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Mapping the Energy Future

一般財団法人　日本エネルギー経済研究所
The Institute of Energy Economics, Japan

PREFACE

Chairman & CEO,
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Masakazu Toyoda

This Joint International Energy Symposium, which the Institute of Energy Economics Japan launched jointly with APERC (Asian Pacific Energy Research Center) to commemorate its 50th anniversary, is celebrating its fifth year. The event was moved to September and was held online this year due to the Covid-19 pandemic. APERC has been independent since April this year, but the IEEJ is looking forward to continuing collaborative research efforts, such as this one.

The theme of the Symposium this year is "Energy Trilemma in the Post-Corona World: Can Innovation and Soft Power Be the Solutions?" This theme is based on the following background.

1) The climate actions of major countries are advancing to the stage of aiming for "net-zero GHG emissions in the second half of the century." The Suga administration of Japan has also announced the goal of net-zero GHG emissions in 2050.
2) Renewables and nuclear power alone are not sufficient for pursuing decarbonization at the global level; decarbonization of fossil fuels is essential.
3) The Covid-19 outbreak has caused the greatest global economic recession since the Great Depression as well as a supply glut and slumping energy prices, raising concern over growing instability in the Middle East.

This special issue of the IEEJ Energy Journal (featuring the 2020 5th IEEJ / APERC Joint International Energy Symposium) is a compilation

巻 頭 言

一般財団法人 日本エネルギー経済研究所
理事長　豊田 正和

日本エネルギー経済研究所設立50周年を記念して、APERC（Asian Pacific Energy Research Center）との共催で始めた国際シンポジウムも、今年で5年目を迎えました。コロナウイルス感染拡大のため、今年は、9月に時期を移行し、オンライン形式による開催と致しました。本年4月に、APERCは「独り立ち」をしましたが、こうした研究協力は続ける方針です。

今年の全体テーマは、「ポスト・コロナのエネルギー・トリレンマ：技術革新とソフトパワーは、解決策となるのか？」とさせて頂きました。このテーマは以下の背景を踏まえたものです。

① 主要国の気候変動への対応が、「今世紀後半での世界の温室効果ガス排出ネットゼロ」に進展しつつあること（日本でも9月半ばに発足した菅政権は、2050年ネットゼロの目標を掲げました）

② 世界全体でエネルギーの脱炭素化を進めるには、再生エネルギーや原子力では不十分であり、化石燃料の脱炭素化などが必要とされていること

③ コロナ感染症は、大恐慌以来の大幅な世界景気の後退、そしてエネルギーの供給過剰と価格低下をもたらし、中東情勢が不安定性を増しているとの懸念があること

本「エネルギー経済」特別号（合同シンポジウム連携版）は、登壇された弊所特別客員研究員に、各人のメッセージを論文として改めて整理していただいたものに加えて、そのほかの特

of presentations by Distinguished Fellows of the IEEJ who spoke at the event, rearranged by the speakers as articles for this publication, as well as articles authored by other Distinguished Fellows and researchers of the IEEJ on the same themes.

There are three sub-themes.

1. Is it possible to fully decarbonize the global supply of energy by 2050? – The role of renewable energy, nuclear energy and energy efficiency

It is widely accepted that there is no single perfect energy source. How should we understand the potential and limitations of non-fossil energy technologies (renewables, nuclear, and energy efficiency) that are raising hopes as the main drivers of reducing CO_2 emissions?

2. Are hydrocarbons the enemy or ally for climate change countermeasures?

For many countries, fossil fuels are essential for their energy security as they are cheap and can be produced domestically. This has brought growing attention to fossil fuel decarbonization technologies such as hydrogen and ammonia, and carbon recycling. What kind of strategy should be taken regarding these innovative technologies?

3. What could help stabilize the Middle East region: military power or soft power? Can Japan's soft power play a role?

How will the energy price slump caused by the Covid-19 pandemic affect the path to stability in the Middle East? What roles can major players in Middle East affairs such as the United States, Russia, China, and Japan play to achieve stability in the international energy market and eventually in the Middle East, too?

別客員研究員、及び弊所の研究員が、同じテーマについて書き下ろした論文を集大成したものです。

以下の3つのサブテーマがあります。

第一に、「2050年までに、エネルギーのゼロエミッション達成は可能か？～再生可能エネルギーと原子力、省エネの役割～」というものです。

完璧なエネルギーは無いと言われます。CO_2削減の主力と期待される非化石エネルギー技術等（再生エネルギー・原子力・省エネルギー）の可能性と限界をどう考えるべきなのでしょうか。

第二に、「化石燃料は、気候変動対策の敵か、味方か？」というものです。

化石燃料は多くの国にとって、安価で、かつ自国で産出できるのでエネルギー安全保障上も重要です。そこで注目を浴びているのが、水素やアンモニア、あるいは、カーボン・リサイクリングといった化石燃料の脱炭素化技術です。これらの革新的なイノベーション技術に対する戦略はどうあるべきなのでしょうか。

第三のサブテーマは、「中東の安定化に貢献するのは、ハードパワーか、ソフトパワーか？～日本のソフトパワーの役割は？～」です。

コロナウイルス感染症は、エネルギー価格の低下をもたらしていますが、これは中東の安定化にどのような影響をおよぼすのでしょうか。国際エネルギー市場の安定化、ひいては、中東地域の安定化に向けて、主要関係国（米国、ロシア、中国等）、更には、日本は、どのような役割を果たせるのでしょうか。

The articles in this Journal will help answer these questions. I sincerely hope they will contribute to discussions on policies and corporate strategies for the future.

February 2021

本ジャーナルの各論文の中に、これらの疑問への答えが見出せるはずです。今後の政策論、企業戦略論に、お役に立つとしたら望外の喜びです。

2021年2月

Writer's Profile

Masakazu Toyoda

Mr. Toyoda joined the Ministry of International Trade and Industry (MITI), (now the Ministry of Economy, Trade and Industry) in 1973. He received Master's degree from the Woodrow Wilson School, Princeton University in 1979. He held respected positions such as Director-General, Trade Policy Bureau and Vice-Minister for International Affairs. He greatly contributed on establishment of APEC, Japan-U.S. automobile trade negotiation, the Agreement of Kyoto Protocol, and Doha Development Round.

執筆者紹介

豊田　正和（とよだ まさかず）

1973年通商産業省入省。1979年米国プリンストン大学公共政策大学院修了、OECD/IEA勤務を含め、貿易・エネルギー・環境などの分野で幅広い経験を積む。2003年商務情報政策局長、2006年通商政策局長、2007年経済産業審議官に就任。通商政策担当者として、APEC創設、日米自動車摩擦対応、京都議定書合意形成、ドーハ開発ラウンド開始等に大きく貢献する。2008年内閣官房宇宙開発戦略本部事務局長に就任。内閣官房参与としてアジア経済と地球温暖化も担当。2010年より現職。

Contents
目　次

1. Is It Possible to Fully Decarbonize the Global Supply of Energy by 2050?

2050年までに、エネルギーのゼロエミッション達成は可能か？

Opportunities in the U.S. and Japan to Decarbonize Energy Supplies by 2050: Roles for Renewable and Nuclear Energy

Peter B. Lyons*

In 2020, the world witnessed many climate-related disasters. An alphabetical list of names is prepared each year in the U.S. to label major storms. In 2020, the large number of storms used the entire list, and more names were added from the Greek alphabet. In California, more than 4 million acres have burned in wildfires. Colorado experienced the three largest wildfires in its history.[1] Cyclone Amphan killed many people in India and Bangladesh; its storm surge exceeded 16 feet and extended almost ten miles inland.[2] Super Typhoons Haishen and Maysak hit both Japan and Korea with major blows within a single week.[3] In 2019, the second greatest cost ($20 Billion) of extreme weather was in Japan from Typhoons Faxai and Hgibis, along with serious loss of lives.[4] The Northern Hemisphere had its hottest summer on record in 2020[5] and the atmospheric concentration of carbon dioxide established a new record of 417 ppm.[6] Thus, the world moved closer to the 430-ppm level determined by the United Nations' Intergovernmental Panel on Climate Change (IPCC) as a danger point for exceeding 1.5°C in global temperature increase.

A 2019 study of 26 countries found that climate change is perceived as the greatest threat. That study reported that 75% of Japanese citizens expressed concern on climate change.[7] In 2020, in the United States, 81% believe the earth has been warming for the last 100 years and 82% of people with that belief point to human activity as the cause. However, despite the many indications above, 19% of Americans deny that global warming is happening.[8] In addition, 97% of U.S. climate scientists conclude that human-caused climate change is occurring.[9]

These divergent views trace to the politicization of the climate change issue in the U.S., the world's #2 carbon emitter, rather than respecting the consensus scientific view. The Trump Administration, elected in 2016, rejected anthropogenic climate change, strongly favored fossil fuels as the backbone of U.S. energy independence and argued that efforts to sharply reduce emissions would have devastating economic consequences. In contrast, in the November 3, 2020 U.S. election, a new Administration was elected on a platform that U.S. response to climate change is essential and that economic consequences will be positive with a net creation of jobs in clean industries. On November 4th, the Trump Administration's prior decision to withdraw from the Paris Climate Agreement became official.[10] President-elect Biden has called for 100% clean electricity by 2035 and carbon neutrality by 2050.[11] His vision includes all sources of clean energy, from renewables to nuclear. He has stated that the U.S. will rejoin the Paris Accord early in his term.[12] Despite the Trump

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Administration's position against climate change, many U.S. states, cities, companies, and utilities have pledged to reach carbon neutrality by 2050.

A major step toward global carbon neutrality occurred when Prime Minister Suga on October 26, 2020, committed Japan, the world's #6 carbon emitter, to reach carbon neutrality by 2050. In his remarks, the PM suggested greater use of renewable energy and nuclear power.[13] Japan's Fifth Strategic Energy Plan suggests 20-22% of energy from nuclear power by 2030.[14] Japan announced on October 13 the start of deliberations for its Sixth Plan that should incorporate PM Suga's vision.[15]

Other countries have also stepped forward to achieve carbon neutrality. The European Commission, #3 in carbon emissions, has called for a climate-neutral Europe by 2050.[16] In September 2020, President Xi Jinping of China told the United Nations that China, #1 in carbon emissions, would strive to be carbon-neutral by 2060.[17] On October 28, President Moon Jae-in of South Korea, #9 in carbon emissions, announced carbon-neutrality by 2050.[18]

The importance of limiting climate-induced temperature rise to 1.5ºC is discussed in many publications including those of the IPCC[19], which also discuss the dire consequences if future temperatures exceed that level.[20] In addition, global warming is not uniformly distributed across the globe; already about 10% of the planet has warmed by 2ºC.[21]

The recent actions in Japan, China, EU, and South Korea as well as the U.S. plans for a new focus on climate change provide grounds for optimism, but all nations will have significant difficulties fulfilling their plans. For example, 80% of U.S. energy in 2019 came from fossil fuels[22] and, for the year ending in March 2019, Japan derived 77% of its energy from fossil fuels.[23]

With significant global interest in zero carbon emissions by 2050, many studies have explored paths to reach that goal. These studies, such as major ones by the International Energy Agency (IEA), typically depend, along with improved efficiency, on substantial electrification of all sectors including transportation, clean electricity generation, and/or use of hydrogen as a clean energy source. Renewable energy sources must increase substantially along with requirements for additional zero-carbon baseload generation, such as nuclear. Use of fossil fuels without Carbon Capture, Utilization and Storage (CCUS) drops substantially.[24] Even in a case that achieves zero emissions by 2070, 601 GW of nuclear are necessary according to the IEA, versus current capacity around 450 GW.[25] In another study, the IEA Executive Director noted that, "Without action to provide more support for nuclear power, global efforts to transition to a cleaner energy system will become drastically harder and more costly." That same study found several vital actions that are needed, such as: extend lifetimes of nuclear plants wherever it is safely possible, value the dispatchability of nuclear power, and value its environmental and energy benefits.[26] These recommendations should be followed in the U.S. and Japan!. Studies at MIT confirm that costs of decarbonizing electricity are far higher when only renewables are employed instead of inclusion of a baseload carbon-free source.[27] Another MIT study noted that using intermittent renewables for 80% of electricity might be possible, but moving to 100% would be prohibitively expensive.[28]

Neither Japan nor the U.S. is following the IEA suggestions. In the U.S., 95 reactors are now in operation but about ten have closed due to poor economics. The average age of U.S. plants is 39 years.[24] And while most U.S. reactors are now approved for 60 years of operation, leading to many expected closures in the 2030's and 2040s, only four plants to date have received approval for 80 years with another four under review. In Japan, the situation is even more dire. Only 9 plants have been approved for restart after Fukushima, and only the Genkai plant was operating in November 2020.[29] Japan also has significant reliance on coal power. In 2019, Japan had built 12 new coal plants since 2012, with 15 under construction and 10 in the planning stage.[30] Very few nuclear plants are under construction in either country and both nations will need many new nuclear plants to meet their climate goals.

New plants could use the Generation III or III+ GW-class of plant that is used in both countries or could move to alternate designs. In the U.S. there is significant interest in GenIII+ light-water-cooled small modular reactors (SMR). The NuScale GenIII+ SMR, recently certified by the NRC, offers many improvements including: rapid construction using largely factory-built assemblies, greatly improved safety with no operator actions required in any upset, no need for off-site electricity, a very small (or site boundary) emergency planning zone, and the potential for air-cooling to avoid the need for proximity to a river or ocean. Tentatively the first construction will supply the Utah Associated Municipal Power Systems. NuScale plants will consist of several modules (between 4 and 12 delivering between 307 and 924 MW_e), and their recent price estimate is $2850/kW.[31] It could be an attractive construction choice for Japan.

Gen IV plants, using alternative coolants, are under development in both nations for future deployment and offer attributes like very high levels of safety requiring no or minimal operator actions in any upset, waste re-use and disposal, and high output temperatures. Japan's High Temperature Engineering Test Reactor (HTTR) achieved criticality in 1998. It has demonstrated outlet temperature of 950°C.[32] In the U.S. several GenIV designs are under development with gas, liquid metal, or molten salt coolants. Many private companies are involved in these development projects and the DOE has invested in a wide range of research projects. As part of the Advanced Reactor Demonstration Project, the DOE recently awarded $160 Million to two companies for demonstration of their concept, one for a sodium-cooled fast reactor with thermal energy storage and one for a high temperature gas-cooled design.[33] Several micro-reactor designs with powers below 20 MW_e are also development in the U.S.

To achieve complete decarbonization, clean energy must produce far more than electricity. The IEA has explored options for the chemical, steel, and cement industries and noted that CCUS and hydrogen are potential zero-carbon applicable technologies.[34] Of course, hydrogen is not a solution unless produced with zero emissions! Nuclear power presents another strong option for cleanly addressing these industries and studies in both countries are exploring these options using either GenIII+ or IV reactors. In Japan, both hydrogen production and steel production are under study. Japan has used their HTTR, coupled to a thermo-chemical water splitting process to demonstrate hydrogen production.[32] In the U.S. substantial research exploring coupling of nuclear and renewable energy is under way at the Idaho National Laboratory (INL), the National Renewable Energy Laboratory (NREL), and MIT. Approaches that directly generate heat, rather than electricity, are more efficient since the heat demand across all sectors far exceeds electricity use, 83% to 17%. Gen IV reactors are one source of high temperature heat.[35] Additional study has focused on the use of LWRs for these missions.[36,37] In contrast to the work in Japan using thermo-chemical processes for hydrogen production, INL has focused on high temperature steam electrolysis.[38] With the importance of utilizing hydrogen produced with nuclear energy, several demonstration projects in the U.S. are funded.[39]

The existential imperative to move to carbon-free energy should be evident. The technologies to accomplish this for electricity, intermittent renewables with some fraction of clean baseload power, are available now. Fission can provide that clean baseload power today and other technologies (hydro, geothermal and possibly concentrated solar power (CSP)) may also contribute. But of those clean baseload options available today, only nuclear can be readily expanded with favorable economics. In the future, other clean baseload technologies may become available like CCUS to enable clean use of fossil fuels, long duration storage systems, and fusion power; research programs in these areas now may prove to be vital in the future.

Extensions of renewables and nuclear into sectors beyond electricity are in the demonstration phase in several countries for clean production of hydrogen. Several studies are exploring direct utilization of clean high temperature reactor heat for industrial processes. Electrification of transportation is expanding. The optimum mix of renewables and nuclear energy will vary by location, and no one prescription will be ideal everywhere. Several regions have already developed blueprints to achieve zero-carbon goals.

Many nations have pledged carbon-free energy by dates around 2050. But the challenges to fulfill those pledges are immense. It remains to be seen if nations around the world are ready to make the commitments today that will provide that reality for future generations. Substantial construction of both renewables and nuclear energy will be needed to achieve future carbon-free societies. We can achieve this future vision, but it remains to be proven that we have the collective willpower around the globe to achieve success.

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Writer's Profile

Peter B. Lyons

Dr. Lyons led the Office of Nuclear Energy in the U.S. Department of Energy while serving as the primary policy advisor to the Secretary of Energy on issues involving U.S. and international civilian nuclear energy research, development and demonstration activities. He was a Commissioner of the Nuclear Regulatory Commission and served as Science Advisor on the staff of U.S. Senator Pete Domenici and the Senate Committee on Energy and Natural Resources, where he focused on military and civilian uses of nuclear technology. He now acts as a consultant to several corporate and laboratory boards, is a member of the Board of Directors of the American Nuclear Society (ANS) and received the 2020 Dwight D. Eisenhower Medal from the ANS and Dr. Susan Eisenhower.

Decarbonization by 2050: Looking Back to Look Ahead◆

Kenneth B Medlock III*

Carbon neutrality is now dominant in commercial and political discourse. There is a growing list of net-zero commitments by large firms – including BP, Shell, Equinor, Repsol, Eni, Occidental Petroleum, Cenovus, Canadian Natural Resources, Southern Company, Entergy, Total, Lundin Petroleum, Dominion Energy, NRG, Baker Hughes, Duke Energy and Williams – all of which have significant fossil fuel portfolios. In addition, a growing number of large banks and investors – including Morgan Stanley, JPMorgan, Citigroup, BlackRock, Pimco and Bank of America – have pledged to review the climate impacts of future capital allocations.

Many governments around the world are also expressing net-zero intentions, with various pathways under consideration – including greater use of renewables, electrification, hydrogen, and carbon capture technologies. The European Union (EU), perhaps the most aggressive in its intentions, is contemplating ways to drive lower carbon intensity in the products it imports, including a border carbon adjustment mechanism.

The COVID-19 pandemic has also had a lasting impact. The human and economic tolls are well-documented and staggering. Recovery has many governments looking to link economic stimulus with green energy initiatives and policies to address environmental concerns. This is especially true in the developed countries in the Organization of Economic Cooperation and Development (OECD).

While the fiscal wherewithal to focus on green recovery will vary by region, simultaneous efforts to improve energy access in developing nations present an important juxtaposition. The world of energy is one of "haves" (OECD) and "have-nots" (non-OECD). Although the paradigm is shifting, a large fraction of the global community still lacks access to modern energy services, most of whom are in the non-OECD. Access to modern energy services is critical for economic growth and improved living standards. Economic progress supports the investment required to expand energy access; hence a virtuous cycle. The concomitant growth in energy use need not be in conflict with net-zero commitments. Indeed, the dual goals of economic growth and environmental sustainability are paramount, which begs the question, "Is net-zero attainable?"

◆ This article builds from arguments presented in Medlock, III, Kenneth B., "Energy Transition, COVID-19, Comparative Advantage, and a World of Uncertainty," *Oxford Energy Forum: COVID-19 and the Energy Transition*, Issue 123, pp. 63-66. (https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/07/OEF123.pdf).

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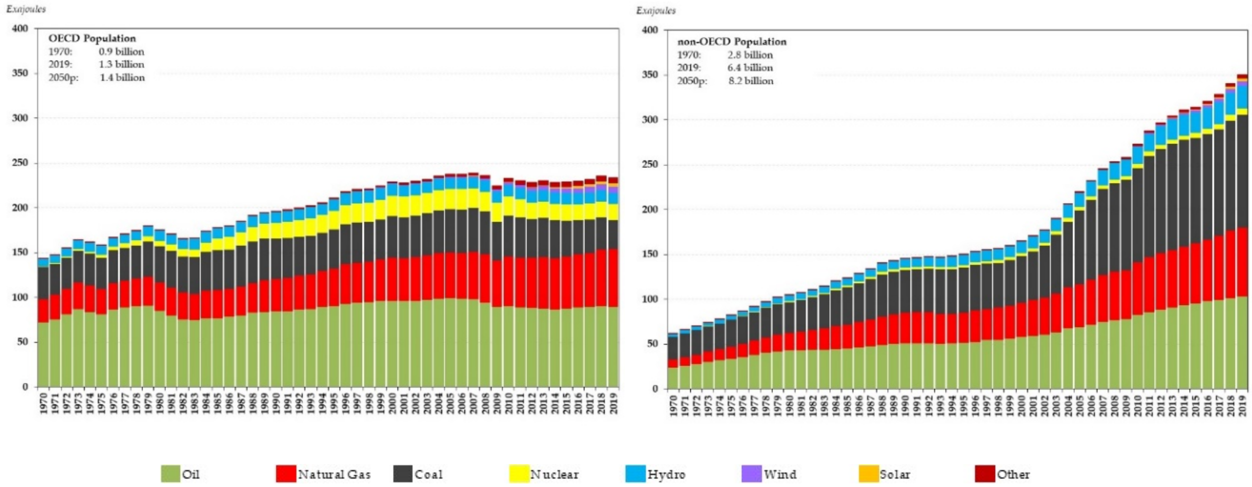
History Sets the Stage

Previous investments define the *legacy* of energy systems around the world. The *scale* of existing global energy infrastructure is massive and heterogeneous, supporting a range of economic activities, health and human services, and lifestyles across multiple geographies. As such, energy ecosystems are built on a legacy that is difficult to replace, costly to dismantle, and impossible to ignore in energy transitions. There are multiple options to reduce the carbon intensity of energy use, and *technologies* that can leverage existing legacy infrastructures are most likely to see rapid uptake.

As indicated in Fig. 1, OECD demand has virtually stagnated over the past two decades, but non-OECD demand (especially in developing Asia) has seen steep growth, overtaking OECD demand in 2007. Moreover, demand growth has been largely driven by fossil fuels. In 1970, the EU and North America accounted for 26.4% and 36.2% of global energy demand, respectively, while developing Asia accounted for 7.1%. By 2000, the shares shifted to 18.7% for the EU, 28.9% for North America, and 19.1% for developing Asia, and by 2019 the EU accounted for 11.8%, North America 20.0%, and developing Asia 36.9%. The rest of the world (RoW), comprised of about 3.0 billion people at varying levels of economic development, has held steady in the 30% range. But as the economies of developing Asia mature, the energy needs in the RoW will continue to increase, particularly in developing regions where energy access is still lacking. Such an outcome is supported by various projections of population and economic growth.[1]

Fig. 1 Global Primary Energy Use by Source, OECD and Non-OECD (1970-2019)[2]

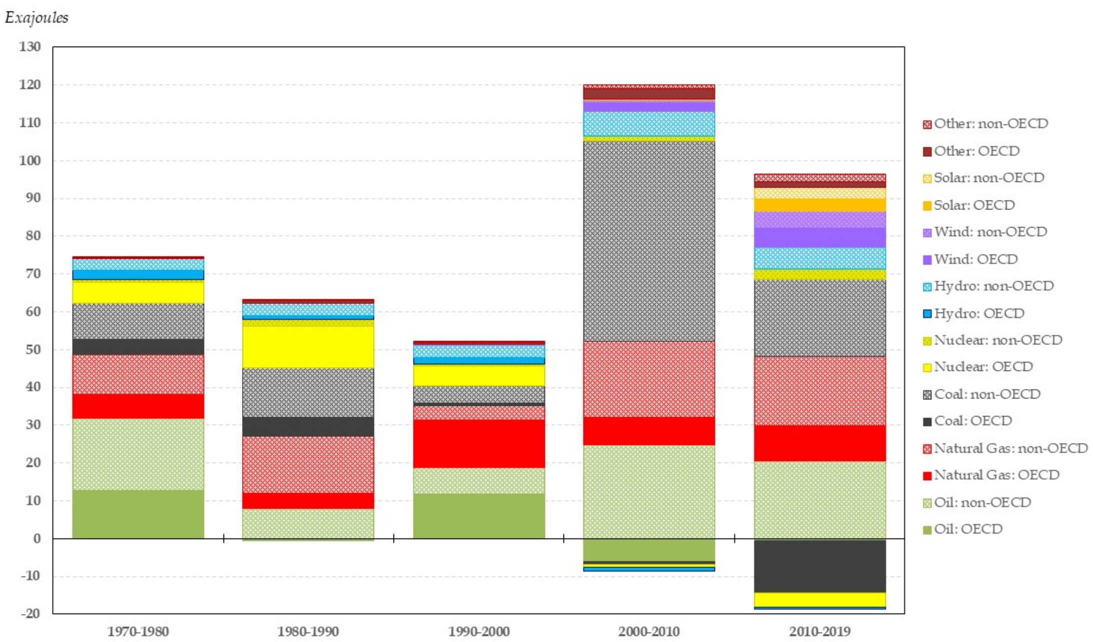


1 These include projections from the United Nations (https://population.un.org/wpp/), the International Monetary Fund (https://www.imf.org/en/Publications/WEO), and the International Energy Agency (https://www.iea.org/reports/world-energy-outlook-2020), to name three.

2 All energy data used in this paper are from the BP Statistical Review of World Energy (2020). Population data are compiled from OECD.stat.

Fig. 2 indicates how various sources of energy have changed by decade in the OECD and non-OECD since 1970. Notably, 1970s, 80s and 90s saw increases in every form of energy in both the OECD and non-OECD. Since 2000, oil, coal and nuclear have all seen declines in the OECD, but increased use of oil, coal and nuclear in the non-OECD has more than offset the declines in the OECD. For example, since 2000, OECD coal use declined by 30% as non-OECD coal use increased by 240%, now accounting for almost 80% of global coal use. So, the combined effects of population growth,[3] economic growth,[4] and gains in average individual wealth[5] drove up demand for all forms of energy by 285% from 1970 to 2019, even as energy efficiency improved.

Fig. 2 Change in Energy Use by Source, OECD and Non-OECD (1970-2019)



Figs. 1 and 2 indicate the depth of the challenge of getting to net zero by 2050, and help highlight how multi-faceted achieving such a goal will need to be. Over the last 30 years, the *share* of fossil fuels in the global primary energy mix declined from 86.0% to 84.3%, but *total* demand for fossil fuels increased as total energy demand grew by 70%. Hence, achieving net zero will require a much more rapid shift in energy composition over the next 30 years if it is to be done solely through eliminating fossil fuels.

This is even more pronounced when one considers the pace at which wind and solar have expanded since 2010 and the implications for total supply. The growth in wind and solar energy have been nothing short of astounding, reaching average annual rates in excess 16% and 39%,

3 Global population grew from 3.7 billion to 7.7 billion. See United Nations, *World Population Prospects 2019* (https://population.un.org/wpp/).

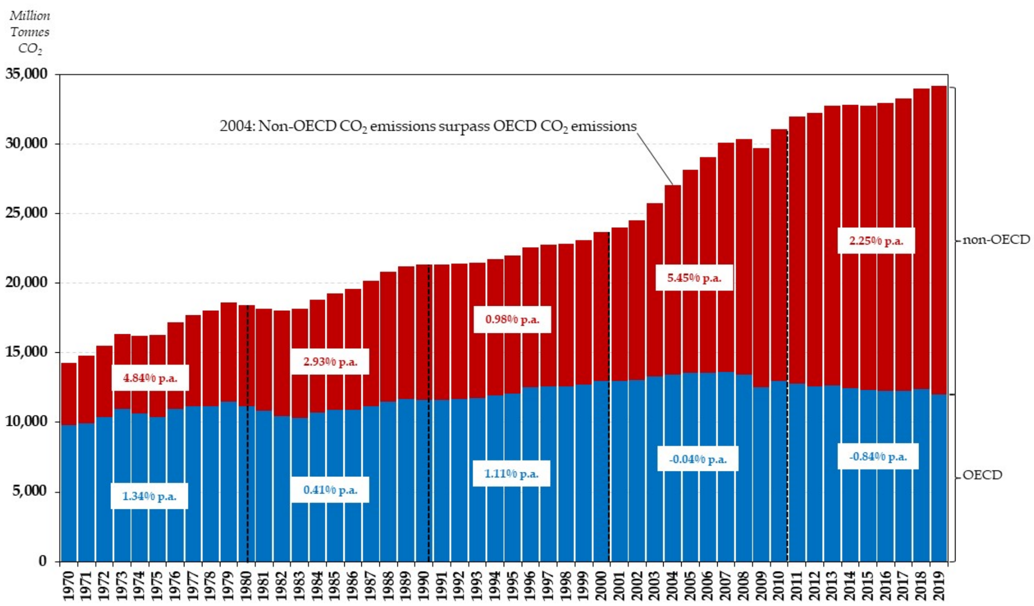
4 Global gross domestic product increased from 2010$19.211 trillion to 2010$84.865 trillion. See World Bank (https://data.worldbank.org/indicator/NY.GDP.MKTP.KD).

