the second quarter of 2020 [12].

（2）Electrolysis reduction method

Getting metal iron by electrolyzing melted iron ore is technically possible but yet to be economically realized.

This method needs a large amount of electricity. The primary unit for producing 1 ton of steel is 2.6 MWh. Supposing that all the crude steel in the world (1.7 Gt) is made by this method, 4,420 TWh of electricity is needed, which amounts to 19% of the total electricity consumption in the world [13].

（3）Outlook

Achieving CO_2 zero emission in the steel industry seems difficult.

Steel manufacturing by coal coke is a representative and symbolic technology innovation with which humankind has developed modern civilization based on fossil fuels. Hydrogen steel making will be a symbolic technology in sustainable civilization.

Steel-making technology using coke as a reducer is a great and long-established integration of empirical technology. Experience with hydrogen steel making has begun recently. Experience with steel-making technologies using hydrogen as a reducer that are completely different from the use of coke will accumulate, and it may be possible to realize a technological breakthrough in hydrogen steel making and achieve zero emission in the steel industry.

2.2.2 Cement industry

There are two routes in emitting CO_2 in the cement industry.

1. Emissions from fossil fuels that are used to fire the clinker: this accounts for 40%
2. Emissions that come through the chemical process $CaCO_3 \rightarrow CaO + CO_2$: this accounts for 60%

As for the first route, it is technically possible to replace fossil fuels with hydrogen burning or electric heating. Hydrogen burning occurs explosively, but Toyota has developed a burner that can fire the hydrogen slowly. For electric heating, there exist technologies to obtain heat of high temperature, such as plasma heating.

As for the second route, there are no other measures than developing a new material and replacing existing with it. MgO-based cement is being studied. MgO_3Si as its raw material does not emit CO_2 when burned, and it absorbs CO_2 when it hardens.

NEDO, Tokyo Institute of Technology, and Takenaka Kogyo Company, Limited developed a kind of blast furnace cement called Energy CO_2 Minimum (ECM), which can reduce CO_2 emissions more than 60%. They increased blast furnace slag to be mixed, reduced Portland cement to 30%, and succeeded in putting them to practical use [14].

2.2.3 Chemical industry

The technology to make basic chemicals, such as ethylene, propylene or BTX, by synthetic gas ($CO + H_2$) and methanol can be regarded as established. In China, a chemical process (called MTO process) to produce ethylene and propylene by methanol has been developed and already industrialized [15].

Synthetic gas and methanol are made from coal gas in China. However, it is possible to make synthetic gas and methanol from hydrogen and CO_2. Thus, if synthetic gas and methanol are made using CO_2-free hydrogen, one can realize zero emission in making basic chemicals, such as ethylene and propylene. This means realizing zero emission in making most of the chemical products that are induced from ethylene and propylene.

The problems are the large amount of electricity to make CO_2-free hydrogen and its cost. Supposing that the amount of hydrogen needed to make all the ethylene and propylene in the world is obtained from electrolysis of water, 5,830 TWh is estimated necessary, which is equivalent to 24% of world's total power supply [13]. Without great cost reduction of electricity from renewables, zero CO_2 emission in the chemical industry does not seem feasible.

The technology to capture CO_2 from fossil fuels and utilize it exists — carbon capture and utilization (CCU). CCU contributes to reducing CO_2 emissions, while the chemical products made by captured and utilized CO_2 are in use. However, in their incineration disposal, the equivalent CO_2 is emitted.

The final technology to reduce CO_2 involves fixing CO_2 in the atmosphere and utilizing it. This technology actually exists, using a special filter to capture CO_2 in the air [16]. Mass production with its reasonable cost has yet to be realized.

Outlook

Innovation to realize zero CO_2 emission in the chemical industry appears possible, considering that the technology to make most chemical products by hydrogen and CO_2 through basic chemicals is fundamentally established. The difficulty is the availability of a large amount of low-cost hydrogen made by renewables. This relates to the question of zero emission in the power generation sector.

To realize zero emission in the chemical industry means changing the petrochemical industry (based on petroleum) to a chemical industry based on hydrogen and CO_2 as raw material. It seems that CO_2 obtained from fossil fuels through CCU will be used for a while. However, it also seems that technology to capture and utilize CO_2 in the air, which is a negative emission technology, will be realized at some time in the future.