5 Global per capita income increased from about 2010$5,200 to about 2010$11,000.

respectively. Nevertheless, wind and solar combined to contribute an additional 15.6 exajoules to the total global energy portfolio from 2010 to 2019 while fossil fuels contributed 54.3 exajoules even though oil, coal and natural gas grew at much lower average annual rates of 1.2%, 0.5% and 2.4%, respectively. So, scale matters.

This all has direct implication for global carbon dioxide (CO_2) emissions. OECD CO_2 emissions have declined since 2007, and in 2019 were at their 1995 levels (see Fig. 3). By contrast, non-OECD emissions have more than doubled since 1995. In fact, given the scale of non-OECD emissions in 2019, even if OECD emissions were slashed to zero, global emissions would still be at 1995 levels. Hence, the fact that growth in energy demand and CO_2 emissions is being driven by developing non-OECD nations, means that a large part of any strategy to reach net-zero emissions globally must be executed in developing countries.

Fig. 3 Global CO_2 Emissions, OECD and non-OECD (1970-2019)



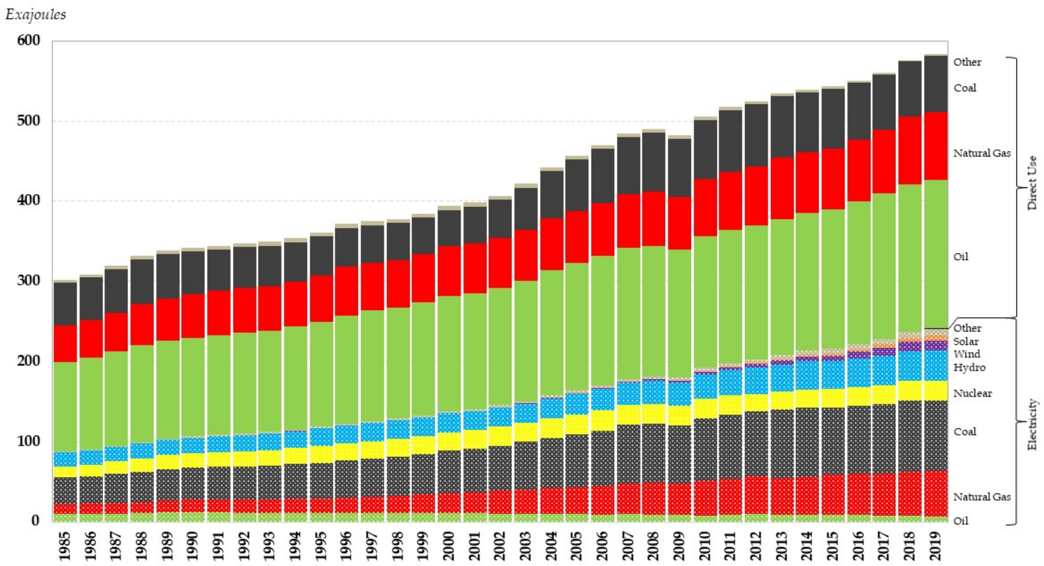
Strategies to Achieve Net Zero Must be All-Encompassing

There are a number of options to drive reductions in CO_2 emissions. To date, renewable energy technologies, such as wind and solar, have grown significantly, but they have been largely confined to the electric power sector. Direct government support has been immensely important for the observed growth, but existing power grids have been equally important, if not moreso. In regions with well-established electricity value chains (from generation to transmission and distribution to end-use), intermittent, non-dispatchable renewable resources can be successfully integrated and managed as part of a broader power generation portfolio. The experience in these regions has engendered a common strategy for achieving net zero: increase electrification in all sectors.

Fig. 4 indicates that electricity accounted for 41% of total energy in 2019. Continued growth in electrification will require massive infrastructure investments to move into sectors where direct combustion of fossil fuels accounts for 99% of all non-electric energy use. In addition, the investment required for greater electrification must be sufficient to replace aging infrastructure, displace fossil fuels, and expand generation capacity and distribution networks to also meet new demands, most of which must occur in developing economies.[6]

All of the preceding is not meant to disparage net-zero aspirations; rather, it is meant to properly frame the discussion about how to get to a desired outcome. Net-zero cannot *only* be about renewable energy technologies. Re-envisioning the combustion of fossil fuels – for instance in ways that allow hydrogen to serve as an energy source while carbon is used in other high-value added ways – is one possible option. Other possibilities include greater investment in carbon capture and storage technologies, expanding nuclear energy options, and development of natural carbon sinks.

Fig. 4 Global Energy and Electricity by Source (1985-2019)



In the end, the long understood but oft forgotten principle of comparative advantage will define how transitions and net-zero goals manifest in different parts of the world. Some regions favor a build-out of intermittent renewable resources (i.e.- wind and solar) that can leverage transmission connections with low-to-zero carbon dispatchable resources (i.e.- natural gas, hydro and nuclear) or perhaps even batteries or hydrogen technologies for load stability. Hydrogen, and its multitude of colors (blue: methane reformation with carbon capture; green: renewable-powered hydrolysis; yellow: biomass conversion; and turquoise: pyrolysis combustion yielding hydrogen and carbon black) also holds promise. Suffice it to say that there is a portfolio of options available,

[6] Non-OECD population is about 6.4 billion people, or 83% of global population, and non-OECD economies total $34.1 trillion, or roughly 40% of the global economy. Moreover, almost all population increase and the majority of global economic activity are projected to originate in the OECD.

but regional comparative advantages should drive adoption of least cost pathways and render energy transitions, and hence net-zero strategies, to be different everywhere. If this is not the case, stated net-zero aspirations will remain unrealized.

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Climate Scenarios are Off Track

Roger Pielke Jr.*

A set of newly published papers indicates the scenarios of the future to 2100 on which much of climate research depends have already diverged from what has actually been unfolding in the real world (Burgess et al. 2020, Pielke and Ritchie, in press). Consequently, these scenarios – developed, collected and assessed by the Intergovernmental Panel on Climate Change (IPCC) -- offer a poor basis for projecting into the future policy-relevant variables, such as economic growth and carbon dioxide emissions. If scenarios are not updated, then the guidance provided to policy makers originating in research and assessment that rely on these scenario will be out-of-date and potentially misleading.

Burgess et al. (2020) perform the most rigorous evaluation to date of how key variables in climate scenarios compare with data from the real world (specifically, it focuses on the four factors of the Kaya Identity: population, economic growth, energy intensity of economic growth and carbon intensity of energy consumption). Burgess et al. (2020) also explore how these variables might evolve in the near-term to 2040, based on near-term energy outlooks, such as those of the International Energy Agency (e.g., IEA 2019).

Burgess et al. (2020) find that the most commonly-used scenarios in climate research have already departed significantly from the real world, and that this divergence is going to only get larger in coming decades. Fig. 1 below clearly shows this divergence. The figure shows carbon dioxide emissions from fossil fuels from 2005, when many scenarios begin, to 2045. The graph shows emissions trajectories projected by the most commonly used climate scenarios (with labels on the right vertical axis, see Burgess et al. 2020 for technical details and original sources). Actual emissions to date (dark blue curve) and those of near-term energy outlooks (labeled as EIA, BP and ExxonMobil) all can be found at the very low end of the scenario range, and far below the most commonly used scenarios.

An important reason for the lower-than-projected carbon dioxide emissions is that economic growth has been slower than expected across the scenarios, and rather than seeing coal use expand dramatically around the world, it has actually declined in some regions.

Fig. 2 below shows the difference between observations of the Kaya factors and the values found in the baseline scenarios of the IPCC Fifth Assessment Report Scenario Database (AR5).[1] The figure shows that most references scenarios of the IPCC AR5 overestimated both carbon dioxide growth and per capita GDP growth, and in most of the subregions of the IPCC (for details, see Burgess et al. 2020).

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[1] https://tntcat.iiasa.ac.at/AR5DB/dsd?Action=htmlpage&page=about

Fig. 1　A Comparison of Energy-Related CO_2 Emissions Projected by Energy Outlooks. By IPCC AR5 Scenarios of Its Working Group 3, and SSP Baseline Scenarios. For Sources and Details, See Burgess et al. 2020

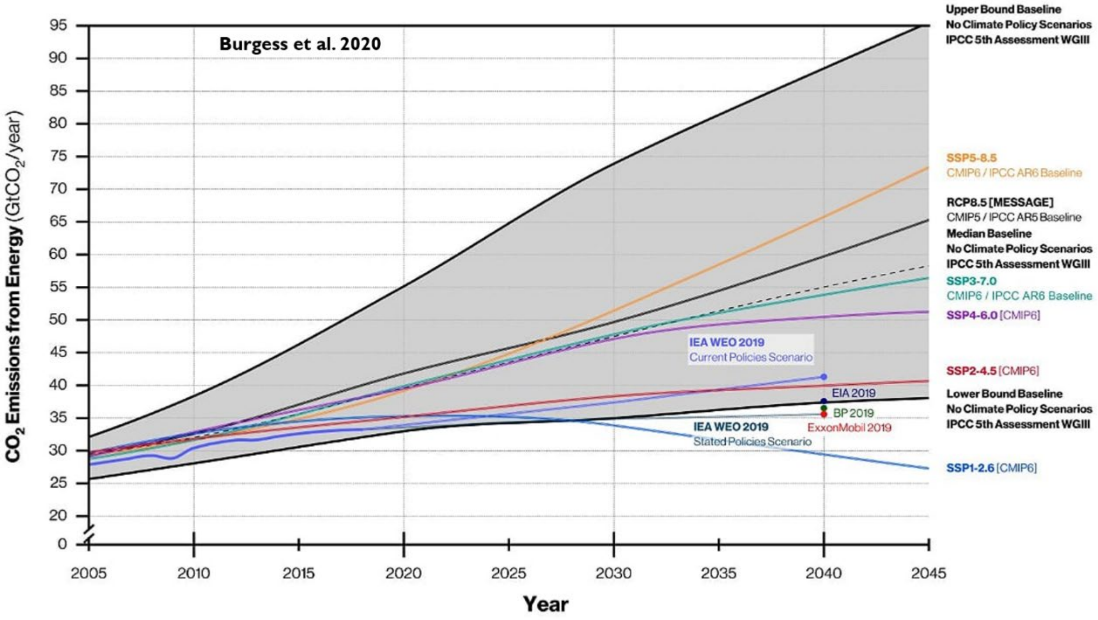
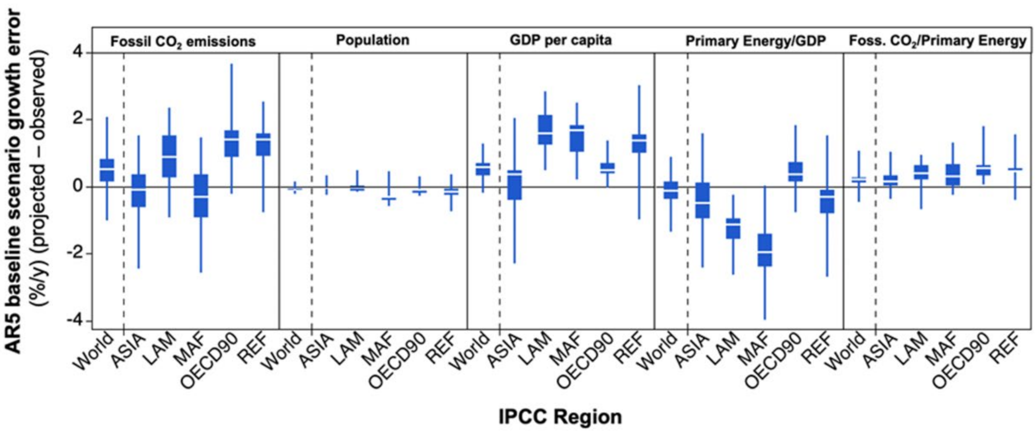


Fig. 2　IPCC Baseline Scenarios (2005-2020) Relative to Observations (2005-2017) (IEA 2019). Boxes Represent 25th-75th Percentiles (white dashes indicate medians). Lines above and below the Boxes Represent the Full (min-max) Range. From Burges et al. 2020



It is even conceivable, if not likely, that in 2019 the world has already passed peak carbon dioxide emissions. Crucially, the projections in Fig. 1 above are pre-Covid19, which means that actual emissions 2020 to 2045 will likely be even less than was projected in 2019 in the various short-term energy outlooks. As Hausfather and Peters (2020) write in *Nature*, the emissions scenario commonly used in research to represent a "business as usual" (or "baseline") trajectory into the future "becomes increasingly implausible with every passing year." Burgess et al. (2020) builds upon a growing literature indicating that commonly used climate scenarios are already well off track and will become increasingly off track e.g.,

A growing literature has begun to recognize the divergence of commonly used scenarios and the evolution of the real world (e.g., see Ritchie and Dowlatabadi 2018 as one of the first and most significant contributions to this literature). O'Neill et al. (2020) has also recognized that the real world and scenario architecture have drifted apart in the years since the scenarios were first developed. That is of course not surprising, as projecting the future is always challenging. Correspondingly, the authors, who include many developers of these scenarios, "recommend establishing a process for regular updates" to the scenarios and recommend that key variables in the scenarios "be updated now to be consistent with new historical data."

While it is excellent news that the broader community is beginning to realize that scenarios are increasingly outdated, voluminous amounts of research have been and continue to be produced based on the outdated scenarios (Pielke and Ritchie, in press). For instance, O'Neill et al. (2020) find that "many studies" use scenarios that are "unlikely." In fact, in their literature review such "unlikely" scenarios comprise more than 20% of all scenario applications in peer-reviewed publications from 2014 to 2019. O'Neill et al. (2020) also call for "re-examining the assumptions underlying" the high-end emissions scenarios that are favored in physical climate research, impact studies and economic and policy analyses. As a result of such high prevalence of such studies in the literature, they are also the most commonly cited within scientific assessments of the Intergovernmental Panel on Climate Change (Pielke and Ritchie 2020). O'Neill et al. (2020) find that the highest emission scenarios comprise about 30% of all applications in studies over the past five years, from a family of 35 different scenarios that they surveyed.

Evidence is now undeniable that the basis for a significant amount of research has become untethered from the real world. The issue now is what to do about it. Pielke and Ritchie (in press) recommend several options, beginning with the need for widespread recognition that scenarios have drifted away from real-world relevance. Pielke and Ritchie (in press) also recommend that the IPCC chose to either oversee scenario development or assess literature, but not both. In addition, policy relevance would be enhanced with a focus on near-term scenarios more closely aligned with real-world observations.

The challenges for climate research are significant. Pielke and Ritchie (in press) found almost 17,000 peer-reviewed articles have already been published (through early 2020) that use the now-outdated highest emissions scenario. That particular scenario is also by far the most commonly cited in recent climate assessments of the IPCC and the U.S. National Climate Assessment (Pielke and Ritchie, in press). And every day new studies are published using outdated scenarios.

The elevated role of scenarios across climate research means that there is a huge momentum behind their continued use. A research reset would be a massive endeavor and would require essentially writing off the policy, economic or other real-world relevance of thousands of studies, and perhaps even their scientific utility. There are of course reasons to use exploratory scenarios in modeling or theoretical studies, but such uses shouldn't be confused with practical relevance. Climate research finds itself at a crossroads and in need to address scenarios that are now off-track.

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Writer's Profile

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Professor Pielke founded and served as Director of the Center for Science and Technology Policy Research at the University of Colorado Boulder from 2001 to 2007 and from 2013 to 2016. He was a visiting scholar at Oxford University's Saïd Business School in the 2007-2008 academic year. His interests include understanding the use and misuse of science in areas such as the Covid-19 response, climate change, disaster mitigation, energy policy; and sports governance.

Is It Possible to Fully Decarbonize the Global Supply of Energy by 2050? The Role of Energy Efficiency, Renewables and Nuclear Power

Gerry Thomas*

Introduction

Many countries are beginning to take the need for a green industrial strategy more seriously, as the human effects of climate change become more apparent. The European summer heatwave of 2003 contributed to at least 70,000 deaths across the continent, and such extremes of heat in summer are expected to become more frequent by the 2040s. at the current rate of climate change. If no action is taken, it is predicted that we will see severe impacts at 3ºC of warming. For example, in the UK, a sea level rise of 0.83 metres would be predicted (1) , river flooding would cause twice as much economic damage and affect twice the number of people it does today (2), and by 2050, up to 7,000 people would die from the effects of heat, compared to around 2,000 at the present time (3). The WHO predicts that between 2030 and 2050, climate change is expected to cause approximately 250 000 additional deaths per year, from malnutrition, malaria, diarrhoea and heat stress. The direct damage costs to health (i.e. excluding costs in health-determining sectors such as agriculture and water and sanitation), is estimated to be between USD 2-4 billion/year by 2030 (4).

Given these findings, which will impact the most vulnerable of our populations, inaction would appear not to be an option for democracies that pride themselves on social justice. So how do we mitigate the effects of climate change, yet retain our industrialised societies?

The Role of Energy Efficiency

Energy efficiency can reduce green house gas (GHG) emissions, both directly from reducing fossil fuel consumption, but also indirectly from changes made to the way in which energy is generated. However, many of the methods used to increase efficiency require the public to make changes in the way that they use energy, for example switching from the use of gas boilers in homes, to electric boilers or installing heat pumps, or increasing insulation in homes. These changes will come at a cost to householders, and at a time of economic stress due to the recent pandemic, household budgets are likely to be under some considerable stress. Provision of government grants may be used to encourage individuals to make their lives more sustainable, but these rarely cover the full cost. It can be demonstrated that energy efficiency can make a difference – improvements in energy efficiency resulted in a 12% reduction of CO_2 emissions between 2000

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and 2017. Energy efficiency in the industrial sector can also be shown to be of value – for example, producing metals like steel, aluminium and copper from recycled scrap is 60-90% less energy intensive than production from metal ores (5).

The Role of Renewables

Most people would expect that the recent growth in renewables, primarily wind and solar power, has played and will continue to play a role in reducing GHG emissions. Whilst it is certainly true that solar and wind produce substantially less GHG in their life cycle than fossil fuels (5), the evidence from Germany's Energiewende policy suggests that this is not the whole story. This policy, at a cost of 160 billion Euros to consumers and government, has seen a very impressive effort to increase the production of electricity using wind power, which now generates 40% of the country's electricity. However, Germany's GHG emissions have not declined less rapidly than expected. This is due in part to the fact that both wind and solar are intermittent sources of energy, and with the German reluctance to use nuclear power, coal, oil and gas power stations have been required for the production of baseload electricity.

In addition, solar and wind are not a solution for all countries. Offshore wind is a valuable source for countries such as the UK, whereas in other areas such as Japan, it is even less of a realistic option. Much of the public focus has been on how to generate electricity in a more climate friendly manner, the reality is that the most difficult sectors of all to decarbonise are heavy industry and transport. In these areas cleaner energy sources are required – particularly hydrogen. Hydrogen generation requires provision of large amounts of reliable energy. Although renewables are favoured by the general public, they have inherent problems with regard to the amount of land required. A recent report (6) has estimated that to replace the UKs current oil consumption with hydrogen generated using offshore wind would require 120 km^2, or with solar PV 26,000 km^2. In contrast the amount of land required using advanced heat sources i.e. nuclear was considerably smaller i.e. 55 km^2. Energy density may be seen as being of particular importance for island nations.

The Role of Nuclear Energy

Whilst both energy efficiency and renewables offer small steps towards the solution to climate change, nuclear could potentially offer a step change in climate change mitigation. The ideal energy source is one that requires smaller amounts of land in order to generate substantial amounts of consistent energy, that could be used both to generate power for a variety of purposes, domestic and industrial, including generation of hydrogen. Nuclear power has the potential to meet all of these criteria, but lacks the general societal acceptance of renewables. In addition, more flexibility will be required of nuclear power. It should no longer be seen in terms of generating only baseload electricity.

There is no doubt that future nuclear power systems will be required to work with an energy system that includes intermittent energy produced by renewables. Any developments in nuclear power would therefore need an inbuilt flexibility to supply energy to the grid when renewables were off line, but in the interests of using energy efficiency, to be able to supply power for other uses when the need for electricity generation was met by the use of renewables.

Heating and transport are the largest energy users and these two areas may be particularly difficult to decarbonise using electricity. Nuclear reactors produce heat on a vast scale – a typical nuclear power station produces heat that is equivalent to the output of a 100,000 domestic gas boilers. A recent report from the Royal Society (7) points out that there are two key issues that impact the utility of nuclear at present: it is most economic when run at high output, and 65% of the energy produced is lost as waste heat. In the past, some of this heat has been used to heat co-localised infrastructure, for example the UK's first nuclear plant, Calder Hall, supplied building heat for Calder Hall itself and nearby Sellafield. The Agesta reactor in Sweden supplied heat to Farsta, a suburb of Stockholm, and the Chinese have recently built a pilot nuclear reactor to heat districts in the colder northern regions of the country. Heat from nuclear reactors has also been used to power co-localised industry – for example the Wylfa power station in North Wales was used to provide power for an aluminium smelter.

Low temperature heat generated from conventional nuclear reactors could be used therefore to heat homes in the local area, which would increase energy efficiency. However, the high temperature heat generated from the newer Generation IV reactors would be better suited to drive hydrogen production, which in turn could be used to decarbonise the "difficult to reach" transport sectors such as aviation, heavy-duty vehicles and shipping.

Barriers to Capitalising on Nuclear's Potential to Decarbonise

There are a number of barriers that need to be overcome in order for nuclear to realise its potential as a major player in decarbonisation strategies. Firstly, it needs to be accepted by the general public as a safe, secure and economic method of producing energy. Improving its energy efficiency, and using the currently wasted heat it produces will potentially increase its economic viability. The move to using small modular reactors may reduce some of the public concern regarding having a very large infrastructure project built in their back yard. However, co-localising of a nuclear power plant with an industrial process plant may prove challenging from both a public and planning perspective. Such developments would provide stable employment of a skilled workforce for decades – in the case of nuclear maybe two or three generations, which is a bonus for community cohesion.

There is no doubt that reaching our climate goals will be challenging, but there is an ethical intergeneration obligation on us to do so. Energy efficiency, renewables and nuclear power all have a role in meeting this obligation. We do have the tools necessary to do this, but the question is do we have the political will and sense of societal responsibility to take some difficult decisions, before it is too late?

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Writer's Profile

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Prof. Gerry Thomas is Professor of Molecular Pathology at Imperial College London and the Director of the Chernobyl Tissue Bank (CTB). The CTB was established in 1998 to facilitate research, in cooperation with Belarussian, Ukrainian and Russian scientists, into the biological mechanism that are involved in development of thyroid cancer following a nuclear power plant accident. Since the Fukushima accident in 2011, she has been engaged in public communication of the real health risks of energy production, including exposure to low doses of radiation from nuclear accidents.

Is It Possible to Achieve Global-Scale Net-Zero Emissions by 2050?

Mitsutsune Yamaguchi*

1. Possibility of Achieving Net-Zero Emissions by 2050 is Largely Dependent on CCS and BECCS

After the IPCC released its 1.5°C special report (SR1.5) in 2018 and, based on this report, in June 2019 the United Kingdom set net-zero emissions of greenhouse gases (GHG) by 2050 as legally binding target, net-zero emissions suddenly came into the spotlight. In September this year, China followed in the footsteps of the EU and announced that it will achieve net-zero emissions by 2060 (though not 2050), and in October, Japan declared the goal of net-zero by 2050. Many other countries are considering similar actions, but to date, the UK is the only country that has published sector roadmaps and technologies for achieving the goal of net-zero, the cost as a ratio of GDP, and the average cost of measures for each sector in detail. The UK's plan is to reduce most of its emissions using electrification, hydrogen, and large amounts of CCS (a technology which reduces emissions to zero by capturing CO_2 from fossil fuel combustion and storing it underground), and deal with the remaining hard-to-avoid emissions using negative emission technologies, specifically BECCS[1] (bioenergy with CCS) and small amounts of forestation and DACS (capturing atmospheric CO_2 directly and trapping it in geological formations semi-permanently) (the negative emissions from these technologies are hereafter collectively called "NEs"). In 2050, the amounts of CCS and BECCS will be equivalent to 35% of the total emissions in 2017, with BECCS alone accounting for some 10% (Fig. 1).

Other than the UK outlined above, what is the global situation? The key feature of the IPCC's 1.5°C scenario is that it depends on large amounts of NEs, mainly from BECCS. An analysis by the International Energy Agency (IEA) shows that 88 of the IPCC's 90 scenarios depend on BECCS, with a median of 4.7 Gt[2] as of 2050. While the central scenario of the IEA is the Sustainable Development (SD) scenario, which sets 2070, not 2050, as the target year for achieving net-zero emissions of CO_2, it has also published a scenario in which net-zero is achieved by 2050 by further progress in innovation. The latter estimates CCS at approx. 8 Gt in 2050, including around 3.3 Gt of NEs (of which about 3 Gt is BECCS). Here, CCS and BECCS together comprise a significant portion or one-fourth of energy-related CO_2 emissions in 2019, while the amount of BECCS is smaller than

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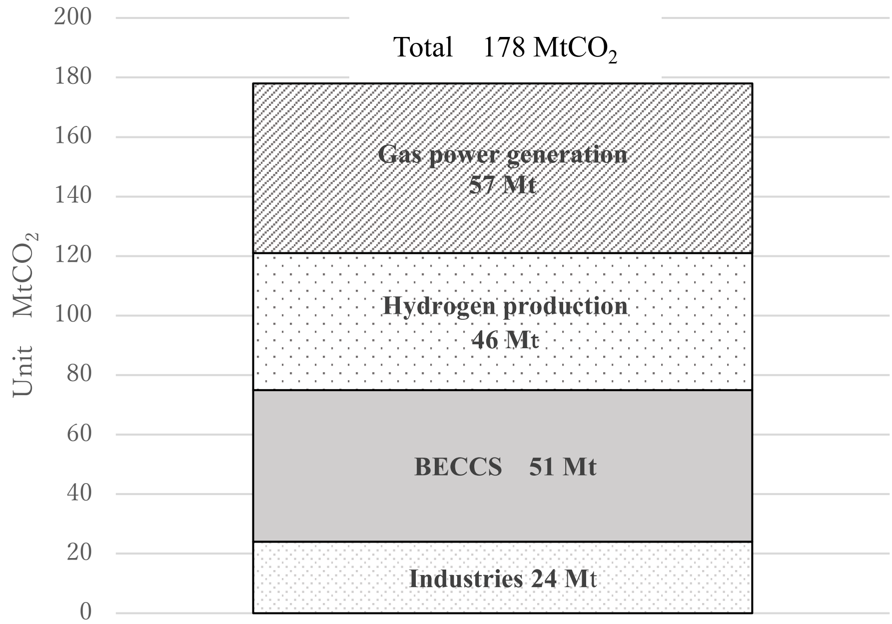
[1] BECCS (Bio-Energy with Carbon Capture and Storage): The CO_2 emissions generated from burning biomass as an energy source are counted as zero since plants absorb CO_2 as they grow. The emissions are counted as negative when captured and stored in the ground, which is why BECCS is counted as a negative emission.

[2] IEA World Energy Outlook 2019, p. 124

in the IPCC 1.5°C scenario[3]. Thus, it is not possible to achieve net-zero by 2050 without large amounts of CCS and BECCS.

Fig. 1 UK's Dependence on CCS and BECCS (2050)



Source: 2019 material by The Committee on Climate Change
As GHG emissions in 2017 in the UK were 503 Mt, the total of CCS and BECCS, 178 Mt, accounts for 35%.

2. Other Measures towards Achieving Net-Zero Emissions by 2050

The reason for having to resort to large amounts of BECCS, as described earlier, is because CO_2 and other GHG emissions cannot be completely eliminated by any means. Why not? Consider the UK as an example, focusing on the power generation, transportation, industrial, and building sectors. The generation sector will boost the share of wind power and solar PV to 57% while dealing with the soaring demand caused by electrification, reduce emissions to near-zero using nuclear and gas with CCS, and use BECCS to achieve negative emissions. The transport sector will reduce emissions from 120 Mt in 2017 to 2 Mt in 2050 by making passenger vehicles and light trucks 100% electrified and large trucks electrified and hydrogen-fueled. To achieve this, only EVs will be sold as new cars from 2035, and about 25,000 chargers will be set up for them. Next, the aviation sector will have 31 Mt of residual emissions due to a lack of options other than replacing a part of fuels with biofuels. The shipping sector can slash its emissions significantly by using hydrogen (ammonia), while industry can cut its emissions to 10 Mt by using hydrogen, electrification, biofuels, and CCS. The building sector will reduce the direct emissions for heating buildings from 85 Mt to 4 Mt by installing

[3] Chapter 6, IEA Energy Technology Perspective 2020. Note that the scope of the IEA's analysis includes only energy-related CO_2. CO_2 absorption and emissions due to forestation and deforestation are not included.

heat pumps and shifting from gas to hydrogen energy. The measures above will be combined with lifestyle changes, such as eating less meat and avoiding air travel, and the last remaining emissions that are difficult to eliminate will be offset by NEs, mainly BECCS, to achieve net-zero emissions. The cost of this scenario in 2050 is estimated at 1– 2% of GDP (see Fig. 1 for the UK's dependence on CCS and BECCS).