2.3. Transport sector

The transport sector emits 7.9 Gt of CO_2, which amounts to 24% of the world's total emissions. Most of the emissions come from automobiles. In Japan, 86% comes from automobiles, 5% from aviation, 5% from shipping, and 4% from railway transport.

Zero emission in the transport sector will probably be realized by EVs and FCVs on the condition that available power and hydrogen are CO_2 free, meaning that the zero emission of the transport sector depends mainly on the power generation sector.

2.3.1. EVs

(1) Energy efficiency of EVs

EVs have high energy efficiency. The well-to-wheel overall efficiency of EVs is 25% to 31%, while that of gasoline cars is 10%. If all automobiles were replaced by EVs, it is estimated that energy consumption in the transport sector would be reduced by one half to one third.

(2) Technology development of batteries

Because of the small energy density of batteries (0.2 kWh/kg, while that of oil is 12 kWh/kg), the loading weight is the biggest problem for EVs. It is difficult for EVs to get 700 km as a continuously drivable distance, as with gasoline cars. The continuously drivable distance of EVs is about one fifth that of gasoline cars with equal weights to EVs.

The progress of EVs depends on the technology development of batteries. It is considered difficult for lithium ion batteries to get 0.3 kWh/kg. All-solid-state lithium ion batteries are expected to exceed the limit. They will have 0.5 kWh/kg and are expected to be available after 2020. Research on lithium air batteries is also being done. They will have 1.2-kW/kg density level, and this is such research and development that is needed for a breakthrough in existing technology. They are expected to be put into use around 2040 [17].

The Nissan EV Leaf has achieved a 570-km continuously drivable distance, loading a battery of 62-kWh capacity. The charging time is 60 min by fast charging. Fast-charging facilities are becoming available in parking areas, service areas, and shopping centers following the gradual spread of EVs and plug-in hybrid EVs (PHVs) in Japan.

(3) Cost

The cost of batteries for EVs in 2016 has come down to one quarter that in 2012. The Nissan EV Leaf is sold at a price at the 3 million yen level. BNEF (a research company) forecasts that the cost of ownership of EVs could go below that of gasoline cars in mid-2020 owing to the fall of battery costs and the extension of the continuously drivable distance [18).

(4) Outlook of EVs

The new policy scenario of IEA Global EV Outlook 2018 forecasts that 20% of new vehicles (21.5 million) will be EVs in 2030. The cumulative number of EVs will be 125 million. In addition, according to the 30@30 scenario, 30% of the new vehicles (38 million) will be EVs, and the cumulative number will be 238 million.

2.3.2. FCVs

(1) Hydrogen stations

Hydrogen has a high energy density, and FCVs have realized continuously drivable distances comparable to those of gasoline cars. In addition, it takes only 3 min to charge hydrogen, whereas, for EVs, it takes 60 min to charge electric power. FCVs exceed EVs on these points.

The biggest problem for FCVs is hydrogen service stations. The cost to construct and maintain hydrogen service stations is far higher than that of fast-charging facilities for EVs. The construction cost is 550 million yen, and the maintenance cost 34 million yen a year. More hydrogen service stations will result in more FCVs, and more FCVs will result in more service stations. Fewer stations bring fewer FVCs, and fewer FVCs bring fewer stations. A good acceleration loop for FCV progress has yet to occur.

(2) Price

The price of FCVs is substantially higher than that of EVs. Toyota began to sell FCVs (MIRAI) with a price of 7 million yen in 2014. This model has not been changed since then. The price of FCVs is expected to go down with their mass production, which depends on the availability of hydrogen service stations.

(3) Outlook

METI has the following targets in “Hydrogen Strategy”: (1) the introduction of 200,000 FCVs (accumulation) by 2025 and 800,000 by 2030, (2) the realization of a price difference between FCVs and EVs as small as 700,000 yen, while the present difference is 3 million yen, and (3) 320 hydrogen stations in service by 2025 and 900 stations by 2030, achieving their operational independence by the late 2020s [19).

2.3.3. Outlook of zero CO_2 emission in the transport sector

The transport sector seems to have a good outlook for zero CO_2 emission compared with the industry sector. EVs seem to be increasing. The charging facilities for EVs have advantages over those for FCVs. To construct and maintain charging facilities for FCVs (hydrogen stations) is not as easy as for EVs.

The development of EVs depends on technology innovations to improve the efficiency of batteries. Innovations are expected to take place. It seems that PHVs will play an important role. PHVs can often be used in the EV mode. It is expected that PHVs will be used for a long time.

To achieve zero CO_2 emission in the transport sector means to electrify the transport sector, and this returns to the issue of zero CO_2 emission in the power generation sector. In the power generation sector, technology innovations of batteries are decisively important, so that they will be used as good balancing/backup power. In the transport sector, technology innovations for batteries for EVs are also of crucial importance.

2.4. Buildings sector

The emissions from the sector of buildings in the world are 3.0 Gt, which is 9% of the world's total emissions. Zero emission in this sector can be achieved by so-called "all electrification." All electrification in many offices and houses has been realized. Achieving zero emission in the buildings sector returns to the question of that in the power generation sector.

3. Conclusions

(1) It seems possible that humankind can change the energy basis from fossil fuels to renewables that do not emit CO_2. The technology to achieve this has yet to be completed, but there seems nothing that excludes the possibility in terms of technology. Many technological innovations are necessary, including breakthroughs to realize economically viable technologies, but there are no grounds to believe that this is impossible. Emerging viable technologies can be seen everywhere. People have realized in the energy field many technological innovations that never had been imagined. It seems that people will achieve the innovation for energy change as they have in the past.

(2) To achieve zero emission in the industry sector, particularly in steel manufacturing, seems difficult. However, an electrolysis reduction method for iron that does not emit CO_2 exists, although it requires tremendous electric power. The best candidate appears to be hydrogen steel making, considering that the experience with the technology to reduce iron ore by hydrogen has begun. Through the accumulation of technological experience over a long time, a technological breakthrough to realize a practical method of hydrogen steel making could take place.

(3) Achieving zero emission of the whole energy basis depends, to a great extent, on zero emission in the power generation sector. Zero emission in the industry, transport, and buildings sectors will never be achieved without CO_2-free electric power. Therefore, to achieve zero emission in the power generation sector is crucial.

To change most power generation to renewables is possible. The potential and basic technology to achieve it exists. When power changes to renewables, the capability of balancing/backup power is decisive. The cost reduction of battery and hydrogen systems by innovations is necessary to have this capability increase.

Because of further reduction of the costs of renewables, batteries, and hydrogen systems (gas to power, power to gas), combined with pumped-storage hydropower, it should be possible to achieve zero emission in the power generation sector.

(4) It is realistic and practical to use nuclear power to achieve zero emission in the power generation sector. Nuclear power will, to a great extent, ease the difficulties of achieving zero emission in the power generation sector only by renewables. In fact, this can be achieved only by nuclear power and pumped-storage hydropower, both of which are existing technologies put into practical use. Nuclear power will probably provide further cost reduction as a result of continuous research and development.

Zero emission in the power generation sector can be most realistically achieved by a mix of renewables and nuclear power.

(5) Changing the energy basis to sustainable energy that does not emit CO_2 can be achieved, although it will be very difficult. The challenges facing humankind will cause this creation. If global warming brings unbearable difficulties to mankind, the required energy change accompanied by creative innovations will take place. If global warming does not bring unbearable suffering to mankind, the energy change will probably not take place.

(6) Even if global warming does not cause energy change, people will, one day, face a shortage of fossil fuels. Humankind will face the difficulty of

maintaining a society sustained by fossil fuels. People must inevitably change their sources of energy. First, a shortage of oil and natural gas, the reserves of which are relatively small, will occur. They will become unusable because of their soaring costs, just as wood could no longer be used as fuel because wood costs soared because of shortages. Owing to a relatively large amount of coal resources, coal will probably be used for a long time. However, it is sure that coal is also limited and not perpetual. (7) The driving force to achieve energy change is neither morality nor ethics, nor is it the United Nations. It is the capabilities to create new technologies that can economically and practically penetrate the existing energy basis. Competition accelerates technological innovations. At present, competition among nations in the world to achieve supremacy over the technology is becoming intense. Intense competition among nations will promote the innovations to change energy.

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