Next, the IEA has conducted a detailed analysis of 800 technologies in the context of global CO_2 reduction based on the SD scenario. The analysis concluded that electrification, CCUS (carbon capture, utilization, and storage), hydrogen, and bioenergy will be the keys, in addition to energy conservation and renewable energy which are basic requirements. The analysis then grouped the 800 technologies into six stages, namely conceptual (lithium air batteries, etc.), initial prototype (battery-powered aircraft, etc.), prototype (ammonia-powered ships, DAC, etc.), demonstration (ammonia from electrolysis with decarbonized electricity, etc.), initial marketing (off-shore wind power, heat pumps, etc.), and mature (hydropower, railways, etc.), and applied them to the key sectors described above to estimate the residual emissions of each sector in 2070. The industrial (steel, cement), transportation (shipping, air transport, large trucks), and building sectors would have about 3 Gt of residual emissions, which would be offset by using BECCS and small amounts of DACS in the generation and energy conversion sectors to achieve overall net-zero emissions as a result. The IEA has also released a 2050 net-zero scenario for reference purposes; major additional requirements for achieving net-zero emissions 20 years earlier than the SD scenario are described in Table 1.

Table 1 Additional Requirements for Achieving Net-Zero by 2050 (main differences with the SD scenario)

- The technologies currently in the prototype stage must reach the market faster than prior successful cases, and the market is assumed to expand if there is just one case of commercial implementation.
- It is essential that innovation progresses at an unprecedented speed. Technologies currenty in the demonstration or prototype stage, such as steel production using hydrogen, ammonia fuel from electrolysis for shipping and CCS in cement production, must be available in the market in 6 years at most.
- Technologies in the lab or small prototype stage must become available within 10 years from now in average. The only technology that has achieved this is LED.
- The power generation sector needs 20000 TWh of additional output by 2050 compared to the SD scenario. This is equivalent to the output of China and India combined in 2050.
- Renewable capacities must grow by 770 GW each year up to 2050 (50% more than the SD scenario).

Source: Created by the author based on Chapter 6, IEA Energy Technology Perspective 2020

3. Is it Possible to Achieve Net-Zero Emissions by 2050?

This question needs to be approached from three standpoints: (1) speed of innovation, (2) emissions from existing facilities, and (3) the potential of NEs. Among them, Table 1 indicates that the issue of (1) speed of innovation would be extremely difficult to tackle.

The greatest problem in terms of (2) emissions from existing facilities is China. CO_2 stays in the air very long time, which makes the cumulative amount of CO_2 and temperature increase almost directly proportional to each other. Accordingly, it is possible to estimate the total cumulative emissions in order to keep the temperature increase to, for example, below 2°C or 1.5°C above pre-industrial levels. This amount minus the amount of emissions generated to date gives the maximum amount of emissions, or remaining carbon budget, permitted to keep the rise in temperature to 2°C or 1.5°C. The IPCC's SR1.5 estimates the remaining carbon budget for the 1.5°C scenario (equivalent to reaching carbon-neutrality in 2050) at 420–580 Gt, but a study[4] published in the academic journal Nature points to the growth in the number of coal-fired thermal power stations being constructed or planned in developing countries, particularly in China, and states that these facilities worldwide will generate 846 Gt of emissions if they operate until the end of their lives, exceeding the carbon budget. Therefore, the possibility of achieving net-zero by 2050 will depend on whether CCS can be installed in the thermal power stations of China and other countries, or whether these facilities can be scrapped before the end of their lives.

As for (3) the potential of NEs, the main issues with BECCS, the most important NE technology, include adverse effects on biodiversity, availability of land for growing biofuels, and competition with food production. The IEA's special report on CCUS has estimated the land area necessary for 1 Mt of BECCS[5]. This, when multiplied by 3 Gt, the IEA's estimate for the amount of BECCS in 2050, gives 300–5100 Mha, and when multiplied by the IPCC's median of 4.7 Gt, gives 470–8000 Mha. The former is roughly 0.33–5.5 times, and the latter 0.5–8.7 times, the area of the United States. The greater figures were presumably calculated for agriculture and forest residues and the smaller ones for energy crops, but are inconceivable all the same.

From these three standpoints, achieving net-zero emissions by 2050 appears to be extremely difficult, if not impossible.

Writer's Profile

Mitsutsune Yamaguchi

Mr. Yamaguchi's previous position include Visiting Professor/Project Professor, University of Tokyo (2006-2015) and Professor of Economics, Keio University (1996-2004). Prior to this, he was Senior General Manager at Tokio Marine & Fire Insurance Co., Ltd. He served in numerous positions on committees and councils related Climate Change and Environmental issues such as a Lead Author of IPCC Working Group III.

4 Tong et al. Committed emissions from existing energy infrastructure jeopardize 1.5°C climate target, Nature **572**, 15, Aug. 2019, 373–377

5 IEA Energy Technology Perspectives 2020, Special Report on Carbon Capture Utilization and Storage, CCUS in clean energy transitions, p. 87

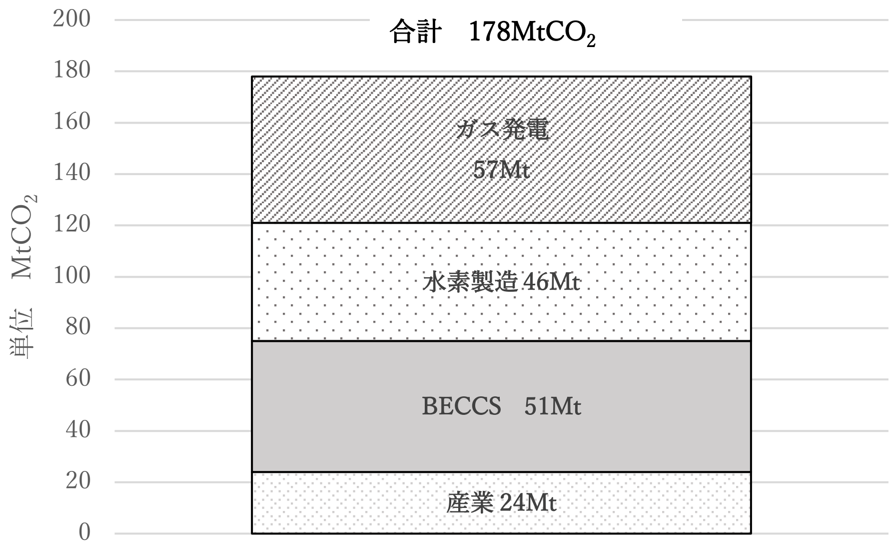
2050 年までに地球規模での
ゼロエミッション達成は可能か

山口　光恒 *

1.　CCS と BECCS に大きく依存する 2050 年ネットゼロ

2018 年の IPCC の 1.5℃特別報告書（SR1.5）と、これを受けてイギリスが 2019 年 6 月に 2050 年温室効果ガス（GHG）ネットゼロを法律で定めて以降、ネットゼロが俄に脚光を浴び、EU に続いて本年 9 月には中国が 2060 年にネットゼロを表明し、10 月には日本が 2050 年ネットゼロを宣言した。このほか同様のことを検討している国はかなりの数となっているが、このうち国として net-zero 目標達成の部門別ロードマップと技術、GDP 比のコストと部門別平均対策コストの詳細を公開しているのはイギリスのみだ。電化と水素、それに大量の CCS（化石燃料からの炭素を捕捉して地中に貯留する事で排出をゼロにする技術）で削減に努めるが、最後に残る排出はマイナス排出、具体的には BECCS[1]（CCS つきバイオエネルギー）及び極めて少量の植林及び DACS（大気から直接 CO_2 を捕捉し地下に半永久的に貯留）で相殺してネットゼロを

図1　イギリスのCCS及びBECCS依存量（2050年）



出典：イギリス気候変動委員会　2019年資料
イギリスの2017年の温室効果ガス排出量は503MtなのでCCSとBECCS合計178Mtはこの35%に相当する。

* （公財）地球環境産業技術研究機構　参与（Special Advisor, Research Institute of Innovative Technology for the Earth [RITE]）

[1] BECCS とは Bio-Energy with Carbon Capture and Storage の略称で、バイオマスをエネルギー源として燃すとここから CO_2 が発生するが、植物は成長過程で CO_2 を吸収するのでこの場合には排出がゼロとカウントされる。しかしこの排出される CO_2 を捕捉してこれを地中に貯留するとその分はマイナス排出とカウントされる。これが BECCS がマイナス排出にカウントされる理由である。

実現しようというものである（以下これらマイナス排出を Negative Emissions、NE と呼ぶ）。2050 年の CCS および BECCS 合計は 2017 年の総排出量の 35%、BECCS だけでも 10%にも達する（図 1）。

以上はイギリスの話であるが世界レベルではどうか。IPCC の 1.5℃シナリオの最大の特徴は BECCS を中心に大量の NE に依存している点である。国際エネルギー機関（IEA）の分析では IPCC の 90 のシナリオのうち 88 が BECCS に依存し、2050 年時点での BECCS の中央値（Median）は 4.7Gt[2]である。他方、IEA の中心的シナリオは「持続可能シナリオ（SD シナリオ）」で、これは 2050 年ではなく 2070 年 CO_2 ネットゼロを目指したものであるが、このほかイノベーションが更に進む 2050 年ネットゼロのシナリオも提示している。後者の場合 2050 年には CCS は約 8Gt、うち NE が 3.3Gt 程度（うち BECCS 約 3Gt）となっている。BECCS は IPCC1.5℃シナリオよりは少ないとはいえ、CCS 及び BECCS 合計で本年のエネルギー起源 CO_2 排出量の 1/4 と大きな割合占めている[3]。以上から大量の CCS 及び BECCS に依存しない限り 2050 年ネットゼロはあり得ないことが分かる。

2. 2050 年ネットゼロ達成に向けてのその他の対策

上記の通りかなりの量の BECCS への依拠が必須と言うことは CO_2 及びその他 GHG の排出をどうしてもゼロに出来ないからである。これはなぜか。先ずイギリスだが、発電、運輸、産業、建物に絞って述べる。発電部門は電化による需要増に対処しつつ風力・太陽光の発電割合を 57%に増やし、これに原子力、CCS つきガスで排出をほぼゼロにすると共に、BECCS によりマイナス排出とする。陸運部門は乗用車と軽トラは 100%電気、大型トラックは電気と水素で 2050 年には 2017 年の 120Mt から 2Mt に減らす。この為には 2035 年以降乗用車の新車は全て電気自動車にし、EV 用には約 2.5 万の充電設備を設置する。次に航空だが、一部をバイオ燃料で代替する以外に手は無く、残留排出量が 31Mt となる。海運は水素（アンモニア）で大幅減が可能、産業部門は水素、電化、バイオ燃料、それに CCS で 10Mt まで削減する。建物からの暖房に関わる直接排出 85Mt 分はヒートポンプ、ガスから水素への転換等で残留排出量を 4Mt にまで減らす。これ以外に肉食の減や飛行機での移動回避などのライフスタイルの変化で減らし、どうしても残る排出は BECCS を主とする NE で相殺してネットゼロとするシナリオで、2050 年のコストは GDP の 1～2%としている（イギリスの CCS および BECCS 依存量は図 1 参照）。

次に IEA では上述の SD シナリオについて 800 の技術を対象に世界の CO_2 削減についての詳細な分析を行っている。ここでは省エネ・再エネは当然とし、これに加えて電化、CCUS（炭素捕捉・利用・貯留）、水素、バイオエネルギーが鍵となるとしている。その上で技術を概念（リチウムエアー蓄電池等）、初期プロトタイプ（バッテリー飛行機等）、プロトタイプ（アンモニア船、DAC 等）、実証（脱炭素電気による電解水素由来アンモニア等）、初期市場化（洋上風力、ヒートポンプ等）、成熟（水力、電車等）の 6 段階に分け、これらを上記の重点分野に適用し、その結果としての 2070 年の部門別残留排出量を試算している。それによると産業部門（鉄鋼・セメント）、運輸部門（海運・空運・大型トラック）、建物部門で 3Gt 程度排出量が残り、これを発電部門とエネルギー変換部門での BECCS 及び少量の DACS で相殺してネッ

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[2] IEA World Energy Outlook 2019 p.124

[3] IEA Energy Technology Perspective 2020、第 6 章。なお、IEA ではエネルギー関連 CO_2 のみを分析対象としているので、植林や森林破壊による CO_2 吸収・排出は含まない点に留意が必要。

トゼロを達成としている。なお、IEA では 2050 年までにネットゼロ達成のシナリオも参考として示しているが、SD シナリオに比べてネットゼロ達成を 20 年間繰り上げることによる追加努力を例示したのが表 1 である。

表 1　IEA2050 年ネットゼロ実現（SD シナリオとの比較：例示）

- 現在プロトタイプ段階の技術は従来の成功例以上の速さで市場に出回り、たった一つの商業ベースの実例があれば市場が拡大すると仮定
- 前例のないスピードでのイノベーションが必須。例えば水素による鉄鋼生産、海運用の電解水素由来のアンモニア燃料、セメント生産でのCCSのような現在実証段階或いはプロトタイプ段階の技術が遅くとも今後6年以内に市場に登場しなければならない
- 実験室段階やsmall prototypeな技術は今後平均10年以内に使用可能となっていなければならない。これまでの例ではLEDが唯一成功例
- 発電部門は2050年までにSDシナリオ対比で20000TWhの発電量増加が必要。これは2050年の中国とインドの合計発電量にあたる
- 2050年まで毎年770GWの再エネ容量増加が必要（SDシナリオの5割増）

出典：IEA Energy Technology Perspective 2020 第 6 章から筆者作成

3.　2050 年地球規模のネットゼロは可能か

この点の検討には①イノベーションの速度、②既存設備からの排出、③NE の可能性の 3 つの観点が必要である。このうち①は表 1 から極めて厳しいことが分かる。

②の最大の問題は中国である。CO_2 の長期滞留性から累計 CO_2 排出量と気温上昇はほぼ正比例の関係にある。このことから工業化以降の気温上昇を例えば 2℃或いは 1.5℃に抑えるための累計排出量が計算できる。この量から過去の排出量を差し引いたものが当該気温上昇限度に抑える排出上限（炭素予算）となる。IPCC/SR1.5 では 1.5℃（2050 年ネットゼロに相当）の場合の炭素予算は 420～580Gt とあるが、学術誌 Nature に掲載された論文 [4]では途上国、特に中国を中心に近年の石炭火力等建設及び近未来の建設予定が特に多く、世界中のこうした設備が寿命まで稼働すると今後の排出量は 846Gt と炭素予算を超えてしまう。従って 2050 年ネットゼロの可能性は中国等のこうした火力発電所に CCS を付帯させることが出来るか、或いはこうした設備を寿命前に破棄させることが可能かにかかっている。

③の NE であるがこのうち最大のものは BECCS で、ここでの主たる問題点は種の多様性への悪影響、バイオ燃料育成のための土地、食糧生産との競合等で、このうち必要とする土地の面積については IEA の CCUS に関する特別報告に 1Mt の BECCS に必要な面積が出ており [5]、これに IEA の 3Gt を乗じると 300～5100Mha、IPCC の中央値 4.7Gt を乗じると 470～8000Mha となる。前者はアメリカの面積の 33%～5.5 倍、後者は 50%～8.7 倍、大きい方の数字は農業や森林残渣での計算、小さい方はエネルギー用作物と思われるが、ちょっと想像しがたい数値で

4 Tong et al. Committed emissions from existing energy infrastructure jeopardize 1.5℃ climate target , Nature 572, 15, Aug. 2019, 373-377

5 IEA Energy Technology Perspectives 2020, Special Report on Carbon Capture Utilization and Storage, CCUS in clean energy transitions, p.87

ある。

以上 3 つの観点から世界レベルでの 2050 年ゼロについての筆者の判断は「不可能とは言わないまでも極めて困難」というものである。

執筆者紹介

山口　光恒（やまぐち みつつね）

1999年東京海上火災保険株式会社を退社後（役員待遇理事）、慶應義塾大学経済学部教授、東京大学先端科学技術研究センター特任教授等を歴任、2012年4月から現職。気候変動に関する政府間パネル（IPCC）第3作業部会リードオーサー、第5次IPCC報告書国内連絡会座長代理等、気候変動・環境問題にかかる審議会・委員会委員を多数歴任。

What is Energy in the Age of Zero Emissions?

Yukari Yamashita*

2020 has been a turbulent year for society, for the economy and for energy. The spread of the Corona virus has dealt a serious blow to the world economy causing energy consumption to decline sharply with a direct hit to the oil and gas industry. The competing views between Saudi Arabia and Russia at the start of the year regarding the impact of COVID-19, caused sufficient turmoil in the crude oil market for prices to plunge further down in early spring. Since then, the corona pandemic continued its spread and countries have been struggling to find a way to economic recovery. The sudden appearance of this new uncertainty has had huge impacts on individual health and life anxiety which are more direct and tangible than the familiar public concerns over climate change.

In this paper, last year, I wrote that a major structural change in the energy system was emerging but I was not expecting the pandemic to further push the energy transformation. In Japan and Asia, it had been viewed until 2020 that the energy transformation was strongly influenced by Europe's commitments and by the financial community demonstrating an increased seriousness for decarbonization. Since the arrival of COVID-19, all this is happening with a sense of increasing swirling speed, as if caught in the rapids.

For example, Prime Minister Suga recently announced Japan's intent of aiming at net carbon neutrality, the Chinese President Xi made a declaration of decarbonization and the US President-Elect Joe Biden is perceived for the moment as an additional runner in the decarbonization race.

This is clearly the beginning of the era of zero emissions. **Is it possible to achieve zero emissions by 2050** with only renewable energy and nuclear power that can be considered as clean energy? At the IEEJ/APERC symposium 2020, we asked U.S. experts this simple question.

The Current Situation: The Corona Virus, and Energy-Environmental Policy

In 2020, the disaster caused by the corona virus introduced a sense of impasse in our economic and social life, and its impact on the economy spread beyond people's expectations. The intensity of its effects within the different forms of energy was divided.

In each country, lockdowns and bans on mobility were imposed to limit the damage caused by the pandemic. The economic and social impacts rapidly spread through the value chain from industries such as food and beverage, retail trade, as well as transport industries such as aviation and railways, to other industries such as manufacturing, agriculture and fisheries. Issues of employment and income rapidly developed. Regarding energy, as shown in Fig. 1, the largest negative impact hit oil because of banned or restricted transport. In addition to that, the impact of

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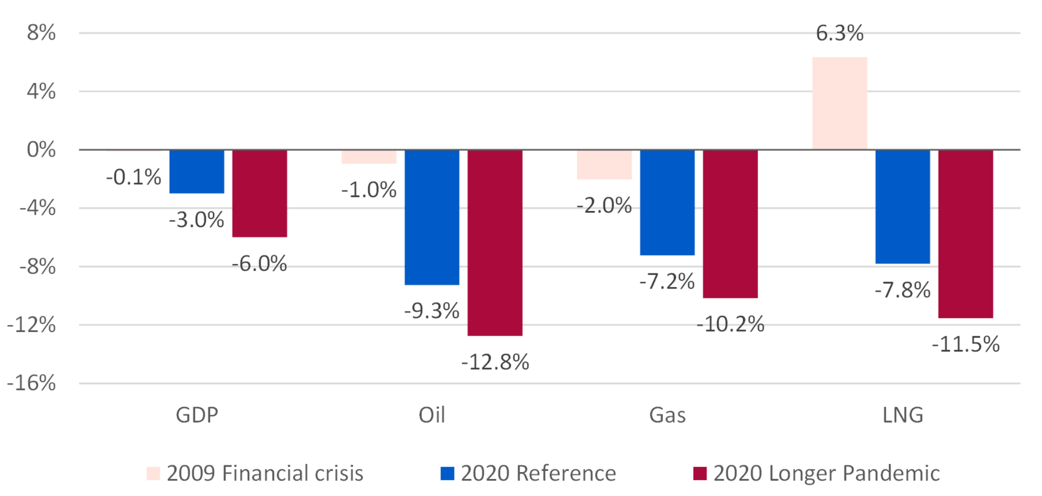
the economic slowdown negatively affected natural gas and LNG demand, resulting in a large market oversupply creating pressures for lower international energy prices.

Fig. 1 Global GDP and Energy Consumption y/y 2020



Source: S. Suehiro and K. Koyama, "A Study on the Impact of "City-wide Lockdown" on Global Energy Demand", and others

Policies in Europe that combined economic recovery stimulus with climate change countermeasures, such as green recovery in the EU and sustainable recovery suggested by the IEA, attracted lots of attention. Climate change countermeasures were quickly recognized as an essential part of the important agenda of combating the global economic slowdown. However, due to differences in energy supply and demand structures and industrial structures, the country's responses are not uniform.

As a result to the pandemic, CO_2 emissions are expected to decline significantly in 2020. The rate of decline is almost the same as the CO_2 reduction rate that would be required "every year" to achieve the two-degrees target by 2050, giving the impression that the possibility of achieving the target has increased. In reality, though, if you look at the power generation sector, many countries have fossil fuel facilities that would be considered extremely difficult to replace with renewable energy and nuclear power alone, while meeting the increasing demand for electricity in the future. Other rising issues include meeting thermal demand for industry, electrification of transportation fuels, and conversion to non-fossil fuels. In particular, the emerging economies in Asia, Africa, and Latin America, where economic growth and energy consumption are expected to increase in the future, would find it difficult to decarbonize without the full cooperation of the international community.

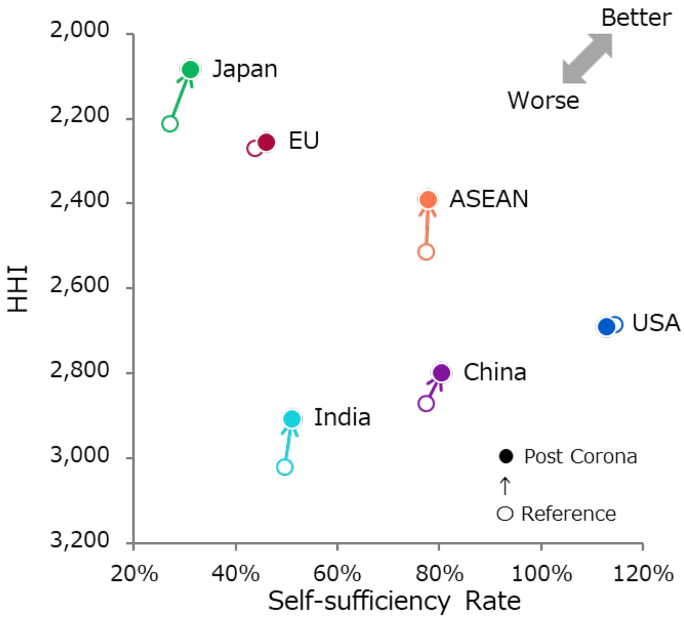
Against this backdrop, a series of decarbonization declarations took place around the world. The magnitude and sudden disappearance of energy demand caused by the pandemic may have induced such trend. The impact of lower demand hit hard the international energy companies and energy producers, which have also been under pressure from the financial community. Emphasis on ESG investments in recent years, and the deterioration of the investment environment caused by the Corona pandemic accelerated the movement or conversion from business models centered on fossil fuels towards decarbonization.

Challenges for Decarbonization in Asia

Last year's symposium took up the subject of energy transformation and pointed out the different sentiments between Europe, the United States, Asia, and other countries towards global warming countermeasures (especially decarbonization). Even with the Corona pandemic, the uncertainties and unpredictability associated with climate change remain high, and long-term investments still have difficulties in attracting funding. And yet, political declarations toward decarbonization continue amid prolonged economic losses and increasing uncertainties caused by the pandemic. This is due to the belief that climate change countermeasures can drastically contribute to the economic recovery, as symbolized by the green recovery in Europe.

In IEEJ Outlook 2021, we depict a scenario where structural changes in economic and social conditions, caused by the pandemic, are prolonged. In the scenario, through a scenario planning exercise, experts identified "emphasis on security" and "progress of digitization" as important elements that bring about structural changes resulting from the disaster. The emphasis on energy security will lead to diversification of energy sources in Asian countries and a shift toward indigenous resources (improving self-sufficiency rates). As shown in Fig. 2 and compared to the reference scenario, the self-sufficiency rate increases and the diversification of energy sources in each country progresses (moves towards the upper right corner). Advances in digitalization will encourage an increase in demand for electricity, therefore, securing clean power supplies will

Fig. 2 Changes in Self-Sufficiency Rate and Primary Energy Consumption Composition in Post-Corona World Transformation Scenario



Source: Institute of Energy Economics, Japan, IEEJ Outlook 2021, (October 2020) become an increasing challenge.

One of the major differences between European and Asian countries is that many Asian countries do not yet have electricity or gas connected by transmission lines or pipelines with surrounding countries. Each country will consequently introduce measures according to its energy supply and demand structure. A drive to use domestic energy sources has the potential to intensify not only the use of renewable energy but also the use of coal which is abundant. All means of decarbonization in Asia, including carbon capture, storage, use and sink, are essential.

In September 2020, the Chinese government declared decarbonization by “as early as 2060”. China’s economic recovery is ahead of other countries, but as the difficulties of transportation and trade increase, its function as the world’s factory is shifting to Southeast Asia and India. It seems as if China had an intention to lead the global society while positioning climate change countermeasures as a trigger for future economic growth in China. Decarbonization, which is a challenge to be met by 2050, has become increasingly important also for an industrial policy of gaining supremacy through science and technology and industrial technology in each country.

Last October, Japan’s Prime Minister Yoshihide Suga announced carbon neutrality by 2050. Carbon neutrality target is expected to strengthen Japan’s industrial policies, including decarbonization and development of innovative technologies.

Weight of Technological Development

The key to achieve sustainable economic growth while addressing climate change towards 2050, or the end of this century, depends whether innovative technologies will be utilized in the future. As announced in January 2020, the Cabinet Office’s “Environment Innovation Strategy” is a long-term growth strategy, which has been developed to be in compliance with the Paris Agreement. The Strategy advocates the development of innovative technologies to reduce greenhouse gas emissions not only in Japan but also around the world. Under 16 research themes, 39 technologies for decarbonization, including hydrogen and carbon recycling technologies, are considered in addition to clean energy, such as nuclear power and renewable energy or storage batteries.

Hydrogen has been of increasing interest in Europe and the United States for several years. A series of energy-related international conferences held in Japan in the fall of 2020 focused on technologies that will be fundamental to future energy use. Many ministers and CEOs, [1] demonstrated a high level of international interest in this field. In Europe, hydrogen could be produced from renewable energy while in Asia, hydrogen may be produced from a combination of fossil fuels and CCS.

Saudi Arabia, this year’s G20 presidency, is advocating the concept of “carbon circular economy”. By applying the principles of a circular economy to carbon, it is possible to focus on technologies and processes that utilize carbon dioxide removed during fossil fuels combustion (CCU) in manufacturing processes and others. It is an effort to define the principles of a circular

[1] ICEF, Hydrogen Ministerial Meeting, Carbon Circular Economy Council, etc.

economy as a comprehensive concept that would accelerate the technological development and social implementation internationally. The 4 main areas are presented in Table 1. A series of fossil fuel decarbonization technologies is important in Asia, where short-term energy transformation with only renewable and nuclear is difficult.

Table 1 Major "4R" Technologies in the Carbon Circular Economy

Reduce	Reuse	Recycle	Remove
Reducing the amount of carbon entering the system	Reusing carbon without chemical conversion	Recycling carbon with chemical conversion	Removing carbon from the system
• Energy and materials efficiency • Renewable energy, including hybrid use with fossil fuel • Nuclear energy, including hybrid use with fossil fuel • Advanced ultra-super-critical technologies for coal power plants • Hydrogen (blue/green) fuel cells for long-distance heavy-duty vehicles • Ammonia produced from zero-carbon hydrogen (blue/green) for power generation and ships • Direct reduction in steel making by using CO_2 free hydrogen (blue/green)	• Carbon capture and utilization (CCU) • Use CO_2 at carbon utilization facilities, such as at greenhouses for enhancing crops • Bio-jet fuels with reed beds • Algal synthesis	• CCU • Artificial photosynthesis • Bioenergy recycle in the pulp and paper industry • Bioenergy with carbon capture and storage • Carbamide (urea production using CO_2 as feedstock) • Coal ash concrete curing with absorbing CO_2 • Electrochemical reduction of CO_2 • Fine chemicals with innovative manufacturing processes and carbon recycling • Fischer-Tropsch exothermic of carbon dioxide with hydrogen syngas • Hydrogenation to formic acid • Oil sludge pyrolysis • Sabatier synthesis (CO_2 methanation: exothermic of carbon dioxide with blue/green hydrogen) • Thermal pyrolysis	• CCS • Direct air capture (DAC) • Carbon dioxide removal • Fossil fuels-based blue hydrogen

Source : Mansouri, N. Y. *et al.*(2020) "A Carbon Management System of Innovation: Towards a Circular Carbon Economy"

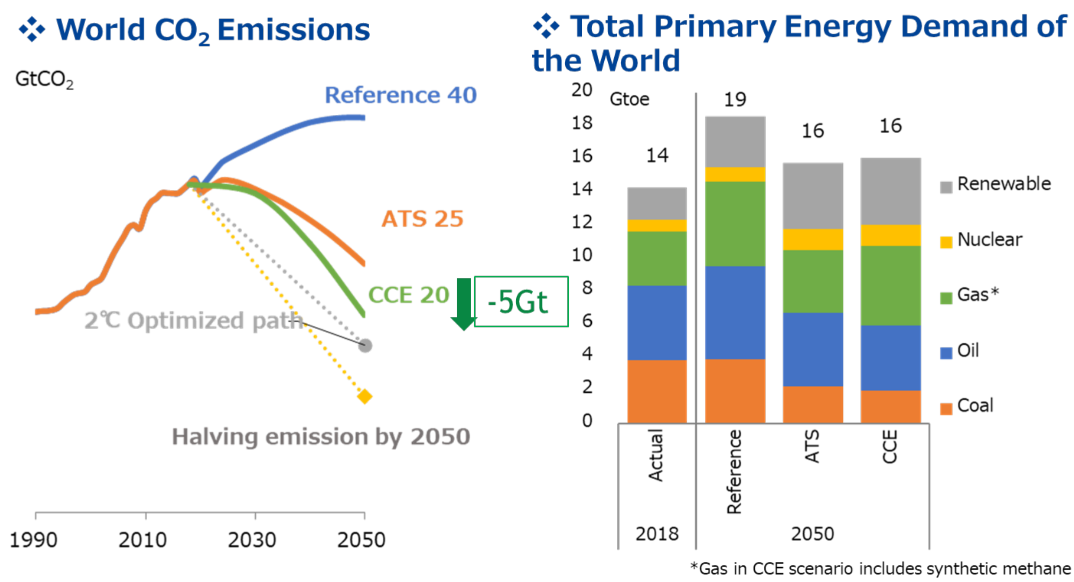
IEEJ Outlook 2021 compares the CO_2 emissions and primary energy demand results of various scenarios (Fig. 3). In the Carbon Circular Economy (CCE) scenario, carbon recycling technologies are significantly introduced in addition to those already assumed in the Advanced Technology Scenario. The CCE scenario will reduce CO_2 emissions by an additional 5 Gt when compared to the Advanced Technology Scenario, in which maximum technological innovation and environmental measures are taken. However, the total amount of primary energy demand will not change significantly.[2] The introduction of decarbonization technologies could significantly reduce CO_2 emissions without drastically changing fossil fuel consumption. Looking at the breakdown within the fossil fuels, increase in the blue hydrogen (hydrogen with CCS) produced from natural gas induced a shift from coal and oil to natural gas. CO_2 emissions will not halve by 2050, therefore, achieving carbon neutrality will require further reductions in technology costs, energy savings, and early additional reductions through the introduction and adoption of innovative technologies.

Our estimates show that hydrogen offers large potential for decarbonization. It is because carbon-free hydrogen, which is under the "Remove" category, has already reached the stage of demonstration and assumed to be promoted ahead of the other 3Rs. However, carbon-free hydrogen and/or ammonia remain imported energy for the Asian energy-consuming countries, including

[2] In fact, the additional conversion demand by 4R technology is expected to increase primary demand a little from the Advanced Technology Scenario and such additional demand could be bigger than this estimate.

Japan. Further developments of technologies under the "Reuse" and "Recycle" categories which are technologies to reduce CO_2 emissions, by utilizing CO_2, domestically, is awaited.

Fig. 3 CO_2 Emissions and Primary Energy Demand in Three Scenarios



Source: Institute of Energy Economics, Japan, IEEJ Outlook 2021 (October 2020)

Summary

Is it possible to achieve zero emissions by 2050 with only clean energies, such as renewable energy and nuclear power? All speakers at the Symposium remarked that it would be difficult because we must not forget the challenge of how to supply available energy economically and cleanly to the additional population of 2 billion people expected by 2050 and the one billion currently in developing and emerging countries that does not yet have energy access. In the development of decarbonization technology, it is important for various countries and companies to cooperate and compete. It is also important to secure a diverse supply of clean energy while lowering costs.

Writer's Profile

Yukari Yamashita

Ms. Yamashita is responsible for quantitative and qualitative analyses on energy policy issues. In the aftermath of the tsunami and nuclear incident, her team's analyses and recommendations contributed greatly to the electricity saving campaign and continue to this day to contribute to the debate regarding a national energy mix for Japan. She has been serving as a member of various government councils and committees in the fields of energy and science & technologies. She has been leading miscellaneous international and regional programs in the area of energy cooperation through IEA, APEC, ERIA and IPEEC. She served as a President of the International Association for Energy Economics in 2020 and serves as an Executive Vice President for 2021.

ゼロエミッション時代のエネルギーとは？

山下　ゆかり *

2020 年は経済・社会及びエネルギーにとって大激動の年であった。年明けのサウジアラビアとロシアのシェア競争による原油市場の混乱と急激なコロナ禍拡大による移動の激減や経済への打撃から春先に原油価格が急落し、石油・ガス産業を直撃した。その後コロナ禍は拡大の一途を辿り、各国は景気回復の糸口すらつかめない状況が続いている。気候変動よりも身近で、個々人の健康や生活不安という直接的な影響の大きい新たな不確実性の登場である。

昨年の本稿でエネルギーシステムの大構造変化が起きていると書いたが、疫病がさらにエネルギー変革（Energy Transformation）を後押ししたのは想定外であった。日本やアジアにおいてはあくまでも欧州と金融界リードの印象の強いエネルギー変革であるが、急流に巻き込まれるかのようなスピード感で、脱炭素化への真剣度が増した一年でもあった。

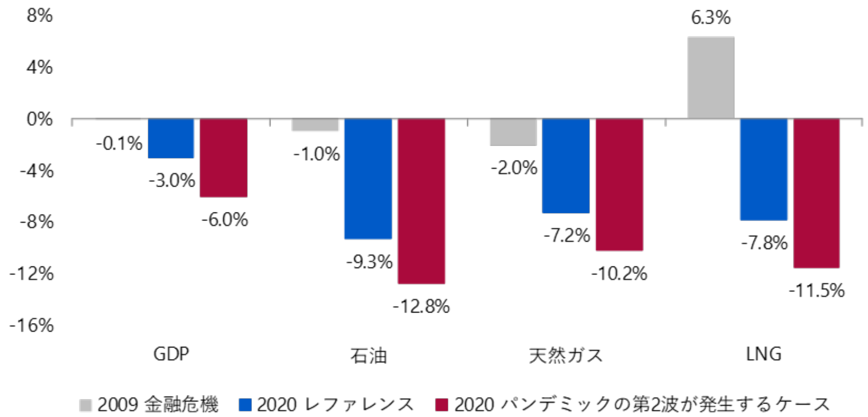
菅首相による所信表明演説や中国の習国家主席による脱炭素化宣言で日本や中国も脱炭素化を目指すメンバーとなり、米国においても民主党バイデン前副大統領の大統領選勝利は脱炭素化レースへの参戦を示唆するものとして受け取られた。

こうしてゼロエミッション時代の幕開けとなったが、果たしてクリーンなエネルギーである再生可能エネルギーと原子力だけで 2050 年までにゼロエミッション達成は可能なのか？という素朴な疑問を今回の IEEJ/APERC シンポジウムでは米国の専門家にぶつけた。

【現状認識：コロナ禍とエネルギー・環境政策】

足元の 2020 年はコロナ禍による急速な経済・社会生活の閉塞感が増し、経済への打撃は人々の予想を超えて広がった。エネルギー産業においてはその影響の濃淡が分かれた。

図 1　世界の GDP および各エネルギー消費の前年比（2020 年）



出所：末広、小山「「都市封鎖」による世界のエネルギー需要への影響に関する一考察」」他

* （一財）日本エネルギー経済研究所　常務理事　計量分析ユニット担任

各国でコロナ禍を抑え込むための都市部の封鎖（ロックダウン）や移動禁止措置がとられたが、その経済・社会への影響は飲食業や小売業、航空・鉄道などの交通機関を中心とした第三次産業から、バリューチェーンを通じて製造業、農林水産業等まで多方面に渡り、急速に雇用・収入問題が深刻化した。エネルギーでは図 1 に示した 2020 年春の短期推計にあるように、移動が制限されたことによる石油への打撃が最も大きいが、経済減速の影響は天然ガス・LNG 需要にも及び、市場における大規模な供給過剰と国際エネルギー価格への低下圧力を生じた。

EU のグリーンリカバリー、IEA のサステナブルリカバリー等、欧州における景気対策と気候変動対策を組み合わせた政策誘導が注目を集めた。世界的な景気減速の中でも気候変動対策は重要なアジェンダとして認識された。但し、エネルギー需給構造や産業構造などの違いから、各国の対応は一様ではない。

以上から 2020 年の CO_2 排出量は大きな減少が見込まれている。その減少率は 2050 年までの２度目標達成に今後毎年必要とされる CO_2 削減率とほぼ同じであり、あたかも目標達成への可能性が高まったかのような印象を与えるが、実際には各国は多くの化石燃料設備を抱えており、発電部門だけを見ても、今後増大する電力需要を供給するためにそれらの設備を再生可能エネルギーと原子力だけで代替することは極めて困難だと考えられる。産業の熱需要や輸送用燃料の電化や非化石燃料への転換も課題である。特に今後の経済成長とエネルギー消費増加が見込まれるアジアやアフリカ、中南米の新興国は国際社会の協力なしに脱炭素化に向かうことが難しい。

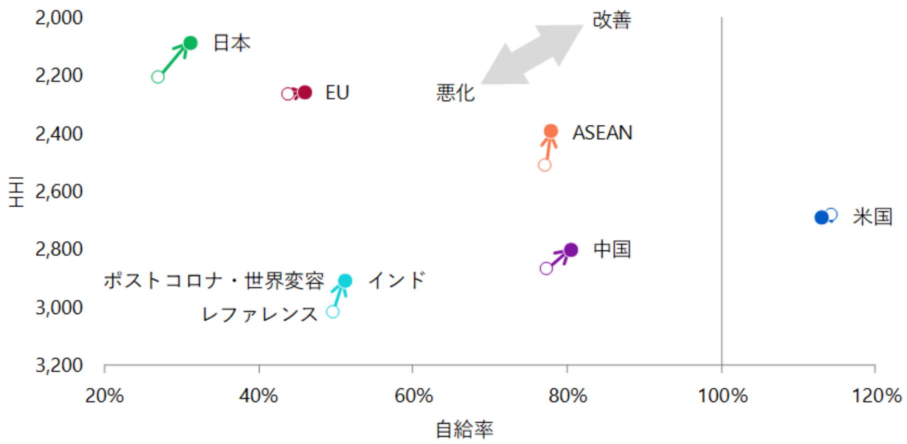
そのような中でも、脱炭素化宣言が続いた背景には、急激な需要の消滅が国際エネルギー企業やエネルギー産出国に与えた打撃の大きさがある。各企業はこの数年 ESG 投資を重視する金融界からの圧力も受けており、コロナ禍による投資環境悪化は化石燃料を中心としたビジネスモデルからの転換に向けた動きを加速化し、脱炭素化を後押しした。

【アジアにおける脱炭素化に向けた課題】

昨年の本シンポジウムではエネルギー変革を取り上げたが、欧州と米国そしてアジア等での温暖化対策、特に脱炭素化への温度差を指摘した。コロナ禍の下、気候変動対策において不確実性や不透明性が高く、回収が長期にわたる投資ができない環境には変わりがない。他方、コロナ禍による経済への打撃が長引き、さらなる不確実性が増す中で、脱炭素化に向けた政治的な宣言が続いている。この背景には、欧州のグリーンリカバリーに象徴されるように、大幅に悪化した経済の回復策として気候変動対策を位置づける傾向がみられる。

IEEJ アウトルック 2021 ではコロナ禍によって経済・社会に生じた構造変化が長期化するシナリオを描いた。専門家によるシナリオプランニングではコロナ禍による構造変化をもたらす要素として「安全保障の重視」と「デジタル化の進展」を抽出した。エネルギー安全保障の重視によってアジア諸国におけるエネルギー源の多様化や自国資源へのシフト（自給率の向上）が進む。図 2 に示したように、レファレンスシナリオと比較して、各国の自給率増加とエネルギー源の多様化が進み、図の右上に動く。デジタル化の進展は電力需要の増大を促し、クリーンな電源の確保が課題となる。

図 2　ポストコロナ・世界変容シナリオにおける自給率と一次エネルギー消費構成の変化



出所：日本エネルギー経済研究所「IEEJ アウトルック 2021」（2020 年 10 月）

欧州とアジア諸国の大きな違いは、アジア諸国の多くは電力やガスが周辺国との送電線やパイプラインで繋がっておらず、各国がそれぞれのエネルギー需給構造応じた対策をする点にある。自国産エネルギーシフトは自然エネルギーだけでなく、豊富に賦存する石炭利用を継続させる可能性を持つ。アジアにおける脱炭素化には炭素回収や炭素吸収源の拡大を含む全ての手段が必須である。

中国政府は 2020 年 9 月に 2060 年までの早い時期での脱炭素化を宣言した。国際社会をリードしたいという思惑も見え隠れするが、中国の経済回復は他国に先んじているものの、移動や貿易の困難度が増大する中で、世界の工場としての機能は東南アジアやインドに移りつつあり、今後の経済成長の起爆剤として気候変動対策を位置づけた印象がある。2050 年に向けた課題である脱炭素化は各国の科学技術や産業技術による覇権獲得という産業政策として重要度を増す。日本においても 10 月の菅首相による 2050 年までのカーボンニュートラル達成宣言によって脱炭素化と技術開発を含む産業政策の強化が期待される。

【技術開発の重み】

2050 年あるいは今世紀末に向けて気候変動対策をとりつつ持続可能な成長を続けるには、これから開発される革新的技術をも活用できるかどうかが極めて重要な鍵となる。

内閣府の「革新的環境イノベーション戦略」（2020 年 1 月発表）はパリ協定に基づく長期的な成長戦略として国内だけでなく世界における温室効果ガスの排出削減に寄与する革新的技術の開発を謳う。原子力や再生可能エネルギーなどのクリーンエネルギーや蓄電池に加えて、水素やカーボンリサイクル技術等、脱炭素化に向けた 16 課題 39 の技術を課題にする。

水素については数年前から欧米でも関心が高まっている。2020 年秋に日本で開催された一連のエネルギー関連の国際会議 [1]は今後のエネルギー利用の中心となる技術をテーマとし、多くの閣僚や CEO 等の参加を得て、国際的なこの分野への関心の高さを示した。欧州では再生可能エネルギーからの水素、アジアでは化石燃料と CCS 利用による水素を念頭においた水素利用が進められる。

[1] ICEF、水素閣僚会議、炭素循環経済会議等

炭素循環経済は、今年の G20 議長国であるサウジアラビアが提唱する新たな概念である。循環型経済の考え方を炭素にも応用し、化石燃料の燃焼時に取り出した二酸化炭素をプロセスなどで活用する CCU 関連の技術に着目した。研究開発や利用強化等、より包括的な概念として整理することで国際的に技術開発と社会実装を加速化しようとする取り組みである。表 1 に主な技術を整理した。一連の化石燃料の脱炭素化技術は、短期的な再生可能エネルギーや原子力によるエネルギー変革が困難なアジアにおいて重要である。

表 1　炭素循環経済における主な「4 R」技術

炭素循環経済における主な「4R」技術

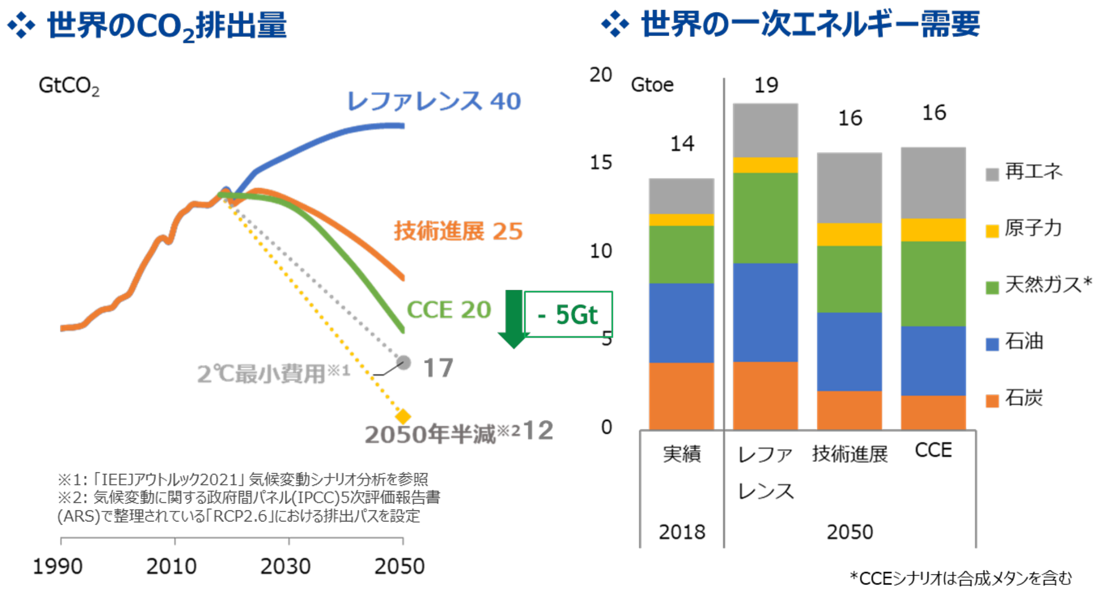
4Rの種類	削減（Reduce）	再利用（Reuse）	再循環（Recycle）	除去（Remove）
内容	大気中に排出されるCO_2の量を削減	大気中から回収したCO_2を化学変化を加えない形で別の用途に利用	大気中から回収したCO_2を化学変化を加えた形でほか別の用途に利用	大気中のCO_2を回収して除去
主な技術	● 省エネルギーの推進 ● 再生可能エネルギーの導入促進 ● 原子力の導入促進 ● 先進超々臨界圧石炭火力の活用 ● 燃料電池車の導入促進 ● 水素発電 ● アンモニアを発電用燃料や船舶用燃料として利用 ● 石炭灰等の混和材を用いたセメント生産量削減 ● 水素を用いた還元製鉄プロセス	● 回収したCO_2を用いた油田の増進回収法(Enhanced Oil Recovery: EOR) ● CO_2濃度を高めたグリーンハウスにおける農産物栽培 ● 回収されたCO_2を活用した藻類系バイオ燃料 ● 葦を原料とするジェット燃料の生産	● 回収したCO_2をコンクリートに吸着させる技術 ● 回収したCO_2を炭酸塩として固定 ● 回収したCO_2と水素を原料とした合成液体燃料の生産 ● 回収したCO_2と水素を原料とした合成メタンの生産 ● 回収したCO_2と水素を原料とした化学原料の生産	● 炭素回収・貯留（CCS） ● 二酸化炭素直接吸収（Direct Air Capture：DAC）によるCO_2の回収

出所：Mansouri, N. Y. *et al.*(2020) "A Carbon Management System of Innovation: Towards a Circular Carbon Economy"を基に作成

図 3 で IEEJ アウトルック 2021 から各種のシナリオの CO_2 排出量と一次エネルギー需要を比較した。最大限の技術革新や環境対策がとられる技術進展シナリオに加えてカーボンリサイクル技術が大幅に導入される「炭素循環経済（CCE）」シナリオでは、CO_2 排出量が追加的に 5 Gt 削減されるが、一次エネルギー需要総量は大きく変わらない[2]。脱炭素化技術の導入で化石燃料消費を大きく変えることなしに CO_2 排出量を大幅削減する可能性が示される。化石燃料の内訳をみると、天然ガス由来のブルー水素（CCS 付き水素）の増加で、石炭・石油から天然ガスへのシフトが見られる。2050 年に排出量が半減する水準には届かず、カーボンニュートラルの達成にはさらなる技術コストの低減や省エネ、革新的技術の導入と普及の加速化による早期の削減追加が求められる。

[2] 実際には 4 R 技術による追加的な転換需要で技術進展シナリオよりやや増加すると見られ、本試算よりも多く追加的な転換需要が必要な可能性もある。

図 3　カーボンリサイクル技術導入シナリオの CO_2 排出量と一次エネルギー需要



出所：日本エネルギー経済研究所「IEEJ アウトルック 2021」（2020 年 10 月）

我々の試算では、４R のうち Remove に位置付けられるカーボンフリー水素の導入が先行することから、水素導入による脱炭素化の比重が大きい結果となっている。しかしながら、日本を含むアジアのエネルギー消費国にとってカーボンフリーの水素やアンモニアは輸入エネルギーであることに変わりなく、４つの R のうち自国で CO_2 を活用することによって削減する Reuse や Recycle 技術の開発が待たれる。

【まとめ】

クリーンなエネルギーである再生可能エネルギーと原子力だけで 2050 年までにゼロエミッション達成は可能なのか？という問いには、全ての登壇者から難しいという発言があった。これから生まれてくる 20 億人の将来世代といまだ十分なエネルギーアクセスのない途上国や新興国の人々が利用可能なエネルギーを如何に経済的にクリーンに供給するかという課題を忘れてはならない。脱炭素化技術の開発において、様々な国や企業が協力し、競争し、コストを下げつつ多様なクリーンエネルギーの供給を確保することが重要である。

執筆者紹介

山下　ゆかり（やました ゆかり）
震災後の停電回避や節電広報のための計量分析を担った他、我が国のエネルギーミックスの議論に資する各種分析で貢献。国際エネルギー機関（IEA）、APEC、ERIA、IPEECなど、エネルギー分野の国際協力で活躍し、国際会議等での講演・モデレーターの経験豊富。2020年国際エネルギー経済学会会長、2021年同エグゼクティブ・バイスプレジデント。2020年6月より現職。

2. Is Hydrocarbon the Enemy or Ally to Climate Change Countermeasures?

化石燃料は、気候変動対策の敵か、味方か？

Is Hydrocarbon the Enemy or Ally to Climate Change Countermeasures?

－What Should We Consider When Measures to Achieve Zero Emission Status are Key Factors?－

Hiroki Kudo*

Introduction

The focus of climate change policies is shifting from short to medium-term approaches to initiatives based on long-term targets. This has been indicated by the long-term target put into the Paris Agreement, requests for national strategies, high evaluation of the special report by the Intergovernmental Panel on Climate Change (IPCC), the United Nations' requests for each country's zero-emission initiatives, growing international opinion for the significance of long-term targets, and European, Chinese, and other offers to enhance initiatives to achieve specific long-term targets. As it is widely shared that substantial transition from existing systems and technological innovations would be indispensable for realizing a zero-emission society, desirable or potential future pictures of energy supply and demand and other sectors are being considered. The problem is what specific actions would be required to achieve zero emissions. Various views are identified about what energy would be required to realize decarbonization, whether fossil fuels should be restricted or used jointly with decarbonization technologies, and other questions about future pictures. If 2050 is set as the target year for achieving zero-carbon status, 30 years are left. What actions would be feasible to achieve zero-carbon status within 30 years should now be considered along with relevant economic and social impacts.

This paper discusses what zero-emission actions should be considered now, while touching on recent international trends regarding zero-emission actions and referring to views given by foreign experts at the International Energy Symposium[1] sponsored by the Institute of Energy Economics, Japan (IEEJ), and the Asia Pacific Energy Research Center (APERC) in September 2020.

Climate Change Policy Trends under COVID-19

While the COVID-19 pandemic is spreading throughout the world, major economies are considering how best to promote long-term initiatives to reduce greenhouse gas emissions. As the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change,

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1 5th IEEJ/APERC International Energy Symposium: "Energy Trilemma in the Post-Corona world -- Can Innovation and Soft Power be the Solutions?" September 18, 2020
https://eneken.ieej.or.jp/whatsnew_op/200918jointsympo.html

known as COP26, has been postponed until late 2021, the current situation is feared to lead priority to be lowered for climate change policies. Given growing discussions on Green Recovery initiatives to take advantage of climate change countermeasures for economic recovery, however, we see a momentum for promoting climate change countermeasures. These initiatives can be seen as moves designed to combine sustainable economic growth with environmental conservation using funds for climate change countermeasures, which may produce win-win effects. Such initiatives may be sustained for the immediate future.

Zero-emission Targets

On September 22, Chinese President Xi Jinping in his general speech at the United Nations stated that China would try to lead CO_2 emissions to peak by 2030 and achieve carbon neutral status by 2060, sending a strong message to the international community. The European Union is in final talks to agree on the enhancement of its 2030 emission reduction target and on the 2050 zero-emission target, acting as a driver of global moves towards zero emissions. After his inauguration, U.S. President-elect Joe Biden is expected to take procedures for the United States' comeback to the Paris Agreement and promote initiatives to implement campaign promises to (1) cut GHG emissions to zero in the United States by 2050, (2) achieve net zero GHG emissions in the power sector by 2035, and (3) invest $2 trillion (about JPY210 trillion) in four years to create jobs and achieve environmental justice. Japan's Prime Minister Yoshihide Suga in his policy address declared that Japan would cut GHG emissions to zero by 2050 or achieve carbon neutral status or a decarbonized society in 2050. Major economies are seemingly keeping step with each other in trying to achieve zero-emission status in 2050.

Zero-emission Actions and Fossil Fuels

While major economies declare decarbonization targets, specific energy choices to achieve a zero-emission society are attracting attention. Fossil fuels such as oil, coal, and gas supported global economic growth from the 19th century to the 20th century and still account for more than 80% of global primary energy consumption (as of 2018) even at a time when climate change policies are viewed as important. Given an assumption that the world's dependence on fossil fuels in 2050 will decrease only slightly from 2018 if present energy technologies and relevant policies are maintained with population growing in emerging market and developing economies, the world will have to break away from the past trends to achieve zero-emission status[2].

Given such situation, the second session of the IEEJ/APERC International Energy Symposium discussed how to handle fossil fuels in zero-emission actions under the title "Is Hydrocarbon the Enemy or Ally to Climate Change Countermeasures?" Foreign experts agree that each country should improve energy efficiency and promote renewable and low-carbon energies while

[2] Institute of Energy Economics, Japan, "IEEJ Outlook 2021－Energy Transition in the Post Corona World," 436th Forum on Research Work, October 16, 2020

recognizing that energy supply and demand conditions differ by country. Particularly important technologies in this respect include hydrogen, carbon capture, utilization, and storage (CCUS), bioenergy, and batteries. Initiatives to decarbonize and utilize existing infrastructure are also indispensable. While technology combinations and needs differ by region or country, all potential technologies should be mobilized to realize net zero-emission status. Regarding renewable energy that is expected to play a central role in decarbonization, fossil fuels should be used for energy system supply chains to some extent from the viewpoint of economic efficiency for the energy system. The so-called Circular Carbon Economy (CCE) approach to manage carbon emissions from the global energy mix has been suggested along with the 4Rs (Reduce, Reuse, Recycle, and Remove) approach that seeks to introduce a mechanism for assessing all decarbonization options from the 4Rs viewpoint and build a decarbonized society combining CCUS with fossil fuel use.

While it is generally pointed out that it is important to transition from fossil fuels to renewable energy and other zero-emission resources to achieve decarbonization, the feasibility of a decarbonization path in which fossil fuels would be used along with technologies that capture and/or utilize CO_2 such as CCUS is expected to be discussed for future zero-emission initiatives.

Japan's long-term strategy

At a meeting of the Growth Strategy Council on December 1, 2020, Japan compiled a draft growth strategy action plan[3] that gives specific initiatives of a growth strategy designed for recovering from the COVID-19 disaster. After Prime Minister Suga declared the 2050 zero-emission status target in his policy address in October 2020, the draft action plan includes a green growth strategy towards the 2050 carbon neutral status. It calls for considering specific fiscal and tax measures to support private enterprises to develop innovative technologies under national projects and for formulating a draft plan including specific target years for green initiatives within 2020.

Regarding technological development, the draft plan recognizes that existing technologies alone would not be enough to achieve carbon neutral status by 2050 and that innovative technology development would be indispensable. It identifies three priority technology areas – (1) electricity and green electricity (next-generation storage batteries, etc.), (2) hydrogen (technologies for massive hydrogen supply to decarbonize the heat and power sectors and for hydrogen use), (3) CO_2 capture and recycling (carbon recycling, biomass power generation with CO_2 capture/storage technology, etc.) and calls for enhancing government support for technological development. The draft action plan also indicates the directions of specific initiatives for hydrogen, automobile batteries, carbon recycling, offshore wind power generation, semiconductors, and information and communication technologies that are indispensable for achieving carbon neutral status, seeking to expand government-wide initiatives. It also suggests that relevant government organizations be united to formulate action plans for aircraft and ships, nuclear, solar photovoltaics, logistic systems, lifestyles, and other areas where the virtuous cycle of economy and environment is expected.

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3 https://www.cas.go.jp/jp/seisaku/seicho/pdf/jikkoukeikaku_set.pdf

In this way, the Japanese government has indicated an attitude of adopting European and other strategies to promote zero-emission actions as part of measures to recover from the COVID-19 disaster. Specific zero-emission actions include not only the further diffusion of renewable energy, energy efficiency improvement, and other existing technologies but also the utilization of all future technologies such as hydrogen and carbon recycling. This basic approach will be reflected in the new Strategic Energy Plan and the Global Warming Countermeasure Plan to be formulated in the future.

Conclusion

At a time when countries in the world are urgently required to take measures to recover from the COVID-19 disaster, Europe and Japan demonstrate an attitude of promoting funding for zero-emission technologies to resolve both economic and environmental challenges. Given that the United States is expected to consider a similar attitude under new President Biden from 2021, the international community is likely to sustain zero-emission actions. As it is difficult for existing technologies alone to achieve a zero-emission society, the feasibility of all potential technologies may be tested in the future. Particularly, major countries will consider their technology strategies meeting their respective conditions from the viewpoint of securing their industries' international competitiveness.

When global zero-emission status is considered, we must recognize that zero-emission technologies developed by competent major countries should be spread to other countries including developing economies. While the COVID-19 pandemic is assessed as leading the international community to be divided into blocs, international collaboration and cooperation may be indispensable for realizing global zero-emission status. At the abovementioned IEEJ/APERC international symposium, participants indicated that each country should advocate long-term policies to pave the way for enterprises to easily implement investment in zero-emission actions, that all countries in various conditions regarding fossil fuels should cooperate and share best practices, and that it is important whether the world could have a disciplined manner to transition to a decarbonized society benefitting the global economy.

While major countries are now considering actions to promote all potential technological innovations to achieve zero-emission status, it is expected that the international community develop a path to zero-emission status through cooperation.

Writer's Profile

Hiroki Kudo

Mr. Kudo has served as ISO/TC207/SC7/WG5 (ISO 14064-2: Guidance for the GHG project) Convener, ISO/TC17(Steel)/WG24(ISO 20915) Convener (Life Cycle Inventory Calculation Methodology for steel products), and a committee member/working group members related to climate change policy (including emissions trading scheme) and renewable energy policy organized by central and local governments. Former UNFCCC, The Joint Implementation Supervisory Committee (JISC) member. He is an expert in Global Warming, Energy Conservation and Renewable Energy Policy, Standardization for GHG related activities and Sustainable Finance (ISO).

化石燃料は、気候変動対策の敵か、味方か？
－ゼロエミッション達成手段が問われる今の局面に何を考えるべきか－

工藤　拓毅 *

はじめに

気候変動対策の主眼は、短期・中期的な視点から、長期的目標を見越した取り組みのあり方に移りつつある。これは、パリ協定において合意された長期目標と各国への戦略策定の要請に端を発し、IPCC による特別報告の評価、国連によるゼロエミッション化に向けた各国への働き掛け、長期目標の重要性に関する国際世論の高まり、そして欧州や中国等による具体的な長期目標達成に向けた取り組みを強化するという姿勢が顕在化していることにも顕れている。また、ゼロエミッション化の社会実現に向けては、既存のシステムの大幅な転換と技術革新の促進が不可欠であることが共有されており、エネルギー供給セクターやエネルギー需要セクターなど様々な分野において、将来的なあるべき姿やその可能性が検討されている。そこで問われるのは、ゼロエミッション化に向けて具体的にどういった取り組みが必要かである。脱炭素化を実現するための主力となるエネルギーは何か、化石燃料の利用は制限すべきか脱炭素化技術との組み合わせで活用すべきか等、将来像に関する様々な見方や見解が認められる。仮に 2050 年をゼロカーボンの目標年とした場合、残された時間は 30 年である。今考えなければならないのは、この期間内においてどういった取り組みが実現可能なのか、経済・社会的影響も加味してその方向性を定めることであろう。

本稿では、最近のゼロカーボン化に向けた国際的動向を確認しつつ、2020 年 9 月に開催された IEEJ/APERC 国際エネルギーシンポジウム [1]での海外専門家による見解を参照しながら、現時点で考えるべきゼロエミッション化に向けた取り組みのあり方について述べることにする。

コロナ禍における気候変動対策の動向

コロナ禍の拡大が世界大で継続する中で、主要国・地域では長期的な温室効果ガス（GHG）排出削減に向けた取り組みを促進する検討が進行している。2020 年末に開催される予定であった第 26 回気候変動枠組条約締約国会議（COP26）が翌年に延期されるなど、足下の諸情勢は気候変動対策の優先度を下げる可能性が考えられたものの、現下の景気減速への対応策に気候変動対策を組み込むグリーン・リカバリーという考え方が様々な場所で議論されるなど、気候変動対策をより前進させるというモメンタムが顕在化している。景気回復局面に向けた資金の流れを気候変動対策に向けることで、経済の持続的な成長と環境対策の両立を図るという win-win の効果を期待する動きとみることもでき、当面はこうした働きかけが継続することが考えられる。

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[1] 第 5 回 IEEJ/APERC 国際エネルギーシンポジウム －ポストコロナのエネルギー・トリレンマ：技術革新とソフトパワーは解決策となるのか？－、2020 年 9 月 18 日；
https://eneken.ieej.or.jp/whatsnew_op/200918jointsympo.html

ゼロエミッション目標

そうした中で、国連の一般演説（9 月 22 日）において習近平国家主席が「中国は、2030 年までに CO_2 排出量がピークに到達するよう努め、2060 年までに炭素中立を達成するよう努る」と演説したことは、国際社会に向け強いメッセージとなった。また EU は、2030 年目標の強化と加盟国の 2050 年ゼロエミッション目標への合意に向けた協議の最終段階になりつつあり、ゼロエミッション化に向けた牽引役とも映る。米国のバイデン次期大統領は、就任後にパリ協定の復帰手続きを行うことと共に、①2050 年に国全体の温室効果ガス排出実質ゼロ、②2035 年に電力分野の温室効果ガス排出実質ゼロ、③4 年間で 2 兆ドル（約 210 兆円）の投資による雇用創出および環境正義の達成、という公約の達成に向けた取り組みを進めることが予想される。日本の菅総理も所信表明演説で「2050 年までに、温室効果ガスの排出を全体としてゼロにする、すなわち 2050 年カーボンニュートラル、脱炭素社会の実現を目指す」ことを宣言するなど、主要国は 2050 年のゼロエミッション化に向けて足並みを揃えて取り組む様な姿勢を表明している。

ゼロエミッション化に向けた取り組みと化石燃料

主要国からの脱炭素化宣言が示される中で、次に注目されるのは具体的にどういったエネルギー選択により社会全体のゼロエミッション化を進めるのか、具体的な技術選択のあり方となる。19 世紀から 20 世紀にかけて世界の経済成長を支えてきたのは石油や石炭、ガスといった化石燃料であり、気候変動対策の重要性が指摘される現在（2018 年実績）でも、世界の一次エネルギー消費の 8 割以上が化石燃料に依存しているのが現実である。また、今後の新興国や途上国における人口の増加により、現状のエネルギー技術利用や関連する政策措置が継続すると想定した場合、2050 年断面における化石燃料への依存度は 2018 年に比べ微減に止まると考えられるため、ゼロエミッション化を実現するには過去のトレンドから脱却することが不可欠となる[2]。

そうした状況を鑑み、IEEJ/APERC 国際エネルギーシンポジウムの第 2 セッションでは、「化石燃料は、気候変動対策の敵か、味方か？」と題して、ゼロエミッション化に向けた取り組みの中で、特に化石燃料への対応のあり方が議論された。海外の有識者間で共通しているのは、国ごとにエネルギー需給構造が異なることを認識しながら、どの国もエネルギー効率を高め、再エネ・低炭素エネルギーの導入を促進する必要があるということである。その中で特に重要となる技術は、水素、CCUS、バイオエネルギー、バッテリー等であり、既存インフラを脱炭素化しながら活用する取り組みも欠かせない。技術の組み合わせや必要性の度合いなどは地域や国ごとに異なるが、あらゆる技術がネットゼロの世界を実現するためには必要であるということである。その中では、脱炭素化の中心になると目される再生可能エネルギーについても、エネルギーシステムのサプライチェーンで考えれば、システム全体での経済性の観点から一定の化石燃料利用が重要である。また、循環型炭素経済（The Circular Carbon Economy；CCE）という世界のエネルギーミックスにおける炭素排出量を管理する考え方が示され、4 つの R（Reduce, Reuse, Recycle, Remove）によってすべての脱炭素化に向けた選択肢を評価する仕組みを導入し、CCUS と化石燃料利用を組み合わせた脱炭素化社会の構築を目指すべきとの考え

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[2] （一財）日本エネルギー経済研究所、IEEJ アウトルック 2021 －ポストコロナのエネルギー変革－、第 436 回定例研究報告会、2020 年 10 月 16 日

方も示されていた。

一般的には、化石燃料から再生可能エネルギー等のゼロエミッション資源への転換によって脱炭素化を目指すことが重要との見方が多く示される中で、CCUS の様な炭素の固定化や利用という技術を活用して、化石燃料が一定の役割を果たすパスの実現可能性も、今後のゼロエミッション化に向けて、並行して議論されることが考えられる。

日本の長期戦略の検討状況

日本では、2020 年 12 月 1 日に開催された成長戦略会議において、日本の成長戦略の実行計画（案）[3]が取り纏められ、コロナ禍における経済影響からの復興も視野に入れた成長戦略における具体的な取り組みが示されている。同年 10 月の所信表明演説において、菅総理は 2050 年ゼロエミッション化を宣言したが、実行計画（案）では、2050 年のカーボンニュートラルに向けたグリーン成長戦略が盛り込まれている。革新的なイノベーションに取り組む民間企業に対して国家プロジェクトとして新たな技術開発を支援し、予算上や税制上の具体的支援を早急に検討する、あわせて、グリーン分野について年限目標を明示した具体的な計画案を 2020 年内に策定するとしている。

技術開発に関しては、2050 年のカーボンニュートラルを達成するには現存する技術だけでは不十分であり、革新的技術開発を促進することが不可欠であるとの認識が示されている。その上で、特に重点的に取り組むべき技術分野として、①電力＋電力のグリーン化（次世代蓄電池技術、など）、②水素（熱・電力分野等を脱炭素化するための水素大量供給・利用技術）、③CO_2 固定・再利用（カーボンリサイクル、CO_2 回収・貯留付バイオマス発電等）の 3 分野が特定化され、政府支援の強化による技術開発を促進するという姿勢が示されている。また、グリーン成長戦略の実行計画では、カーボンニュートラルを目指す上で不可欠な水素、自動車・蓄電池、カーボンリサイクル、洋上風力、半導体・情報通信に関する具体的な取り組みの方向性が示され、全政府的な取り組みを拡大するとしている。また、航空機や船舶、原子力、太陽光発電、物流システム、ライフスタイル等の経済と環境の好循環が期待される分野に関しても、関係省庁が一体となって実行計画を策定していくことが示されている。

この様に、コロナ禍による経済影響からの回帰策の一つとしてゼロエミッション化の促進を図るという欧州等が指向している戦略を日本も採用するという姿勢が示された。具体的なゼロエミッション化に向けた取り組みは、再生可能エネルギーや省エネルギーといった既存技術の更なる普及拡大を目指すだけではなく、水素やカーボンリサイクル等のあらゆる将来技術の活用が視野に入れられている。この基本的な考え方が、今後策定されるエネルギー基本計画や地球温暖化対策計画に反映されていくことになる。

おわりに

世界各国がコロナ禍による経済影響からの回復策の必要性に迫られる中で、欧州や日本は、ゼロエミッション実現に向けた技術等に対する資金の流れを促進することで、経済と環境的課題解決の両立を図る姿勢を示している。米国も、2021 年からはバイデン新大統領の下で、同様の取り組みが検討されることが考えられ、コロナ禍の影響下においても、国際社会におけるゼ

[3] https://www.cas.go.jp/jp/seisaku/seicho/pdf/jikkoukeikaku_set.pdf

ロエミッション化に向けた取り組みが継続していくことが予想される。そこでは、ゼロエミッション社会の実現は既存技術のみの対応では困難であり、今後、あらゆる技術の活用可能性が試みられていくことが考えられる。特に主要国では、自国産業の国際競争力確保の観点からも、それぞれの実情に応じた技術戦略が検討されていくであろう。

一方で、改めて世界全体でのゼロエミッション化を考えれば、能力のある主要国が開発したゼロエミッション化に貢献する技術を、発展途上国等の他の国々に普及させる必要性を認識する必要がある。コロナ禍は、国際社会のブロック化を誘発しているとの評価もある中で、世界大のゼロエミッション化の実現には、国際的な協調・連携が不可欠であろう。前述した IEEJ/APERC 国際シンポジウムでも、「国レベルで長期的な政策を掲げることで、必要な投資を企業が行いやすい環境を形成する」ことに加え、「国ごとに化石燃料の状況やその将来は異なる中で、各国間で協調しベストプラクティスを共有すること」が引き続き必要であり、「規律のとれた形で世界経済に恩恵をもたらす脱炭素化への移行ができるか」が重要という意見が示されていた。

現在の局面は、ゼロエミッション化の実現に向け、主要国があらゆる技術革新を促進する取り組みのあり方を検討している一方で、国際社会が協調してゼロエミッション化を実現するための道筋を構築できるのかが問われていると思われる。

執筆者紹介

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Is Hydrocarbon the Enemy or Ally to Climate Change Countermeasures?

～Unexpected Innovative Value of Fossil Fuels～

Joan MacNaughton*

Introduction

For the first time this year, International Petroleum Week in London featured a plenary session on climate change. As a speaker, I expected to be challenged on whether we needed to act immediately, if not on the need to act. But the C suite attendees were not on that page at all. Instead they discussed how they were going to reduce the emissions for which they were responsible – both from their own operations and from consumption of their products. The question therefore whether there is unexpected value in hydrocarbons to be unlocked by innovative technologies is highly topical. Is there enough potential value that companies can rely on modest evolution of their current business models, or must they drive on to more radical change?

The Context

To address this question, we must consider how quickly emissions must be reduced. Building on the original agreement at COP 21 in Paris to limit global temperature rise to 'well below 2 degrees', a report from the Intergovernmental Panel on Climate Change* warned of the dramatic risks inherent in the two degree goal amid mounting evidence of well nigh unmanageable impacts like wildfires, floods and other extreme events. The world took note. Policy is increasingly driving towards a 1.5 degrees goal, which requires 'net zero' GHG emissions by 2050, that is, a small residual level of emissions accompanied by emission removal measures. It is significant that the International Energy Agency has for the first time now published a scenario based on limiting global temperature rise to 1.5 degrees Celsius (World Energy Outlook for 2020**).

The UN Conference on Climate Change scheduled for November 2021 was originally centred on getting governments to ratchet up their commitments to deliver 'well below 2 degrees' but is now increasingly focused on the 1.5 degrees agenda. In line with this, some 24 national governments have announced commitments to 'net zero' before or by 2050 (or 2060, in the case of China); with the USA expected to join them. Non-state actors (states, regions and global corporates) have joined them.

* Chair of the Board, The Climate Group

The Implications for Future Demand for Hydrocarbons

Notwithstanding all this, some remain optimistic about the continued role of high emitting hydrocarbons because of how challenging it will be to phase them out. I would invite them to consider the case of coal, whose future is bleak. According to the IEA's World Energy Outlook 2020, the pandemic has catalysed a structural fall in global coal demand: falls in forecast demand in developed countries the USA and Europe outweigh growth in Asia. In the USA, some 100 GW of coal plants is forecast to retire by 2025 and there is not a single proposal for new build. This is notwithstanding President Trump's commitment to support the industry. Admittedly the fall has driven as much about coal to gas switching as replacement by renewable power generation. But lest the gas developers seize on this, they might want to note President Elect Biden's commitment to a zero carbon power generation system by 2035.

Consider investor attitudes. Global financing for coal projects has been excluded by many IFI's and large investors. Oil and gas projects now face the same fate: the UK announced at the recent Climate Action Summit*** that they would be ineligible from UK export financing support. Thirty asset managers, who collectively oversee $9trn, have committed to net zero across their portfolios by 2050 and some investors have announced that they will no longer invest in fossil fuels. Denmark has announced the cancellation of remaining licensing rounds for exploration of oil and gas in its offshore waters.

This will be beginning to affect the financeability of projects, and in turn, might prompt price increases - adding to the challenge (already considerable in the power sector) of competing with renewables on cost.

Fossil fuels therefore face a toxic mix of an increasingly hostile policy framework, and greater challenges in securing financing - unless of course they can be produced so as not to emit GHG's. The most obvious way to do this is through carbon capture, use and storage technologies (CCUS) which would be relevant in some of the current markets for hydrocarbons, notably the power generation and industrial sectors.

The Potential of CCUS for Emissions Removal

i) The Power Sector

CCUS has been a proven technology at lab and pilot demonstration scale for at least a decade and exciting new technologies continue to emerge. But they have struggled to secure the financial support to get deployed at scale. With some isolated exceptions, and despite significant investment by OEM's, the hydrocarbon industry has been slow to commit support. Some campaigners have opposed it (often not for sound scientific reasons) and - whether influenced by such campaigns or for other reasons - governments have moved slowly or not at all. Only a tiny fraction of the funding given to renewables has been available to move CCUS from lab or pilot demonstrations to deployment; nor have other polices such as carbon pricing or regulation been harnessed to do so.

Although efforts have been stepped up significantly in a few jurisdictions over recent years, the development of business models along the whole value chain (capture, transport and storage or usage) remains rudimentary. Importantly, CCUS is expensive as cost reductions from learning by doing and economies of scale have yet to be realised. The costs of renewables by contrast have fallen dramatically. They are for instance already viable subsidy free, and cost competitive with thermal power generation, in many regions of the world. It is difficult to see how CCUS can penetrate that market, given the cost it adds to either new or retrofitted thermal plant. Any market for CCUS abated coal and gas power plants therefore depends on whether governments are prepared to subsidise them.

The exceptions might be plants operating with bioenergy coupled with carbon capture and storage (BECCS), or thermal plants with CCUS where the captured CO_2 has a value elsewhere. There are difficulties with either proposition. There is much competition for biomass (for heating and transport particularly), concern over how sustainably it is produced, and competition for land use for food production. Markets for CO_2 streams have to be developed which are compatible with the net zero agenda – and scalable.

ii) Industry and Hydrogen Production

There is probably be more prospect of continued use of hydrocarbons with CCUS beyond the power sector, such as where there are not alternative technologies sources or energy cannot be sourced from renewables. But the challenge again is scale and competing with some of those industries which are themselves researching possible alternatives with lower emissions. Added value will of course be derived from hydrogen production through steam reformation for uses such as transport or heating. Here, the competition will be with electrification and with the production of green hydrogen (electrolysed from water using renewable power).

Hydrocarbons in the Transport Sector and Elsewhere

The role of hydrocarbons in the transport sector is likely to be confined to the indirect one of producing hydrogen. How large a market might this become? In the UK, the government has recently been advised by the independent Committee on Climate Change**** to confine the use of hydrogen for transport to freight, and public transport such as buses or trains – usually alongside electrification as part of the solution, in part because of the constraints on hydrogen production and distribution before the ban on new internal combustion engine cars (ICE's) with effect from 2030. Sales off electric cars have reached record levels in the last few months, even as conventional sales have fallen: the technology appeals and they are cheap to run. According to a recent report by BNP Paribas*****, the cost of electric mobility (based on a renewables powered grid) will within 25 years become up to seven times cheaper than ICE's on a full lifecycle basis. To compete, oil prices would have to fall to uneconomic levels - below $20 bbl . So the market for hydrogen in cars may go the way of CCUS for coal or gas power, that is, be pre-empted by another technology which is cheaper and readier earlier.

Innovative technologies could enable hydrogen to contribute to the decarbonisation of heating in buildings depending on the scale of trials over the next decade – and their success in showing how to overcome considerable challenges over safety and storage.

These examples are far from the whole story for the potential value of hydrocarbons to be unlocked by innovative technologies, but lack of space precludes that discussion in areas such as fertilisers and plastics. Suffice to say that innovative technologies will be needed even to maintain some of those traditional markets to match the future emphasis on sustainability, eg in terms of reusable or recyclable products.

Conclusion

The hydrocarbons sector has driven the world's prosperity for centuries but climate change means that the capital stock which it has accreted over the centuries must now be replaced. Innovative technologies which could enable hydrocarbons to continue to be valued in a low carbon world are already evident. But they will be limited in extent by several factors. First, leaders of the hydrocarbons sector are all too conscious that it must regain trust in the sustainability of its operations. It must put its house in order as regards operational emissions and fugitive methane. Second, it must rapidly accelerate efforts to deploy innovative technologies in a world where the process of replacement of hydrocarbons has already begun. In certain sectors even abated hydrocarbon technologies will struggle for market share, such as power generation where it is difficult to see how CCUS can compete effectively with renewables (unless added value can be secured at scale from by products such as hydrogen). Third, while other uses such as packaging, chemicals and fertilisers offer continued promise, developing those markets successfully must be conditional on whether doing so meets sustainability criteria.

The sector certainly has the ingenuity, technical expertise and motivation to develop innovative products beyond its traditional markets. The question is whether it will be given enough time, and have the financial firepower, to succeed in a world where erosion of the market for its products has already begun.

Writer's Profile

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Ms. MacNaughton chairs The Climate Group and the International Advisory Board of the New Energy Coalition, and is a Non Executive Director of En+ Group plc. She sits or has sat on several other boards in the academic, public and corporate sectors, and the Advisory Boards of the Grantham Institute, the Joint Institute for Strategic Energy Analysis, and Engie UK plc. She is one time Vice Chair of the UN High Level Panel on the CDM, former Chair of the Governing Board of the IEA, and a former Director General of Energy in the UK Government.

The Role of Hydrocarbons in the European Energy Transition: Policies and Financing in the Wake of Coronavirus

Jonathan Stern*

2020 – the year of COVID-19 and net zero targets

In early 2020, the European Union (EU) proposed that 'Union-wide emissions and removals of greenhouse gases regulated in Union law shall be balanced at the latest by 2050, thus reducing emissions to net zero by that date'. At the end of the year EU ministers agreed a 2030 greenhouse gas (GHG) reduction target of 'at least 55%' below 1990 levels (compared with the previous target of 40%). In Autumn 2020, carbon neutrality commitments were announced by governments in major Asian importing countries – Japan (2050), South Korea (2050) and China (2060) – as well as the incoming US Biden Administration (2050 with net zero electricity to be achieved by 2035). While this was happening at the government level, major international oil and gas companies (IOCs) also committed to achieving net zero emissions by 2050. Although 2020 will be remembered more generally as the year of COVID-19, energy and climate researchers will remember it as 'the year of net zero'.

Net zero targets require a substantial reduction in greenhouse gas (GHG) emissions from the energy sector, particularly for the European Union and individual EU and non-EU countries (such as the UK) which have committed to climate neutrality and accelerated 2030 reductions. But in relation to hydrocarbons, they raise four very important questions.

What do these targets mean for the development of zero-carbon technologies?

Commitment to net zero targets will require an intensification of political and corporate decision making around emissions from the production and trade (imports and exports) in all fossil fuels - oil, natural gas and coal. Many scenarios have been published by the EU, the IEA, national governments and IOCs show the possibilities of moving to a different mix of energy sources and zero carbon technologies. The most important technologies are:

- various types of zero carbon renewables dominated by (onshore and offshore) wind and solar and bioenergy,
- batteries of various types to cater for the intermittency of renewables and for transportation,
- fossil fuel decarbonisation technologies for the production of hydrogen (and potentially also ammonia) with carbon capture utilisation and storage (CCUS),

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- identification and reduction of methane emissions from fossil fuel production and also carbon dioxide from flaring,
- a new generation of nuclear reactors,
- low and zero carbon transportation fuels particularly for aviation and heavy transport,
- efficiency technologies for buildings and industry.

Different countries will focus on different sets of these technologies depending on their particular energy situation and aspirations, but it is clear that the availability of investment will not be sufficient for all technologies to be treated equally. The COVID 19 pandemic has limited the financial capacity of governments to support the transition compared with what it would otherwise have been. These two developments lead us to the second question.

How much investment will be needed to meet 2030 and net zero targets and who is going to provide it?

More aggressive reduction targets for 2030 will require urgent action and increased expenditure. In July 2020, the EU agreed a multilateral financial framework (MFF) budget of €1.1 trillion plus a Next Generation EU (NGEU) fund of €750bn for the period 2021-27. An overall climate target of 30% will apply to the total expenditure of MFF and NGEU which would mean that €555bn will be spent on climate-related sectors over this period. This would provide funding of €80bn/year spread across energy, agriculture, rural affairs and biodiversity. While this is an impressive amount of investment it will be spread across these four sectors of 27 EU member states. This suggests that the majority of investment, which in the larger economies will probably require double digit billions of Euros per year, to meet GHG reduction targets will have to come from national governments and the business sector. A report published at the end of 2020 by the UK Climate Change Committee found that in order to meet government targets, investments of £50bn (€55bn) per year would be needed in the period 2030-50 (although in net terms it claimed the costs would be very low due to reduced cost of fossil fuels and avoided climate damage).

At present, the only low and zero carbon supply technologies which are commercially viable on a large scale are wind and solar power, all other technologies require significant financial support from governments or regulators. Experience of wind and solar power suggests that with large scale development, and improvements in design, costs of other technologies will fall substantially. However, the urgency introduced by more stringent targets for emissions reduction in 2030, means that waiting 10 years for large scale technology development is not a realistic option. Governments are looking to industry to provide guidance on which are the most promising technologies. But private investors are looking to governments to provide a 'long term roadmap' for each technology, specifically the amount of funding which will be available. There is no consensus on which technologies – from the list above – are the most suitable in which countries and how they can be made commercially attractive to investors.

What does this mean for the future of hydrocarbons?

It is clear that, certainly in a European but also in a global context, hydrocarbon usage must fall substantially if climate change targets are to be met. In Europe (and much of the rest of the world outside Asia) the impact on coal has already been much more dramatic than for oil and natural gas. Many European governments have set targets for a complete phase-out of coal, which has become more realistic by dramatic fall in the share of coal-fired generation due to switching to renewables.

The impact of the COVID-19 pandemic on oil demand has also been significant due to the decline in travel of all types. Natural gas demand both in Europe and globally has not been impacted to the same extent as coal and oil, but significant initiatives and investments in hydrogen – which could replace natural gas in industrial and residential heating sectors – are under way. There is a debate about whether the first decades of hydrogen development will need to be principally from reformed natural gas with carbon capture and storage (CCUS) so-called 'blue' hydrogen. Or whether hydrogen from renewable energy – so-called 'green' hydrogen – can be developed sufficiently rapidly and at a sufficiently low cost. CCUS is not yet being developed on a large enough scale – partly because in many countries it is not environmentally acceptable – to give confidence that sufficient blue hydrogen will be available. Electrolysers to produce green hydrogen will be scaled up from the current 10-megawatt capacity to gigawatt scale but this is likely to take at least a decade.

Can oil and gas companies create a business model to play a major role in the transition?

Many IOCs have already declaring net zero corporate targets for 2050 which means they will need to substantially change their business models. The IOC business model has been to spend significant sums of money finding large accumulations of oil and gas. They then seek exclusivity from governments to develop these reserves over periods of 20 or more years, underpinned by legally guaranteed property rights in return for tax and royalty payments. Having developed the reserves, they sell them at market prices internationally, and market or regulated prices domestically. The traditional business benchmark for IOCs has been a 12-15% post-tax real rate of return. This is the level of return that has led investors to commit funds to these companies and the sector in general. A differentiating factor for oil and gas companies is the scale of their traditional business which meant that few could challenge their position. Many large companies can organise and finance projects requiring investments of several billion dollars. But IOCs launch projects requiring investments of tens of billions of dollars outside the countries in which they are located.

The business model problem for oil and gas companies is two-fold: most low and zero carbon energy projects are on a much smaller scale, and the returns on these projects are relatively low (in comparison to traditional IOC expectations) and mostly require the support of governments. In fact, it is debatable whether low and zero carbon energy can be described as ‘a business’ in terms of providing attractive returns to investors. And it is uncertain whether profitability will be based on selling wind turbines, solar panels and electrolysers, or selling the units of electricity or hydrogen that they will generate. Whatever the answer, low and zero-carbon energy is not compatible with traditional oil and gas business models either in terms of project scale or return on investment. The much smaller scale of projects means that many companies can compete successfully and raises questions as to whether oil and gas companies can create a significant comparative advantage in the low carbon energy sector.

Conclusion: does climate change mean that energy has become ‘a business for governments’?

If governments are going to meet COP21 (let alone net zero) targets by 2050 then fossil fuels have to be decarbonised or phased out. Government intervention and support has already, and will increasingly, be required to achieve this outcome. For countries where energy sectors remain dominated by state-owned and controlled companies this is not a major change. For the electricity sector it is already the current situation the IEA tells us that in OECD countries government policy already determines 75-90% of decisions. The European Union has its own carbon trading regime (EUETS) and some governments have introduced additional national carbon levies and taxes. Carbon pricing and taxation will be a key government policy to achieve targets, with modelling showing the need for prices in Europe to rise from around €30/ton in 2020 to around €100/ton by 2030 and double that figure by 2040. Governments will control carbon prices and taxes either directly or through the allocation of allowances.

Governments will need to play a large part in the selection of technologies to achieve carbon reduction targets. During the liberalisation era of the 1980s and 1990s, the view in many European countries was that governments should not ‘pick winners’ in terms of energy technologies, they should allow market forces to determine which technologies were the most competitive and hence most successful. However, the lead times for large scale introduction of these technologies, and the changes in infrastructure these require, mean there is no time to allow markets to make those decisions. For example, to introduce hydrogen on a large scale, or build massive offshore wind parks or new nuclear power stations, with all of the gas and electricity network changes those decisions would require, will require a decade (and possibly longer) to achieve. The urgency of the 2030 targets means that governments need to take decisions very quickly about which technologies they wish to support.

In Europe, the required speed of the energy transition requires hydrocarbons to be removed from energy balances starting with coal and oil; natural gas (principally for heating) will probably remain for a longer period of time. National governments will play the major role in determining the speed and direction of the transition, and companies – particularly hydrocarbon companies – will need to react and adapt as best they can. A final thought is that it is not clear whether the trends described in this article should be thought of as Europe-specific – arising from the adoption of more ambitious 2030 targets – or whether they will also be relevant for other countries and regions.

Writer's Profile

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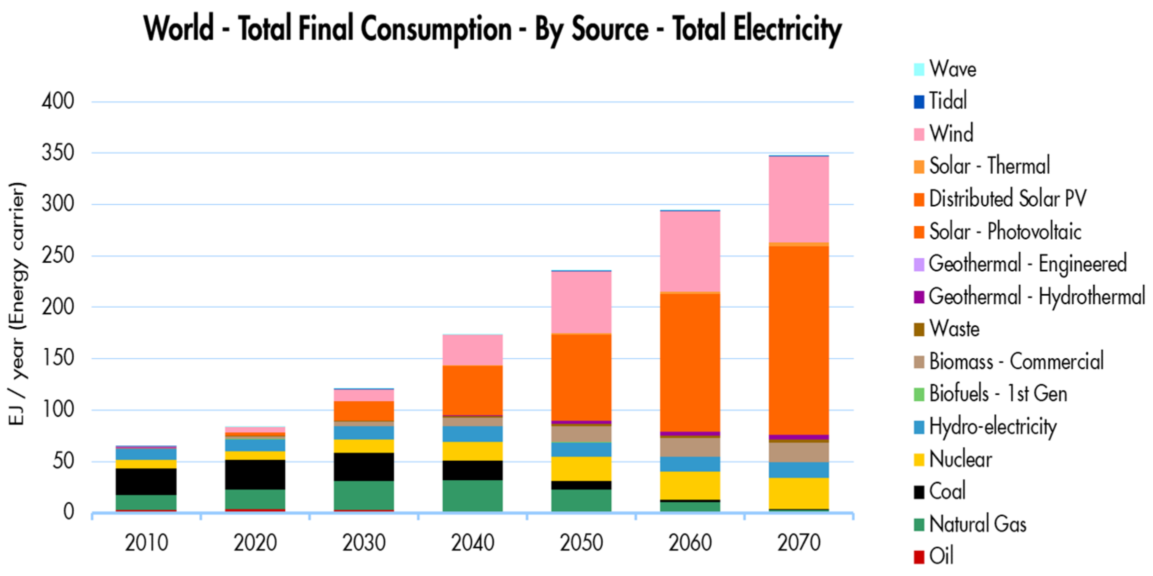
Professor Stern is a Distinguished Research Fellow and founder of the Natural Gas Research Programme at the Oxford Institute for Energy Studies (OIES). He holds professorships at the University of Dundee and Imperial College, London; and fellowships at the Energy Delta Institute and the Institute of Energy Economics, Japan.

The Enduring Role of Hydrocarbons for Climate Change Measures

W.L. Thomas*

As part of many governments' stimulus packages to counter the global recession caused by the Corona pandemic, extra focus is given to a green recovery. Its aim is to stimulate achieving the goals of the Paris Agreement on climate change to limit the increase in the global average temperature to well below 2°C and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels. More momentum is developing for aiming at the more ambitious 1.5°C target, which means that global greenhouse house emissions need to peak as soon as possible and, while within an overall strong efforts to reduce CO_2 emissions, finding a balance between unavoidable anthropogenic emissions and removal of greenhouse gases by sinks like carbon capture and storage as well as nature based solutions. Stronger calls and commitments for reaching net zero emissions by around 2050 are now rising, and the question is posed how much fossil fuels will remain required and for how long to enable this transition. Many scenarios show that electrification is key, but that molecules will remain required in any energy system of the future. This paper examines how much fossil energy will remain required, if any, in such world by taking wind power generation as an example.



Graph 1: World Total final electricity consumption by source (Source: Shell Analysis, Sky Scenario)

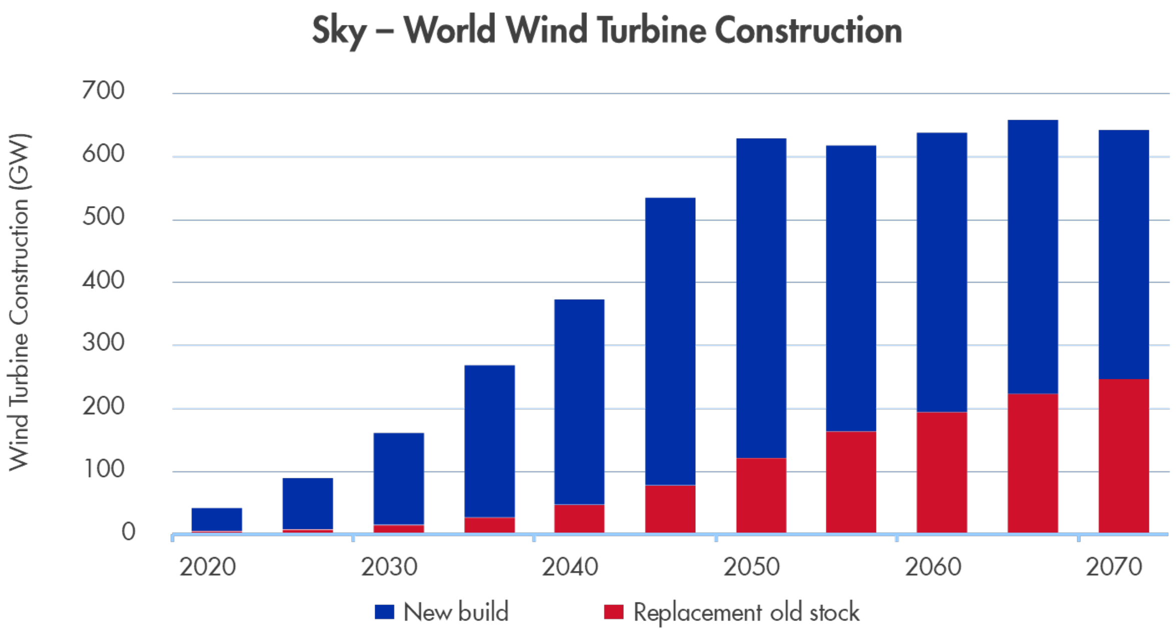
* Former Chief Energy Advisor in Shell and headed the Group's Energy Market Analyses (EMA) community

This case study is based on the wind power projections in the Sky scenario[1], which achieves a well below 2°C target with 85% probability and with additional nature-based solutions 1.5 °C with a 50% probability.

The Sky scenario illustrates a technically possible, but challenging pathway for society to achieve the goals of the Paris Agreement. It describes a set of mutually reinforcing drivers being accelerated by society, market and governments and include a step change in the energy efficiency in the demand sectors, a tripling in the rate of electrification with new energy sources like solar and wind growing up to fifty fold, the prolific use of carbon pricing mechanisms and a wide adoption of Carbon Capture and Storage (CCS) on bioenergy.

How many wind turbines need to be constructed each year?

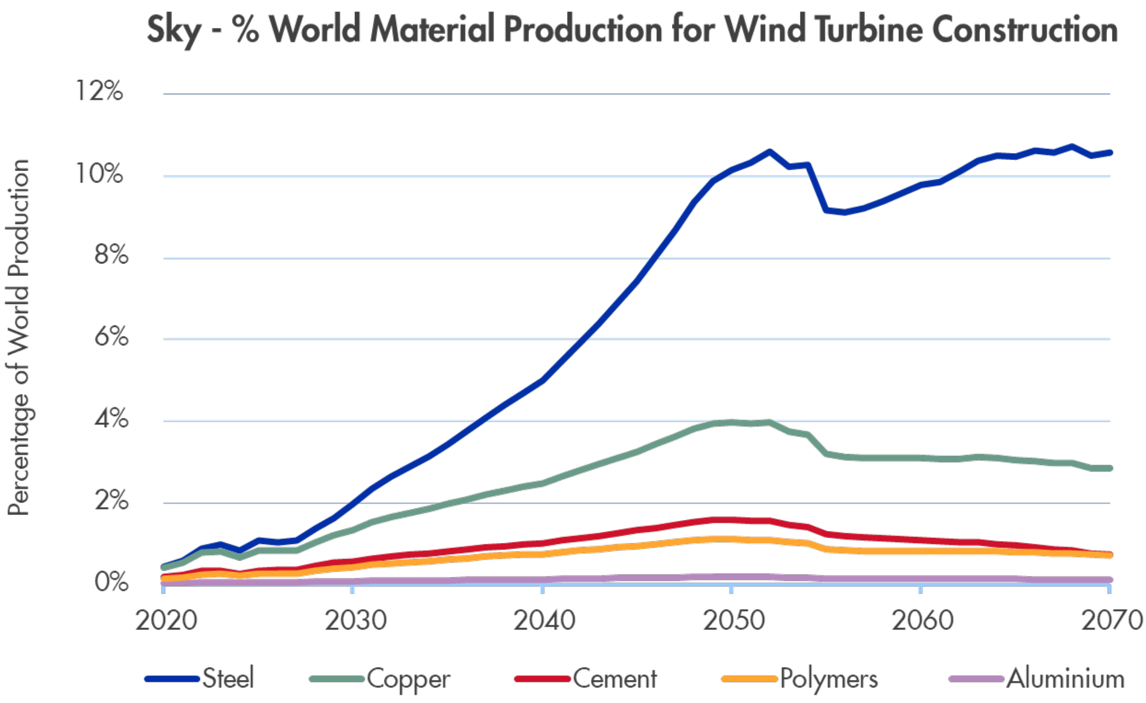
Presently, around 60 GW of new wind capacity is installed but this needs to be three times as much by 2030, and 11 times more by 2050, plateauing around 650 GW per year. Capacity additions will need to grow by some 8.5% annually to 2050s. Today, about 90% of the market for wind turbines is new builds, but by 2070 around 40% will be to replace old turbines (Graph 2).



Graph 2: World wind turbine construction requirements (Source: Shell Analysis, Sky Scenario)

[1] www.shell.com/skyscenario Scenarios are not predictions, plans, or policy proposals – they simply explore what might happen given the assumptions made in the scenario. The Sky scenario paints a technically plausible pathway for achieving the goals of the Paris Agreement.

In spite of the strong energy and material efficiency assumptions in the Sky scenario, seeing only a 10% increase in materials consumption per capita by 2070, the world will still need to produce 50% more core materials like steel, cement, copper, aluminium and polymers, than today. With the energy transition, a significant redirection of materials requirement towards Wind construction will happen with market shares for key materials doubling between now and 2025, increasing fivefold thereafter towards 2050 (Graph 3). Steel will see strongest pull with a tenfold increase for wind park construction. As offshore wind's share is projected to increase from around 10% today to 80% by 2070 in the Sky scenario, more steel will be required, especially with the share of floating wind going up. However, offshore wind will need less cement than onshore wind.

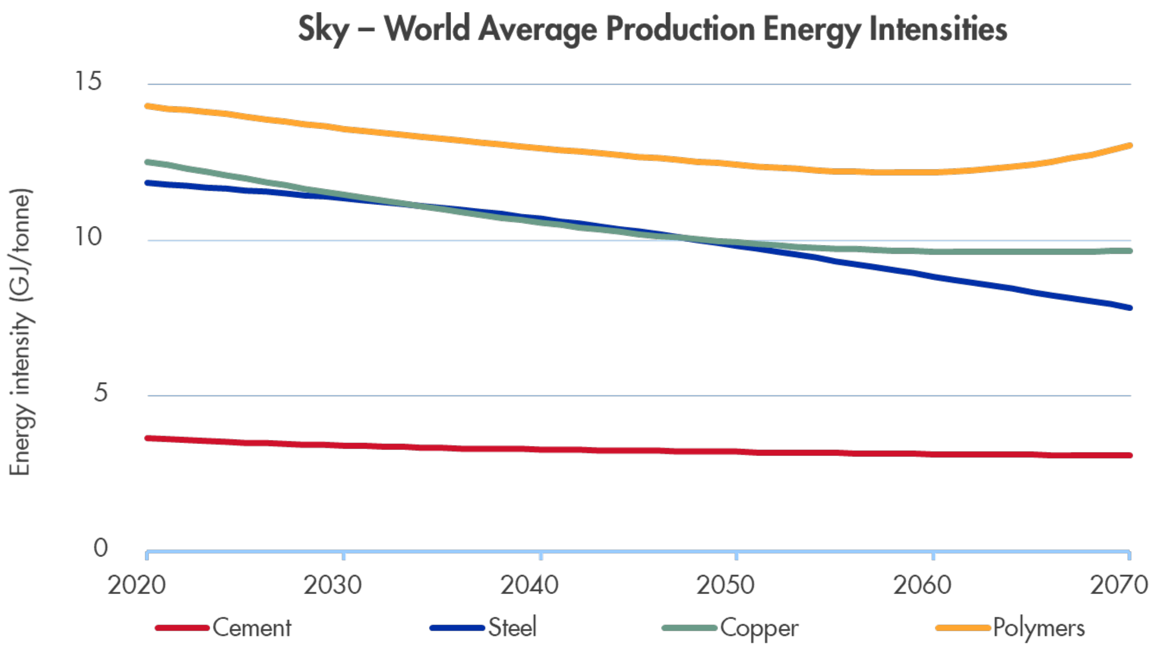


Graph 3: Materials required for wind turbine construction as percentage of global material production assuming today's technologies (Source: Shell Analysis, Sky Scenario)

How much further scope in energy and material Efficiency?

Before we can assess how much and what type of energy is required to construct wind turbines in the future, we need to have a look at the scope for energy and material efficiency. Key is recycling and the use of low or zero carbon energy. But there are practical limits in how much can be recycled because of e.g. impurities in special alloys, logistics, scale and economics. Energy and emissions reduction do not always go hand-in-hand. For instance, compared with a coal fired blast furnace, steel production using green electricity for an Electric Arc Furnace with 100% scrap feed, would theoretically use about 5.5 times less energy input per tonne of steel and emit negligible CO_2. Emissions could be mitigated via CCS or through green hydrogen direct reduction of iron method, but the hydrogen route could use 15% more energy per tonne (source-to-product). Practical limits in recycling, limit secondary production to around 35% of crude steel production, reducing the potential efficiency gain for steel production to around a factor 2. Aluminium and copper also have significant theoretical scope for efficiency improvements through recycling, but also here there are practical limits and the use of those materials in wind park construction are a few orders of magnitudes less than steel.

Other fabrication methods, like for cement, are already approaching theoretical efficiency, and emission reduction is expected to be more economic through CCS. Possible efficiency and emission improvement routes for polymers are plastics recycling and using biomass upgrading to feedstock. However, the latter process will need overall more energy input, increasing again the amount of energy required to produce a tonne of polymers (Graph 4).

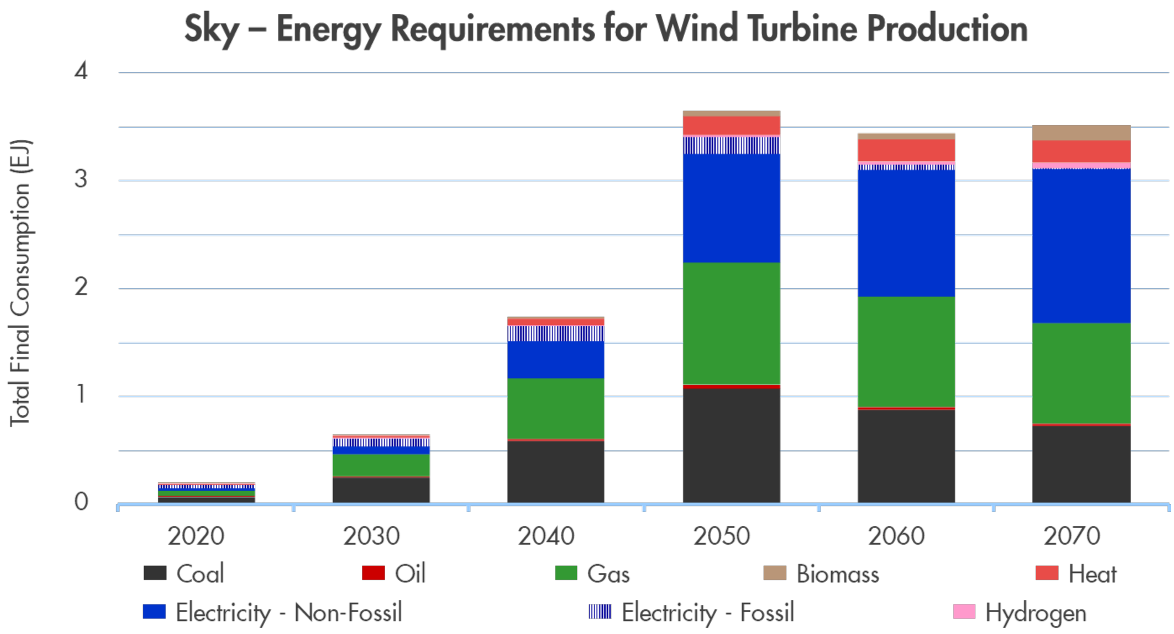


Graph 4: World average source to product energy intensities 2020 to 2070 (Source: Shell Analysis, Sky Scenario)

What type of energy is required for producing wind turbines?

It is estimated that over 80% of energy used today to construct wind turbines comes from fossil fuels, but that could be half by 2070 as new technology and more renewable electricity is used. Electricity's share of energy input is about 28% today, but that may ultimately be over 50% by the second half of the century. Today, two-thirds of electricity used comes from fossil fuel power generation. But as renewables grow, it will drop to negligible by 2070. Nevertheless, fossil fuels will remain an important contributor to build wind turbines due to limitations in efficient material production (steel, cement, non-ferrous metals, resins), but its share will dwindle to around 50% of energy input by 2070 (Graph 5).

Today, approximately 68% of related CO_2 emissions come from iron and steel, 20% from cement, 9% from plastics and 3% from non-ferrous metals. With an increasing share of (floating) offshore wind, over 90% of emissions may come from steel, 4.5% from plastics and 2.5% from cement by 2070 if unabated. Even unabated, the annual construction of around 650GW wind turbines in the second half of the century will emit about 0.6 Gt per year while the emissions avoided compared with gas fired power generation will be over 11 Gt per year. Some $650 bln pa abatement costs[2] might be avoided by wind generation compared with gas generation by 2070.



Graph 5: Energy requirements to construct wind turbines 2020 to 2070 (Source: Shell Analysis, Sky Scenario)

Concluding Remarks

Given increasing societal momentum in willing to meet the goals of the Paris Agreement, coupled with the continuing cost reduction in wind and solar, the energy transition will be unstoppable and be spearheaded in power generation. Despite policy efforts to increase economic, material and energy efficiency, the demand for materials will grow as economy and population grows. Due to practical limits in energy service efficiency, hydrocarbons will continue to be needed over the coming decades in the production processes of building out renewables. Sectors like steel, cement and chemicals are likely to continue using coal and gas as fuel or feedstock as the most economical option, while abatement options like CCS are deployed.

The case study on wind power in this paper illustrates that although 80% fossil fuels are required in building out wind power today, with the increase in renewables and different production processes, that share of fossil input is expected to come down to 40% by 2070. Even if unabated,

2 Based on ~$85/tonne CCS costs by 2070

emissions avoided are multiple orders of magnitudes greater over the lifetime of a wind turbine. The avoided abatement costs make wind (and solar) a preferred cost effective solution.

However, the shift to low/no CO_2 emitting energies alone will not be sufficient to meet the goals of the Paris Agreement, and in addition large-scale carbon capture and storage of remaining fossil, but foremost bio-energy, hydrocarbons (BECCS) will be essential.

Writer's Profile

W.L. Thomas

Mr. Thomas was part of Shell's Scenarios Team, which is part of the Group Corporate Strategy Department. He lead a team responsible for worldwide energy analysis and long-term global energy scenarios, and advised Shell's Executive Committee and the Board and its businesses on a wide range of energy issues, including oil & gas markets and pricing, global supply & demand for all energies, regulations, energy policy and industry structure. He has been with the Shell group of companies for over 35 years, with prior international positions in drilling operations, subsurface reservoir management, upstream commercial and regulatory affairs in gas. Presently, he is a non-executive director at MARIN, a world leading maritime research institute in the Netherlands, and on the Advisory Board of the Buccaneer, an accelerator for innovation on sustainable energy in the maritime sector. He is a Fellow of the Energy Institute of the UK and Distinguished Fellow of the IEEJ. He is a former Chairman of The UK National Committee of the World Petroleum Council and of the British Institute of Energy Economics. Wim holds a postgraduate degree in Maritime Technology, Delft University, The Netherlands.

3. What can Stabilize the Middle East Region; Military Power or Soft Power?

中東の安定化に貢献するのは、ハードパワーか、ソフトパワーか？

Global Landscape Surrounding Peace in the Middle East: Past, Present, and Future

Ken Koyama*

1. History of the International Energy Market and Importance of Stability in the Middle East

When did the modern international energy market begin to develop? Opinions vary, but I believe it involves the development of the "oil market" which began in the late 19th century. Before the industrial revolution, humankind relied on natural sources of energy and power such as humans, animals, windmills, and waterwheels. The dawn of the industrial revolution made coal the number one source of energy. However, an international market had yet to develop because people mostly produced the energy they needed domestically.

However, the importance of oil as an energy source grew after the birth of the modern oil industry in the United States in the late 19th century, and its sources expanded to Russia, Venezuela, and then to Mexico. Finally, the discovery and development of massive oil fields in the Middle East began, started in Iran. As epitomized by the rapid spread of automobiles in the early 20th century, the use of oil as an energy source increased explosively, making the 20th century the "century of oil." This was made possible by abundant supplies of cheap oil, making it essential to secure stable oil supplies through international trade.

Accordingly, stability in the Middle East, which possesses the world's largest and least-cost reserves of oil, became an essential factor for the stability of the international energy market, and in turn the expansion of the world economy and international power politics. Furthermore, oil also became of great interest to major countries as a strategic product that determines the capability of the modern military to mobilize and deploy its forces. As the international energy market developed, who would keep the Middle East stable and how, became the top priority for global energy governance.

2. UK's Hegemony in the Middle East to Ensure Global Energy Governance

The United Kingdom was the first superpower to play a central role in Middle East stability in the context of global energy governance. Oil development in the Middle East began in Iran largely at the initiative of the UK government. The UK was the first to switch the shipping fuel for its navy to oil (heavy oil) led by then First Lord of the Admiralty Sir Winston Churchill. For the UK, which had to rely on oil imports until the North Sea oil fields were developed in the 1970s, stability of the

* Senior Managing Director and Chief Economist at IEEJ

international market, particularly securing stability in the Middle East and its oil supplies, was of utmost importance for its national security.

Back then, the UK wielded power as the provider of governance in the Middle East (and in many other parts of the world) with its powerful imperialistic rule backed by the world's mightiest navy. Governance by the UK continued to function for the most part, despite numerous challenges including Russia's southward expansion and the advance of the newly emerging German Empire into the Middle East.

However, many of the complex problems in the Middle East today, including the Israeli-Palestinian conflict and the Arab-Israel issue, were emerging even during this period of UK-led governance. "Divide and rule," the guiding principle of imperial regional rule, also gave rise to various complex relationships among the region's major countries.

As it became clear that the Middle East's oil resources would generate enormous wealth, various outside forces stepped up their involvement in the region, attracted by oil as a source of wealth and power. This wealth and power also gradually strengthened the power and presence of Middle East oil producers, while at the same time further complicating the geopolitical environment in the region and fueling competition and disputes. The term "powder keg," which was later used to describe the Middle East, partly reflects the wealth and power of oil and the various historical developments and background of the era of British rule.

3. Maintenance of Global Energy Governance by the US as a Superpower

After the ravages of World War II, the UK relinquished its position as the hegemony and was replaced by the United States. From the early 20th century, the US rose to sudden eminence as an emerging country and eventually built up overwhelming military power backed by the world's greatest industrial and economic foundation. The US was the only Western country capable of leading the world after WWII.

Cheap and abundant Middle East oil played a major role in the post-war reconstruction, and large-scale development of the region's oil fields was essential. It was the power of the US that ensured Middle East stability from the standpoint of global energy governance. Governance by the US not only protected regional stability but also the supply chain that enabled Middle East oil to reach global markets without disruption. It was the overall power of the US, both political and military, that ensured an undisrupted supply of oil via the sea lane connecting Middle East oil producers with Asian markets, the focal point of today's global oil market, via the Persian Gulf, Strait of Hormuz, Indian Ocean, Strait of Malacca, and the South China Sea.

The US focus on Middle East stability and governance is reflected in various events. One symbolic example is the Carter Doctrine (1980), issued by the then President Carter when the former Soviet Union invaded Afghanistan in 1979, which declared that "an attempt by any outside force to gain control of the Persian Gulf region will be regarded as an assault on the vital interests of the United States of America, and such an assault will be repelled by any means necessary, including military force." Furthermore, when Saddam Hussein invaded Kuwait in 1990, the US led the multinational forces to fight the Gulf War, destroying Iraq's military forces. The US also waged the Iraq War in 2003 to overthrow Saddam Hussein's government.

As outlined above, the US has intervened in the Middle East, exercising military force when necessary. The US willingness to use its military muscle when necessary is a powerful protector of governance in the Middle East. Further, the country has been regarded by its allies as a trusted defender who protects them from outside (or even inside) enemies.

However, US intervention has also caused complications and new problems. For instance, the Iraq War overthrew Saddam Hussein's government. However, looking at the subsequent turmoil and deterioration of public safety in Iraq and the division of the nation, the initial goal of building a democratic Iraq and ensuring stability has not been achieved. The turmoil and power vacuum have also caused problems such as the emergence of radical terrorist groups, spreading terrorism around the world and causing a mass exodus of refugees, many to Europe, by intensifying the civil war. Further, the turmoil in Iraq has allowed Iran to gain influence in the region, forcing the US to focus its Middle East policy on Iran.

4. Future of US Involvement in the Middle East

The US is now the world's only superpower with unparalleled strength. As such, its intervention in the Middle East continues to play a major role in Middle East stability and international energy markets from the standpoint of global energy governance. However, there is concern about its future role.

The first concern is that while the US is still undoubtedly the most powerful, its lead over others is no longer so great and eventually its power may weaken. In fact, US leaders have recently commented that "the US is no longer the policeman of the world." Further, the US is coming under increasing pressure as China races to catch up. The rise of China may also shift the center of US diplomatic and military strategies toward Asia and China.

More importantly, there is concern that the US is gradually becoming more inward-looking. If the country's interest and involvement in the costly issue of maintaining global stability and order declines under the America First policy, stability and order in the region will inevitably be undermined. Some say the US will wind down its involvement in the Middle East because it is now less dependent on oil imports thanks to the shale revolution. However, I believe the US will not abandon the Middle East merely because it depends less on its oil; rather, I think the US fully understands that its allies in the Middle East and the stable supply of oil from the region are a source of stability for the world economy, and in turn the US economy.

However, there are now more questions and uncertainties regarding the future of US involvement in the Middle East. The Middle East has grown more unstable and volatile under the Trump administration. The administration's unilateral exit from the Iran nuclear deal and hardening of its stance against Iran have caused Iran further economic damage on top of the catastrophe of the coronavirus, making life extremely difficult for the nation. Tensions surrounding Iran have mounted, with a major military clash now just a step away after the US assassinated the commander of the Islamic Revolutionary Guard Corps (IRGC) in January 2020. Although new factors affecting regional stability have emerged, such as the UAE and Bahrain normalizing diplomatic ties with Israel, overall it is not clear whether the Middle East can preserve and strengthen its stability.

There is speculation that the US may return to the Iran nuclear deal when the Biden administration takes office. This should help improve US-Iran ties, but it may not be so simple. The return of the US to the nuclear deal would mean Iran returning to the international community with increased presence. This would cause difficulties for the region's countries such as Saudi Arabia and Israel which oppose Iran. Unlike with the Trump administration, these countries may struggle to coordinate and build relations with the next US administration. As such, peace in the Middle East will remain under threat regardless of the next US administration's policy as new challenges and issues arise.

5. New Challenges for Middle East Stability and the Importance of Soft Power

First the UK, then the US, have played key roles in Middle East stability from the standpoint of global energy governance. Today, no country can take over the present role of the US for the foreseeable future. Having increased its presence in the international community, China may play a major role in global energy governance in the future, but there is no clear path for this to happen yet.

Governance by a superpower has helped maintain regional stability. Challenges to peace in the Middle East have sometimes caused the superpower to exercise its military power. Such hard power has helped overcome outside forces and overthrow unstable forces, but also created new challenges and problems in the region. It is difficult to achieve Middle East stability and resolve problems with hard power alone.

In particular, many of the challenges surrounding Middle East oil producers today have to do with tackling structural economic and social problems. Middle East oil producers are highly dependent on oil revenue, as it is this energy that has made them wealthy and powerful. The greater their wealth and power, the more difficult it is for them to break their dependency on oil and reform their economic and social structures.

As shown by the fact that the coronavirus pandemic caused the demand and price of oil to collapse, leading to economic hardships, the world's future oil demand will significantly affect the future of oil-producing countries. The current decarbonization efforts by major countries are also a major uncertainty for the future of oil-producing countries, while the coronavirus-induced transformation of society may further drive down oil demand. Considering that oil demand may peak, Middle East oil producers must implement urgent reforms to make their economic structures more diverse and sophisticated. To do this, they will need to fully utilize their soft power, including their economic and technological capabilities. To decarbonize fossil fuels and achieve a circular carbon economy, oil-producing countries must boost their soft power while seeking international cooperation in the area of soft power. For long-term stability in the Middle East, it is vital to attach more importance to soft power.

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Dr. Koyama joined IEEJ in 1986. He got his PhD in 2001 from University of Dundee, Scotland. He has held many senior positions in IEEJ, including Head of the World Oil & Energy Group, Senior Research Fellow, Energy Strategy Unit. He has served as a committee member of energy policy related councils and advisory committees of Japanese government in many occasion. His specialized field of research is: energy security issues and geopolitics of energy; and analysis for global energy market and policy development with emphasis on the Asia-Pacific region. He has authored numerous publications in the area of energy economics.

中東安定を巡る国際情勢：過去・現在・未来

小山　堅 *

1. 国際エネルギー市場の発展と中東安定の重要性

近代的な国際エネルギー市場の発展は、その始まりをどこに見出すのが正しいのか。様々な見解が存在するが、筆者は 19 世紀後半から始まる石油市場の発展と密接に関係があると考える。産業革命以前は、人類は人力・家畜労働・風車・水車など自然エネルギーに依存していた。産業革命開始で石炭がエネルギー源の中心に躍り出た。しかし、その時期は、エネルギーは自給自足が中心であり、「国際市場」の発展を見出すことは難しい。

しかし、19 世紀後半に米国で近代石油産業が産声を上げ石油がエネルギー源としての重要性を増すと、その供給源はロシア、ベネズエラ、メキシコと拡大を続け、ついにはイランをその嚆矢として、中東の大油田発見・開発の時期を迎える。20 世紀に入って、自動車の普及が急速に進んだことに象徴される通り、石油はエネルギー源としての利用拡大が大きく進展、まさに「石油の世紀」が現実になった。「石油の世紀」を支えたのは、豊富で安価な石油供給であり、そのため、国際貿易を通じての石油安定供給が重要になった。

その意味で、最大規模で、かつ最も低生産コストの石油資源を保有する中東の安定は、国際エネルギー市場安定と、それを通しての世界経済発展や、国際政治のパワーポリティックスを作用する重要要因となった。また、石油は近代的な軍の動員・展開能力を直接左右する戦略物資としての側面を持つため、安全保障の観点からも大国の関心の的となった。中東の安定を、誰がどのように保つのか、が国際エネルギー市場の発展とともに Global Energy Governance の最重要課題となったのである。

2. 英国による Global Energy Governance としての中東への関与

中東の安定に関して、Global Energy Governance の観点から、最初に覇権国家としてその中心的な役割を果たしたのは英国であった。そもそも中東の石油開発はイランの石油開発に始まるがそれは英国の国家的関与の下で始まったと言っても良い。海軍の船舶燃料をいち早く石油（重油）に切り替えたのも当時海軍大臣チャーチルを有した英国であり、1970 年代以降の北海油田開発以前は石油供給を輸入に頼らなければならなかった英国にとって、国際石油市場の安定、なかんずく中東の安定とその石油供給確保は、国家安全保障にとって重要な問題であった。

当時、世界最大の海軍力を背景に帝国主義的な強力な支配力を有した英国は、中東（のみならず世界各地）において、Governance の主体として力を揮った。ロシアの南下政策や、勃興してきたドイツ帝国の中東進出など、幾多の挑戦があったものの、基本的に英国による Governance は機能を続けてきた。

しかし、同時に、パレスチナ問題、アラブ・イスラエル問題など、今日の中東における様々な複雑な課題の多くは、この英国を中心とした Governance 体制の時期に生まれている。また、帝国主義時代の地域 Governance の基本は、「分割して統治せよ」であったことから、地域主要

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国の間には複雑な関係が生まれることにもなった。

その状況下、中東の石油資源が生み出す富が膨大であることがわかるにつれ、その富とパワーの源泉としての石油に引き付けられ、様々な外部勢力が中東に関与を強めるようになった。また、その富とパワーは、中東産油国の力と存在感を徐々に高めると同時に、中東域内の地政学環境を一層複雑化し、競争や紛争の種が生まれた。のちに、中東は「火薬庫」であるとの比喩が使われるようになったが、その背景には、石油の富とパワー、そして英国の覇権が続いた時期の様々な歴史・経緯が一定の影響を及ぼしている。

3. 超大国、米国による Global Energy Governance の維持

第 2 次世界大戦で疲弊した英国は覇権国家として、世界の Governance を司る地位を退くことになった。代わってその地位に就いたのは米国である。20 世紀に入って「新興国」として勃興した米国のパワーは、最大の工業力、経済力を背景に、軍事力でも圧倒的な力を保有するに至った。第 2 次世界大戦後の世界をリードする力を持つ自由主義圏の国家は米国だけであった。

戦後復興に重要な役割を果たした、石油の低廉で豊富な供給の確保には、中東の大油田開発が不可避であり、米国のパワーが Global Energy Governance の面から、中東の安定を担保してきた。米国の Governance は、地域としての中東の安定を守っただけではない。中東の石油が世界市場に滞りなく流通するためのサプライチェーンの保護もその対象であった。中東産油国から、ペルシャ湾、ホルムズ海峡、インド洋、マラッカ海峡、南シナ海などのシーレーンを守り、今日世界の石油市場の重心となったアジア市場向けの石油安定供給を支えてきたのも米国の政治力・軍事力等からなる総合的パワーである。

米国が中東の安定と中東の Governance を重視してきたことは、様々な事例から見て取ることができる。1979 年にソ連がアフガニスタンに侵攻すると、当時のカーター大統領が発出した、「ペルシャ湾地域を管理下に置こうとする外部からの試みは、米国の死活的な重要な利害への攻撃と見なす」として軍事力の行使をも躊躇わない姿勢を示した「カータードクトリン」（1980 年）はその象徴的な例である。また、1990 年にサダム・フセインがクウェートに侵攻すると、米国は多国籍軍を主導して湾岸戦争を実施、イラク軍を壊滅させた。さらに、2003 年には、「イラク戦争」を遂行し、サダム・フセイン政権を打倒した。

このように、米国は時には軍事力の行使をも厭わず中東に介入・関与した。いざとなれば、軍事力をも行使する米国の力は、中東における Governance 上の強力な「睨み」である。また、米国の同盟国にとっては、自らを外部（場合によっては内部）の敵から守ってくれる頼るべき保護の力とも見なされてきた。

しかし、米国による介入は、時として、問題を複雑化し、新たな問題を引き起こすことにも繋がった。例えば、イラク戦争はサダム・フセイン体制を打倒したが、その後のイラクの混乱と治安の悪化、国家の分断を見ると、民主的なイラクの建設と安定という目標からは程遠い結果となった。また、混乱と力の真空をついて、過激派テロ組織が勃興し、世界にテロを拡散、内戦等の拡大を通じて大量の難民を発生させ、それが欧州に流入するなどの問題を引き起こした。さらに、イラクの混乱で、地域内ではイランの影響力が拡大し、米国は次にイランを強く意識した中東政策の展開を余儀なくされるに至った。

4.　今後の米国による中東への関与はどうなるか

米国は今でも世界で唯一の超大国であり、その総合的なパワーは群を抜いている。その米国の中東への関与は、今日でも Global Energy Governance の観点で、中東の安定と国際エネルギー市場の安定に重要な役割を果たしている。しかし、最近、今後の米国の関りがどうなるかを不安視する声が現れている。

第 1 には、米国のパワーが最大であることは間違いないが、かつてほどの「余裕」がなくその力に陰りが出てくるのではないか、という懸念が生まれている。実際、最近は米国の指導者層から、米国は「もはや世界の警察官ではない」といった発言が度々なされている。また、中国の追い上げ・台頭によって、米国がますます余裕を失いつつあるようにも見える。また、中国の台頭は、米国の外交・軍事戦略の重心をアジア・中国にシフトさせていくことになるかもしれない。

さらに、重要なのは米国が徐々に内向き志向を強めている、という懸念である。自国第 1 主義に走ることで、世界全体の安定や秩序の維持という、「コスト」のかかる課題から関心と関与を低下させていけば、結果として安定や秩序が損なわれていく。なお、米国はシェール革命の進展で石油の輸入依存度が低下したため、中東への関与を低下させる、という見方があるが、筆者は、仮に米国の輸入依存度が低下してもそれだけで中東への関心を持たなくなることは無い、と考える。中東における同盟国の存在、そして中東の石油安定供給が世界経済の安定（ひいては米国経済の安定）につながる点は十分理解されていると感じているからである。

ただ現実には、今後米国の中東への関与について不透明で不確実な要素が増えている。トランプ政権の下で、中東情勢の不安定化、流動化は一層進んでしまった。トランプ政権が「イラン核合意」から一方的に離脱し、イラン敵視政策を強化してきたため、イランは経済的にも困窮し、昨今のコロナ禍による甚大な被害も相まって、国家として極めて厳しい状況にある。イランを巡る緊張関係は 2020 年 1 月の米国による革命防衛隊司令官の殺害で、軍事衝突の本格化の一歩手前まで行ってしまった。他方、イスラエルと UAE やバーレーンが国交正常化するなど、地域の安定を巡る新しい動きも出てきたが、全体として中東地域が安定を維持・強化できるかは予断は許されない。

米国で「バイデン政権」発足となった場合には、「イラン核合意」への米国の復帰の可能性が取り沙汰されている。方向性として、米・イラン関係改善にプラスに作用しようが、物事はそれほど簡単ではないであろう。仮に「核合意」への復帰が現実のものとなる場合には、今度は、それはイランの国際社会への復帰とイランのプレゼンスの台頭を意味することになる。サウジアラビアやイスラエルなど、アンチ・イランの立場に立つ中東諸国にとっては、難しい問題が生ずる。これらの国は、トランプ政権時とは異なり、次期政権との関係の調整・構築も課題となっていく可能性がある。すなわち、次期政権の政策がどうあれ、何らかの新しい課題や問題が生じて、中東の安定にとっては課題がなくなることは無い。

5.　中東安定の新たな課題とソフトパワーの重要性

中東の安定のため、かつては英国が、そしてその後は米国が、Global Energy Governance の面から重要な役割を果たしてきた。予見しうる将来において、現在の米国の役割を直ぐに代替する存在は見えていない。国際社会で存在感を高める中国がいずれ Global Energy Governance の面でも重要な役割を果たす時が来るかもしれない。しかし、少なくとも現時点ではまだその道

筋は見えていない。

覇権国家による Governance は、地域安定に重要な役割を果たしてきた。中東における安定に対する挑戦は、時には覇権国家による軍事力の行使も伴う反応を生み出した。こうしたハードパワーは外部勢力排除や不安定勢力打倒に貢献することもあったが、その結果、中東の内部に新たな課題・問題を生み出すことも見られた。ハードパワーだけでの中東の安定と問題解決は難しい。

とりわけ、今日の中東産油国が直面する課題には、構造的な経済・社会問題への挑戦の色彩が強い。富とパワーを石油が生み出してきた故に、中東産油国は石油依存が極めて強い。その富とパワーが大きいほど、石油依存から脱却して、経済・社会構造を改革することは容易でない。

コロナ禍での石油需要減少が原油価格低下をもたらし、経済的苦境を発生させたことからも、今後、世界の石油需要がどうなるかは、産油国の将来を大きく左右する。その点、主要国の脱炭素化に向けた動きは産油国の将来にとっては大きな不確実性をもたらす。また、コロナ禍による社会変容が石油需要低下をもたらす可能性もある。石油需要ピークの可能性を踏まえると、中東産油国が、今から経済構造の多様化・高度化へ改革を進めていく必要があり、そのため、経済力・技術力等からなるソフトパワーを十全に活用していく必要がある。化石燃料脱炭素化や炭素循環経済構築のため、産油国自らがソフトパワーを強化し、同時に、ソフトパワーの面で国際協力を追求していく必要がある。中東の長期的安定のためには、ソフトパワーをより重視していくことが必要不可欠となろう。

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Middle East Stability and the Role of Japan

Shuji Hosaka*

Breaking Away from an Oil-Dependent Economy

Fossil fuels such as oil and natural gas are facing harsher criticism as the main cause of global warming. Japan depends on fossil fuels, mostly imported, for roughly 80% of its primary energy. Oil accounts for about 40% of Japan's primary energy and comes almost entirely from the Middle East. So long as Japan continues to use oil, stability in the Middle East remains a critical issue for Japan. However, troubled by various conflicts, it is unclear whether the Middle East can remain a stable source of energy into the future.

Middle East stability is critical not only for Japan but also for other countries that depend on fossil fuel supplies from the region. If the Middle East were to destabilize, disrupting oil and natural gas supplies before the countries in the region can transition to carbon-free energies, the consequences for the global economy would be grave.

Dependency on oil is an issue not only for consumer countries but also for producer countries. Middle Eastern countries, particularly oil producers on the Persian Gulf, depend on oil for most of their revenues, and the current backlash against fossil fuels has exposed the vulnerability of their economic and fiscal systems. These oil-producing countries must break the dependence of their economic and fiscal systems on fossil fuel, even more so than consumers.

Currently, each member state of the Gulf Cooperation Council (GCC) is implementing its own policy to reduce its dependency on oil. One typical approach is Saudi Arabia's *Saudi Vision 2030*. Both the public and private sectors of Japan are supporting the Vision, but most oil producers in the Gulf have been suffering worsening fiscal conditions across the board since oil prices plummeted due to Covid-19, forcing them to cut budgets and downscale projects.

Other GCC countries are also taking similar initiatives to diversify their economies, but all such initiatives require the cooperation of developed Western countries and emerging countries. Today, East Asia, including Japan, is the main destination of Gulf oil exports, making the Gulf oil producers and East Asian countries mutually dependent. There is much that East Asian countries can do to help give the oil producers a soft landing from their oil dependency. For Japan, this may include its specialties such as using oil and natural gas to build a hydrogen energy society, and promoting CCS and CCUS initiatives jointly with Gulf oil producers.

Problems in the Middle East

The problems of the Middle East are diverse and complex. The region faces serious threats

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including territorial disputes and ethnic problems such as in Palestine and Western Sahara, Iran's suspected non-peaceful nuclear program, Iran's belligerence toward the US-Israel alliance and the Gulf Arab nations, the civil wars in Syria, Yemen, and Libya, and the Qatar crisis, which seems to be changing for the better recently.

These issues are causing serious problems not only within the region but also outside it. One example is the Qatar crisis, in which Saudi Arabia, the UAE, Bahrain, and Egypt severed diplomatic ties and imposed an economic blockade on Qatar for allegedly sponsoring terrorism. This is a critical issue for Japan's energy security, which imports about 60% of its oil from Saudi Arabia and the UAE and 20% of its natural gas from Qatar, the UAE, and Oman.

Japan's former Prime Minister Shinzo Abe took a particularly strong interest in the Middle East and the Gulf region for a Japanese prime minister, and visited the region multiple times, most notably Saudi Arabia, the UAE, Kuwait, Qatar, and Egypt from April to May 2007 during his first term.

While in office, Prime Minister Abe visited the UAE four times and Saudi Arabia and Turkey three times. Since the visit to Turkey in November 2015 was for the G20 Summit, it is clear that Saudi Arabia and the UAE were Japan's highest priorities. In particular, the renewal of its oil interests in the UAE was a concern for Japan, but this was resolved for the time being when Japan managed to renew its interests in Abu Dhabi oil fields in 2011 and 2018. Regarding the Qatar crisis, unfortunately there was nothing Japan could do even though it has good relations with all the countries concerned. Notwithstanding, the leader of Japan has a duty to convey its concern to the countries directly involved.

From 2015, Prime Minister Abe twice visited Jordan, Israel, and Palestine. This indicates that contributing to the Middle East peace process is the other pillar of Japan's Middle East diplomacy, alongside energy security. Japan supports the two-state solution, or the co-existence of Israel and Palestine, and since 2006, has launched the Corridor for Peace and Prosperity initiative, in which Japan works with the countries concerned to help Palestine achieve economic independence.

While the economic independence of Palestine is essential for stability in the Middle East, developing this region alone is not enough. In 2020, Arab nations of the UAE, Bahrain, Sudan, and Morocco agreed to normalize diplomatic relations with Israel. These agreements have raised the possibility that Japan's Corridor for Peace and Prosperity, which now consists of Israel, Jordan, and Palestine, may expand to include the affluent Gulf countries. The initiative could even link up with projects that involve Israel, Egypt, and Sudan, such as Saudi Arabia's Red Sea Project.

The Yemeni Civil War and Japan

Meanwhile, one of the key current disputes is the civil war in Yemen. Five years have passed since armed conflict began between the Houthis, who captured the capital Sanaa in a de facto coup, and the legitimate government, which has located its provisional capital in Aden, but there is no end in sight. The main obstacle to resolving the crisis is the large number of parties involved and the complex relationships among them. In summary, Iran supports the Houthis, while the Saudi-and UAE-led coalition supports the legitimate government. The Saudi-UAE alliance may appear solid, but the UAE is providing military support to the southern separatists who are at odds with the legitimate government, and this could cause a split in Saudi-UAE relations. Further, Saudi Arabia has good relations with Islah, a Muslim Brotherhood-affiliated political party that the UAE detests.

Further, Al-Qaeda in the Arabian Peninsula, which is Al-Qaeda's Yemeni arm, the Yemeni branch of Islamic State, and the Ḥaḍramawt tribal forces are also clashing with each other. The relationships are so complexly intertwined that no one knows even where to start resolving the conflicts. As the world looks on with folded arms, hundreds of thousands of Yemeni people are dying of hunger, disease, and the fighting.

The first essential action is to treat the Yemeni people suffering from famine and epidemics or those injured by military attacks, and to provide food and medical supplies. However, rescue activities within Yemen require close cooperation not only with the legitimate government and Houthis, but also with the Saudi- and UAE-led coalition, the Red Cross, and the WHO. In some cases, patients in critical condition need to be transported across the border for more effective treatment, for which Yemen's neighbor, Oman, is the preferred destination. The coalition has indeed been transporting injured people to Oman. If Japan is to step in, this is where it could play a role.

Oman is participating in the mediation process for resolving the Yemeni crisis alongside Kuwait and the United Nations. By supporting Oman, Japan can not only treat Yemeni people but also indirectly back Oman's mediation efforts. Oman's economy is more vulnerable than those of other Gulf oil producers, and the country takes a neutral stance in various Middle East issues. It could play a substantial role as a mediator and broker. However, Sultan Qaboos, who had led the mediation efforts, died in early 2020, and the new regime's diplomatic stance is not yet clear. Furthermore, Japan's assistance to Oman could counterbalance China's excessive presence, which has grown significantly in Oman under the Belt and Road Initiative.

Kuwait, which is also engaged in the mediation efforts, lost its ruler Amir Shaikh Sabah, who had been leading the diplomacy of the Arab world, in 2020. His successors Amir Shaikh Nawwaf and Crown Prince Mishal have hardly been seen in the diplomatic arena and their skills are unknown. In order to not waste the achievements of Oman and Kuwait thus far, Japan and others need to support the two countries so they can continue to act as mediators.

Confrontation of the US and Gulf Countries against Iran

Japan has traditionally maintained friendly relations with Iran but began to distance itself from the country during the Koizumi administration. While Iran's suspected development of nuclear weapons was the main reason, Iran's ties with North Korea also made Japan cautious toward Iran. Japan had acquired an interest in the Azadegan oil field in west Iran but had to curtail it significantly under US pressure after allegations of nuclear weapons development were raised.

The situation changed in 2014 when the middle-of-the-road Hassan Rouhani became Iran's president and signed the Joint Comprehensive Plan of Action (JCPOA) in 2015. The JCPOA enabled Japan to approach Iran once again. However, Japan-Iran relations took a step back after the Trump administration led the US out of the JCPOA and began to tighten sanctions against Iran.

However, the traditional friendship between Japan and Iran is a major diplomatic asset for the US as well as for Japan. When tensions in the Persian Gulf rose in 2019, Prime Minister Abe visited Iran, reportedly made at President Trump's request to Japan to act as a mediator. Of course, Iran was never likely to mend relations with the US based on Japan's mediation efforts. However, from Iran's standpoint, the close relationship between Prime Minister Abe and President Trump may have been a valuable channel for communicating with the US. Moreover, it was useful for Japan to be able to convey to Iran the importance of easing tensions in the Gulf for Japan's energy security, and that Iran has a decisive role to play.

Regrettably, in terms of the economy, if Japan steps back, China will move in to fill the void. Even if Japanese companies cannot do business in Iran, Japan should at least strengthen its political and cultural presence to prevent the weakening of Japan-Iran ties.

Meanwhile, at the time of Prime Minister Abe's visit to Iran in 2019, tankers, including the Kokuka Courageous, flagged in Panama and operated by a Japanese company were attacked near the Strait of Hormuz. In response, the US and the Gulf Arab countries formed a coalition to unite against Iran and began surveillance activities in the Gulf. Japan did not join the coalition and instead dispatched ships of its self-defense forces to the Arabian Sea to secure the safety of the seas. This was an extremely delicate operation for Japan, which had to protect its oil tankers and commercial ships, monitor the reaction of its ally the US, not provoke Iran, and avoid any trouble with Gulf Arab countries.

With Democrat Joe Biden winning the US presidential election, the US' Middle East policy could change drastically. Particularly, regarding Iran, there is speculation that the US may return to the JCPOA. While the hurdle for this is not low, if tensions ease in the Gulf, there will be more opportunities for leveraging the Japan-Iran friendship.

However, economic activity in the Middle East is extremely slow due to the Covid-19 pandemic raging in the region, making it difficult for Japan to enhance its political and economic presence. And yet even in times like these, China is ramping up its presence through "mask diplomacy" And "vaccine diplomacy." Japan cannot do the same but needs to explore more effective means of supporting Middle Eastern countries by analyzing the future of the region after the Covid-19 crisis is resolved.

Writer's Profile

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His specialized field of research is: Modern History of the Gulf, Jihadist movements and History of Science and Technology in the Middle East. After receiving an MA (Oriental History) from Keio University, HOSAKA became a Special Assistant of the Japanese Embassies in Kuwait and Saudi Arabia. Since then, he has held various posts in the field of the Middle Eastern studies, including Researcher of the Middle East Institute of Japan, Director of the JSPS Research Station, Cairo, and Professor of Kindai University. He joined JIME Center, IEEJ in 2005. He is currently Visiting Professor of Waseda University.

中東安定化と日本の役割

保坂 修司 *

石油依存経済からの脱却に向けて

地球温暖化の元凶として石油や天然ガス等の化石燃料への風当たりが強まっている。日本は、一次エネルギーの約 8 割が化石燃料由来であり、その大半を輸入に頼っている。石油はその約 4 割を占め、ほとんどが中東からの輸入だ。日本が石油を使っているかぎり、中東地域の安定はきわめて重要となる。しかし、中東地域は、さまざまな紛争に翻弄され、将来的にも安定的なエネルギー供給源でありつづけられるかどうかは不透明である。

中東の安定化は、日本だけではなく、日本と同様に中東起源の化石燃料に依存する国ぐにとっても不可欠である。逆にいえば、これらの国ぐにが、カーボンフリーのエネルギーへの転換を果たすまえに、中東がさらに不安定化し、石油や天然ガスの供給が滞るようなことになれば、世界経済そのものに深刻な影響が出かねない。

石油への依存は、消費国だけの問題ではない。生産国の問題でもある。中東、とりわけペルシア湾岸の産油国は歳入の多くを石油収入に依存しており、化石燃料への風当たりは、湾岸産油国の経済・財政システムそのものの脆弱性を露呈させたといえる。つまり、化石燃料に依存した現行の経済・財政システムからの脱却は、消費国以上に、産油国にとって不可避の課題となっているのである。

現在、GCC 諸国は各国が独自に脱石油依存政策を進めている。その代表的なものが、サウジアラビアの「サウジ・ビジョン 2030」である。日本も、官民挙げて同ビジョンに協力しているが、新型コロナウイルス感染拡大で石油価格が大幅に下落したため、湾岸産油国は軒並み財政状況が悪化、予算を削減したり、プロジェクトの縮小を迫られている。

他の GCC 諸国のイニシアティブもサウジ・ビジョンと同様、経済の多角化を目指しているが、どの場合でも、西側先進国や新興国の協力が不可欠となっている。今日、湾岸産油国の石油の主たる輸出先は日本を含む東アジア諸国である。そして、その意味で、湾岸産油国と東アジア諸国は相互依存の関係にあるといっていい。湾岸産油国を石油依存体質から軟着陸させるためには、東アジア諸国が貢献できる部分は少なくないはずだ。日本の得意分野でいえば、水素社会構築を目指しての石油や天然ガスの利用、さらに CCS や CCUS の取組みを湾岸産油国と共同で進めていくことなどが重要であろう。

中東の諸問題

中東地域が抱える問題は多様、かつ複雑である。パレスチナ問題や西サハラ問題など領土問題・民族問題、イランの核疑惑、米・イスラエルとイランの対立、湾岸アラブ諸国とイランの対立、シリア内戦、イエメン紛争、リビア内戦、カタル危機などが今日の中東地域が直面する深刻な脅威となっている。

これらの問題は単に域内にとどまらず、域外にも深刻な影響をおよぼしている。たとえば、

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カタル危機は、サウジアラビア・UAE・バハレーン・エジプトの 4 国がテロ支援などを理由にカタルと断交して、経済封鎖を行った事件である。日本は石油輸入の約 6 割をサウジアラビア・UAE に依存しており、天然ガスの 2 割近くをカタルと UAE やオマーンから輸入している。カタル危機は日本のエネルギー安全保障にとってきわめて深刻な問題といえる。

安部前首相は、日本の首相としては例外的に中東、とくに湾岸地域に強い関心を有し、第一次内閣のときの 2007 年 4 月から 5 月にかけてサウジアラビア、UAE、クウェート、カタル、エジプトを訪問したのをはじめに何度も中東に足を踏み入れている。

安倍首相は在任中、UAE には 4 度、サウジアラビアとトルコには 3 度訪れている。このうち 2015 年 11 月のトルコ訪問は G20 サミット参加のためであり、したがって日本が UAE とサウジアラビアを最重要視していることがうかがわれる。とくに UAE の場合、石油利権更新という懸案事項があったが、2011 年と 2018 年にアブダビにおける油田の利権を更新できたため、とりあえず一安心であろう。カタル危機に関しては、日本は全関係国と良好な関係をもっているが、残念ながら手詰まり状態ではある。だが、日本のトップとして当事国に危機意識を伝えておくのは必要であろう。

2015 年以降だけでみれば、ヨルダン、イスラエル、パレスチナを 2 度訪問している。エネルギー安全保障とともに、中東和平への貢献も日本の中東外交の柱となっているのがここからもわかる。日本は、イスラエル・パレスチナ共存の「二国家解決」を支持しており、2006 年以降、関係国と協力しながらパレスチナの経済的自立を目指す「平和と繁栄の回廊」構想を打ち上げている。

もちろん、パレスチナの経済的自立は中東安定化にとって不可欠であるが、この地域だけに限定した開発では不十分である。2020 年に UAE、バハレーン、スーダンといったアラブ諸国がイスラエルとの国交正常化で合意した。それによって、日本が構想する「平和と繁栄の回廊」も、従来のイスラエル、ヨルダン、パレスチナという枠組を拡大し、豊かな湾岸諸国を巻き込む可能性も出てきたことは重要である。サウジアラビアの「紅海プロジェクト」等、イスラエルやエジプト、スーダンなどが関わるプロジェクトとの連結も視野に入れられるだろう。

イエメン紛争と日本

一方、現在継続中の大きな紛争としてはイエメン内戦がある。首都サナアを事実上のクーデタで占拠したフーシー派と南部のアデンを暫定首都とする正統政府の武力衝突はすでに 5 年を経過しているが、今のところ解決の糸口さえ見えない状況だ。解決を困難にしている最大の理由は、関係するプレーヤーが多く、しかもそれぞれの関係性が複雑に絡んでいることである。大枠は、イランがフーシー派を支援し、そのイランと対立するサウジアラビア・UAE 主導の有志連合が正統政府を支援するという構図になる。サウジアラビアと UAE は強固な同盟関係を構築しているようにみえるが、UAE は、正統政府と対立する南部分離独立派を軍事的に支援しており、この点は両国関係のあいだの楔にもなりかねない。さらに UAE は、正統政府を構成するムスリム同胞団系政党イスラーフを嫌悪しているが、サウジアラビアはそのイスラーフと良好な関係を有する。

さらに、アルカイダのイエメン支部である「アラビア半島アルカイダ」と「イスラーム国」のイエメン支部、そしてハドラマウトの部族勢力もたがいに対立し、衝突している。これだけ複雑に絡み合っていると、どこから手をつけていいかすらわからない。しかし、手をこまねいているあいだにも、多くのイエメン人が飢餓や伝染病、軍事衝突で死んでいる。

したがって、まず手をつけなければならないのは、飢餓や伝染病で苦しんだり、軍事攻撃で傷ついたりしたイエメン人の治療であり、食糧や医薬品の提供であろう。だが、イエメン国内での援助活動には、正統政府・フーシー派だけでなく、有志連合や赤十字・WHO などとの密接な連携が必要となる。重篤な患者は、場合によっては、周辺諸国に移送し、そこで治療を行うほうが効率的であろう。その場合、イエメンの隣国オマーンが第一候補となる。実際、すでに有志連合は、負傷者のオマーンへの移送を実行している。日本が関与するとすれば、おそらくここであろう。

オマーンは、クウェートや国連とともに、イエメン紛争解決のための調停を行っており、オマーンに支援を提供することで、単にイエメン人の治療を行うだけでなく、間接的に同国の調停努力を支援することになる。オマーンは湾岸産油国のなかでは経済が脆弱であるが、中東の諸問題で中立的な立場をとっており、調停・仲介役として果たせる役割は小さくない。しかし、2020 年はじめに調停外交を引っ張ってきたカーブース国王が崩御、新体制移行後の外交方針は不透明だ。また、近年、一帯一路政策を掲げる中国のオマーンへの進出が顕著であることから、日本によるオマーン支援は、中国の過剰なプレゼンスに対するカウンターバランスともなるだろう。

同様に仲介役を果たしているクウェートでも、2020 年に「アラブの外交団長」と呼ばれたサバーフ首長が亡くなった。後継者のナウワーフ首長やミシュアル皇太子はいずれも外交の表舞台に登場することが少なく、その手腕は未知数である。オマーンやクウェートがこれまで培ってきた成果を無駄にしないためにも、両国が継続的に仲介役を果たせるよう、日本などが後押しする必要がある。

イランと米・湾岸諸国の対立

一方、イランと伝統的な友好関係を有してきた日本は小泉政権時代にイランと距離を置きはじめる。同時期に明らかになったイランの核疑惑が大きな要因であるが、日本の場合、イランと北朝鮮の関係もイランに対する警戒感を高める原因となった。日本はイラン西部のアーザーデガーン油田の権益を獲得したが、核疑惑発覚をきっかけに米国からの圧力が高まり、結局、権益を大幅に縮小せざるをえなくなっている。

状況が変わったのは 2014 年に中道派のロウハーニーがイラン大統領に就任し、2015 年に包括的核合意（JCPOA）が締結されて以降である。JCPOA によって、日本はふたたびイランと接近するようになった。だが、トランプ政権が JCPOA から離脱し、さらに対イラン制裁を強化したため、日本とイランの関係は後退を余儀なくされる。

しかし、日本とイランの歴史的な友好関係は、日本にとってのみならず、米国にとっても重要な外交上のアセットである。2019 年にペルシア湾で緊張状態が高まった際、安倍首相がイランを訪問した。これにはトランプ大統領から仲介要請があったとも伝えられている。もちろん、イランが日本の仲介を受け入れて、米国と関係改善をするとは考えづらい。しかし、イランからみれば、安倍首相とトランプ大統領の緊密な関係は、イラン側の思いを米国に伝える非常に重要なパイプと映ったのかもしれない。また、日本からみれば、日本のエネルギー安全保障上、ペルシア湾地域の緊張緩和が重い意味をもち、イランがそれに決定的な役割を果たせることをイラン側に説明できた点は評価に値する。

残念ながら、経済面では、日本が引けば、代わりに中国が進出してくるだけだ。しかし、日本企業がイランで活動できないならば、せめて政治的・文化的なプレゼンスを維持・強化する

ことで、二国間関係の希薄化を防ぐしかない。

他方、2019 年の安倍首相のイラン訪問時に、ホルムズ海峡でタンカーが襲撃される事件が発生した。こうした事態を受け、米国や湾岸アラブ諸国は反イランの立場から有志連合を組み、ペルシア湾地域の監視を開始した。だが、日本はそれには参加せず、海洋の安全確保のため、独自にアラビア海に海上自衛隊の艦船を派遣した。同盟国である米国の対応を横目に見つつ、同時にイランを刺激せず、湾岸アラブ諸国とも波風を立てないよう、かつ日本の艦船の航行の安全を見守るという綱渡り的な作戦である。

また、米国の大統領選挙で民主党のバイデン候補が当選を確実にしたなか、米国の中東政策も大きく変化する可能性が高い。とくにイランについては、米国が JCPOA に復帰する可能性も取りざたされている。そこに至るまでのハードルはけっして低くはないものの、ペルシア湾岸地域で緊張緩和が進めば、日本とイランの友好関係がふたたび有効活用される機会も増えるであろう。

しかし、現在、新型コロナウイルス感染が中東各国で猛威を振るっており、経済活動が大きく縮小している。日本が政治的・経済的プレゼンスを拡充するのは困難である。だが、中国は、このような時期にあっても、マスク外交として積極的に中東におけるプレゼンスを増している。日本が同じことを行うのは不可能だが、コロナ後の中東の未来を精査したうえで、中東諸国にとってより効果的な支援策を探っていく必要があろう。

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What Can Stabilize the Middle East Region; Military Power or Soft Power

Tatiana Mitrova*

Combatting COVID-19 has resulted in 2020 in a sharp reduction in economic activity and global demand for energy resources and the collapse of energy prices. The oil and gas markets have been affected most of all, with a simultaneous drop in demand and prices. This shock threatened Middle East two-fold: in the short term, a drastic shrinking of revenues from energy exports, and in the long term, the acceleration of energy transition and the redivision of energy markets. The only sustainable solution which could prevent Middle Eastern region from economic and social destabilization accompanied by military conflicts is to help it to diversify and decarbonize its industry.

Middle Eastern economies became much more vulnerable during the pandemic: COVID-19 caused a tremendous oil shock with oil prices and revenues of the oil producing countries collapsing in spring 2020, state expenditures in the region growing in order to face COVID-19 economic slowdown and social dissatisfaction. Oil industry, which is the backbone of all the major economies in the region, is experiencing probably its most painful demand-driven shock ever, members of OPEC+ coalition had to reduce dramatically their output and exports, while total global investment into oil and gas exploration and production fell by 34%, the lowest since 2004, according to International Energy Forum and the Boston Consulting Group[1]. This is indeed a strong macroeconomic and social challenge for all the countries of the region, and many observers are concerned about the military stability of the region in this extraordinary situation with raising marginalization of the society.

This unpleasant current situation is aggravated by a more long-term (and, probably, even more painful) challenge of the energy transition. Basically, COVID-19 could be even regarded as an "energy transition test-drive", illustrating potential impact of decarbonization and moving away from oil on the stability in the resource-rich countries. This process is characterized by oversupplied oil and gas (and coal) markets and expectations of stranded assets lead to "lower-for-longer" prices. Growing share of renewables limits the demand growth for fossil fuels, thus resulting in lower than expected export volumes for hydrocarbons. Creation of carbon border adjustment mechanisms, which is currently being prepared in the EU for introduction in 2022, might well be adopted in the future by the other countries and regions and could become a long-term source of instability for

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[1] https://www.worldoil.com/news/2021/1/29/fossil-fuel-transition-expect-oil-price-spikes-as-capital-investment-declines?fbclid=IwAR3BH0YOegRpZCgoQGjlqHW-u-HBjTzbdoScMLuk8bfB9twrpi47Vab2zFU

economies relying on fossil fuels. Moreover, banks and financial institutions are assessing climate risks and becoming more reluctant to provide financing for fossil fuel – many of them have stated already complete refusal to finance oil and gas related projects.

It is clear that the global energy transition towards a lower carbon system presents some real threats for the Middle East. Perhaps the most obvious is financial, with lower hydrocarbon rents meaning lower budget revenues and slower economic growth, with implications for government spending and the wealth of the population at large. This could have implications internationally, if reduced military spending of some of the countries in the region will clash with marginalized impoverished population in the other countries – in this case military conflicts might become inevitable. At the same time, at home these governments will also face huge risks of domestic conflicts and separatism, if the current political regimes are undermined by their ability to satisfy the welfare demands of its population.

Furthermore, these problems could be exacerbated by the fact that countries of the Middle East may have a weaker position in international financial markets as restrictions on the availability of capital for carbon-intensive industries may well be increased. In addition, even their non-energy exports may be impacted if carbon tax adjustments are made for imported goods in key markets. The combination of all these factors could weaken their global geopolitical position, which could be further undermined by increased use of renewables in countries where they were targeting their energy exports and which were to a certain extent guarantying stability in the region. For example, the U.S. and the countries in North East Asia could become less engaged with the Middle East as their energy needs increasingly focus on alternative sources with lower carbon intensity, and will no longer be interested in playing stabilizing role for the region nor with military, nor with Soft Power. This scenario seems to be very pessimistic for the region and, in the longer term, will definitely have negative consequences for the whole world.

However, despite the presence of these clear threats, there are also reasons for optimism thanks to huge potential of Middle East in solar, carbon capture and hydrogen. If green technology transfers and capital are available, these countries could become leaders in decarbonizing oil and gas, as well in solar generated electricity and heat. Saudi Arabia and several other countries of the region are already very closely studying potential for commercialization of CCUS, direct air capture, usage of CO_2 for enhanced oil recovery, blue hydrogen production, etc. and have even developed the whole concept of "Circular Carbon Economy".[2] In addition to that, Middle East has huge solar power potential, and if improvements in technology could allow DC lines to be connected to major consumers in Europe and Asia, then Middle East could become a major exporter of green electricity or, alternatively, produce and export green hydrogen. The first projects of export-oriented green hydrogen production are already underway in Saudi Arabia.[3]

Transforming this potential into reality would require huge support from the international

[2] https://www.aramco.com/en/making-a-difference/planet/the-circular-carbon-economy
[3] https://www.greentechmedia.com/articles/read/us-firm-unveils-worlds-largest-green-hydrogen-project

partners – but at the end of the day these efforts could be the most efficient "investment" in stabilizing the region and, simultaneously, facing the global climate challenge. The U.S., China, EU and Japan could use their soft power and perform as the key providers of financial and technological support for diversification and decarbonization of the Middle Eastern economies – for the mutual benefit. This would be the most optimistic "win-win" scenario.

But as long as oil is still representing the dominant source of revenues, it is also critically important to try to keep this market stable for the very period of transition – in this respect further cooperation and some sort of coordination between Middle East, Russia and the U.S. (three major oil producing countries) could be extremely valuable not only for the MENA countries, but also for all oil producing countries globally and for the whole global oil market stabilization. This need for producers' coordination on the shrinking oil market became obvious (and supported by all the key global stakeholders, including G20) as a result of COVID-19 and March 2020 oil price collapse.

This critical situation forced producers to agree on compromises which were unthinkable previously. In April 2020, OPEC members and, for the first time ever, non-OPEC countries resolved to collectively decrease production: the former for two years, including by 8.2 million barrels per day in 2020, the latter (the USA, Canada, Brazil) by 5 million barrels per day, without strict obligations. The agreement helped to avoid the worst-case scenario but did not guarantee rapid market growth. The April agreements, like quarantine measures, does not treat the disease but will help mitigate its consequences over time. The agreed reduction in production was sufficient only to avoid overfilled storage facilities and negative prices, as long as all participants fully observe the agreement.

This April 2020 OPEC++ deal marked a new milestone in the global governance of the oil markets and the new role of this coalition – it was no longer blamed by the consumers as cartel, manipulating prices, but fully supported as the only reasonable instrument allowing to avoid complete collapse of the physical, and, more importantly, financial oil market. Up until 2021 only massive production cut and strict compliance with the quotas were providing an acceptable price level for the oil producers.

It is indeed an extraordinary deal without exit: if OPEC + (or any of its biggest participants) will just open the taps, the prices will get back to the situation of March 2020. So now oil producers have to learn, how to operate within this new framework, how to negotiate the quotas with the oil producers outside Middle East (first of all – with Russia, which is thus gaining new instruments of geopolitical influence in the Middle East) and how to remain profitable in the highly competitive market with declining demand. So this is another area, where soft power from the U.S. and Russia on the producer side and China, Japan, EU and India on the consumer side could actually affect the situation and allow to keep oil prices, which are so critical for the region, in an acceptable range.

This whole interplay between medium-term OPEC+ power game and long-term geopolitics of energy transition makes the future of Middle East extremely unclear and unpredictable, but at the same time create some opportunities for a profound change in the region's social-economic model and, most likely, its political model as well.

Writer's Profile

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Covid-19, Oil and Stability in the Middle East

Paul Stevens*

This short article is based upon two assertions: The Middle East is already unstable. The Covid-19 pandemic will aggravated that instability.

Three factors explain the existing instability. First, the causes of the Arab Uprisings, which began in Tunisia at the start of 2011, have not been addressed. Thus there remains popular frustration with incompetence and corruption on the part of governments and general unmet aspirations. Second, there has been a general failure to diversify their economies away from dependence on oil. This is largely because the ruling elites in many countries have stifled the private sector because of a lack of property rights and a tendency to grab all the best deals for themselves. Thus the post-2014 oil price collapse and the consequent collapse in government oil revenues meant they were unable to buy-off popular unrest arising from growing unemployment amongst a rapidly growing young population. Around one third of the population in the region is aged between 15 and 29. Finally, for the last two hundred years at least the region has suffered from interference by outside powers. This created competing ‘client states’ leading inevitably to conflict between these states.

The current ‘energy transition’ has already aggravated this instability. An ‘energy transition’ is when an economy switches from one main source of energy to another. The current transition is away from hydrocarbon molecules to electrons. It was triggered initially by concerns over carbon emissions and climate change but more recently this has been reinforced by concerns over urban air quality. As with earlier transitions, once the triggers have been pulled, reinforcing factors come into play usually related to technical change altering relative energy prices. This time, these revolved around the falling costs of renewables and the development of electric vehicles. The speed of this transition was being seriously underestimated by the ‘energy establishment’ i.e. the IEA, OPEC, the large international oil companies (IOCs) and many others. This was because of vested interests, a degree of intellectual inertia and a tendency for forecasters to cluster together for safety. Their arguments have tended to revolve around a view that ‘energy transitions are slow’. While it is true that some have indeed been slow, in more recent times, the speed has been very much faster especially when governments are involved. Thus the French experience from coal and oil to nuclear took only ten years while the UK switch from coal to renewables took only around 8 years. This ‘energy transition’ has already aggravated regional instability as the slowing of growth in oil demand has led to competition for oil market share with growing conflict between Saudi Arabia

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and Iran, fuelled by the US.

Into this unstable mixture we can now examine the impact of the COVID-19 pandemic. There has been much discussion in the media about the fact the pandemic has led to a lock-down in many countries, leading to “oil demand destruction” and a collapse in oil prices. However, such claims are misleading and confuse demand destruction with demand deferment. The level of oil demand is determined as the result of the consumer taking a three-stage decision. Oil demand is a derived demand. Consumers do not want gasoline or jet fuel. They want the energy services – the light, heat or work – they provide. To get these services, the oil must be consumed in an oil-using appliance – a car, a jet plane etc. Thus the first decision by the consumer is whether to buy the oil-using appliance? The second decision is what type of appliance, related in some case to which fuel to use, assuming there is a technical choice between different fuels. Another choice is whether to buy an energy efficient or energy inefficient appliance. The choice will be determined by the costs of saving on fuel over the life of the appliance versus the difference in purchase price. Efficient appliances tend to cost more. The final decision by the consumer is the capacity utilization of the appliance once bought.

Collectively these three decisions determine how much oil is demanded. Once the first two decisions have been taken, the appliance stock is fixed. Thus in the short-term, oil demand destruction can only occur if the appliance is destroyed and/or replaced by a more efficient appliance or an appliance using another fuel. Once oil demand has been destroyed it cannot return unless a new oil-using appliance is created. However, the consumer has the choice to underutilize the capacity of the appliance. In that case, oil demand is deferred until the capacity use is increased if it ever will be. Thus the fall in oil demand as a result of the COVID-19 pandemic is not per se demand destruction. It is only demand deferment. Whether it will return when the pandemic ends, depends upon what else happens to the appliance stock and how it is utilized, i.e. consumer behaviour. It only becomes demand destruction if the behaviour to reduce capacity utilization of the appliance becomes irreversible and the appliance is scrapped. Any such behaviour can of course be determined by government policy. An important question is whether the changes in behaviour as a result of the pandemic is a blip or a permanent discontinuity.

The global lock-down has severely impacted GDP as a result of recession. Therefore, so far, most of the fall in oil demand has been deferred demand, which implies that it could come back. Estimates of how much oil demand has fallen so far this year vary and the data are very unreliable. The longer the lock-down continues the greater the damage will be in terms of firms going out of business and supply chains being disrupted. There is already a second wave of infections in many countries. If the economic damage continues to grow, oil demand will begin to suffer from demand destruction as the appliance stock shrinks. Also, after some point, as government budget deficits rise, it may be increasingly financially difficult for many governments to mount any sort of effective stimulus package to protect jobs and maintain aggregate demand in the economy so far experienced in many countries.

Whatever the nature of the fall in oil demand, it is indisputable that oil revenues for the oil producing countries have fallen dramatically, greatly aggravating the ability of the governments to buy-off the domestic unrest and consequent political instability that has already been present in the Middle East since 2014.

An important uncertainty created by the pandemic in this context is whether it will speed or slow the energy transition. Some have argued that the pandemic and its aftermath will divert political attention away from climate change thereby slowing the transition. This will be reinforced because lower oil prices may slow the move away from oil and the economic recession may well slow spending on EVs and solar panels. All this might be reinforced if growing conflict between China and the West reduces the chances of agreements linked into COP26 in 2021. However, these arguments have several flaws. Much of the lower crude prices will not be passed onto consumers in full as sellers of oil products try to protect their margins and consumer governments try to capture some of the fall by increasing sales taxes on oil products. Also, the pandemic has actually emphasised the need for governments to intervene even more to correct market failures, which will encourage further regulatory moves towards a lower carbon economy.

By contrast, some have argued the energy transition will be speeded up as a result of the pandemic. As a result of the economic recession many are now expecting oil demand to peak sooner rather than later. This is very much driven by reductions in demand for travel following changes to working patterns. Transport accounts for 60 percent of liquid fuels demand. The pandemic has also raised concerns about self-sufficiency and import dependence in value chains that will constrain international trade. Renewables remove much concern over import dependence. Also, renewables can be small scale and decentralized allowing governments to address issues of fuel poverty without recourse to very expensive grids for electricity of gas.

If the transition is faster than many expect this will lead to lower oil demand post the pandemic. This will aggravate instability in the Middle East as falling revenues cause rising unemployment. Such instability will be greatly aggravated as producers compete for a declining market share. There is however one slight ray of hope on the horizon. As oil becomes less important, it is likely that the importance of the Middle East in the geopolitics of global energy will diminish. Thus there will be much less incentive for others to interfere in the region. As outlined at the start of this short piece, this could reduce what has been a major cause of instability in the region. However, before this happens, and it will take at least a decade if not longer before this might happen, the region faces the serious prospect of an increasing number of failed states as the governments are unable to keep the lid on a bubbling cauldron.

Writer's Profile

Paul Stevens

Professor Stevens was educated as an economist and as a specialist on the Middle East at Cambridge and SOAS; 1973-1979 teaching at the American University of Beirut in Lebanon; 1979-93 at the University of Surrey. Between 1993 and 2008, he was Professor of Petroleum Policy and Economics at the University of Dundee, Scotland, a chair created by BP. He is an expert in the international petroleum industry, economic development in the Gulf and energy economics.

Decarbonization and Energy Geopolitics

Nobuo Tanaka*

Prime Minister Suga declared that Japan, too, will aim to reach net-zero carbon emissions, or carbon neutrality, by 2050. The declaration came soon after Chinese President Xi Jinping surprised the world by declaring in September last year that China will aim to reach carbon neutrality by 2060, after the EU released an ambitious green deal in 2019 aiming to achieve carbon neutrality. Furthermore, the United States, too, is likely to fully engage in decarbonization efforts once the Biden administration is inaugurated. Meanwhile, the International Energy Agency (IEA) has unveiled a 2050 Net-Zero Emission Case (NZE2050) in its latest World Energy Outlook (WEO2020) in addition to its Sustainable Development Scenario.

There are several reasons why a previously unthinkable scenario is now being widely discussed. First, many governments, particularly in the Europe, have pledged to go carbon neutral by 2050. Japan, the US, and China later decided to take the same direction. Second is the significant drop in the cost of renewable energies, including solar PV and wind power. The IEA has said that solar PV will be the new king of electricity. Third, many mega tech firms, the leaders of the digital transformation that has accelerated with the coronavirus pandemic, are now committing themselves to decarbonization one after another. A typical example is Apple, which has declared that the company, together with their component supply chain, will go carbon-neutral by 2030. This will require any company worldwide to aim for carbon neutrality if they want to do business with Apple. I call this phenomenon a “demand-side driven energy transformation.” Fourth, investment in renewable energy is robust, underpinned by the green recovery plans established by governments to emerge from the coronavirus crisis, in contrast to the slump in demand for fossil fuels due to the crisis. I was personally astonished to hear IEA Executive Director Dr Fatih Birol say, “Today, I’m more optimistic than ever about the world’s ability to reach the goals of the Paris agreement,,”. The speed of change is accelerating.

However, to achieve net carbon neutrality, extreme levels of technological innovation and infrastructure investment are required. The IEA has set its sights on four new technologies that will accelerate the use of renewable energy: hydrogen; batteries; carbon capture, utilization, and storage (CCUS); and small modular reactors (SMRs). Infrastructure investment will also be enormous. For instance, the amount of investment needed is roughly the equivalent of building the world’s largest solar park every two days for solar PV, the world’s largest electrolysis plant every hour for hydrogen energy, and a mega CCS site every week. Furthermore, at least half of all new cars will need to be EVs within 10 years. Consumer behavior will also need to change. The necessary changes will

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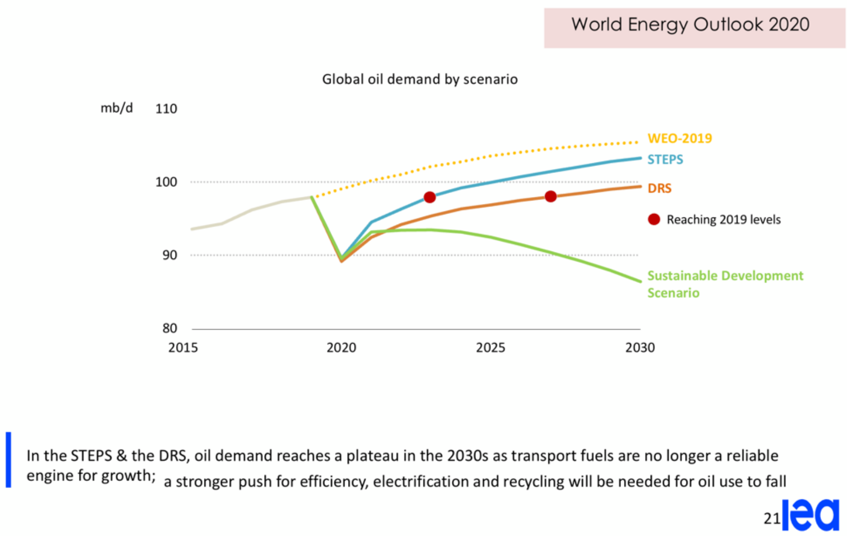
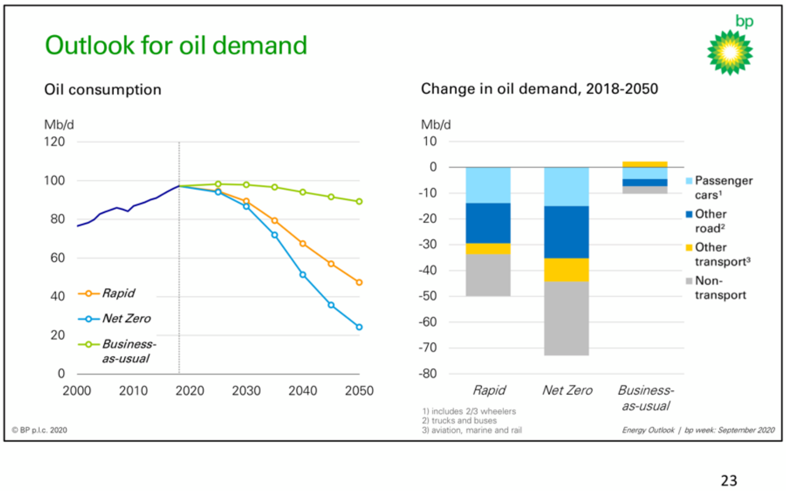
encompass all aspects of daily life; flights shorter than one hour will need to be banned in air transport; car rides shorter than 3 km will need to be replaced by cycling or walking; 20% of all workers in the world will need to work at home three days a week; and household air-conditioners will need to be turned up (or down) 3 degrees Celsius when cooling (or heating). A transformation on this scale will not happen without more rigorous government regulation, in addition to imposing major carbon taxes or creating a carbon credit trading market. Many countries in Europe, China, and the state of California have decided to ban the sale of gasoline vehicles by 2035.

The IEA considers that the global demand for oil will not peak for another ten years, but according to NZE2050, the demand has already peaked, in 2019 (Fig. 1). In its recent energy outlook, oil major BP shocked the world by stating that 2019 could have marked the peak of oil demand if governments implement active measures toward decarbonization, and even if not, the demand would level off without rising significantly above 2019 levels (Fig. 2). This outlook explains why BP decided on a massive write-off of its oil resources in spring 2020. The conventional model in the oil business has been to drill and extract underground resources in limited amounts and sell them at high prices, assuming that demand will keep growing. High prices were made possible by the oligopoly of a handful of oil majors and the cartel of OPEC oil producers. This business model will no longer be feasible if oil demand declines. Even if oil demand declines and international wholesale prices fall, the price of carbon dioxide will rise to some $140 per tonne in developed countries (as per the IEA's Sustainable Development Scenario), pushing up the consumer price of oil, including the price of carbon, thus passing the rents costs from producers to consumers. With the governments of European countries and the EU switching their policies to decarbonization, the European oil majors including BP, Total and Shell have suddenly switched gear to decarbonization. They have abandoned coal, shifted from oil to natural gas, and are ramping up their hydrogen and renewable energy businesses. US majors have been slower to react, but such a transformation will be the global norm in the energy business in the future.

Oil demand will not fall quickly unless there is a major change in policy.

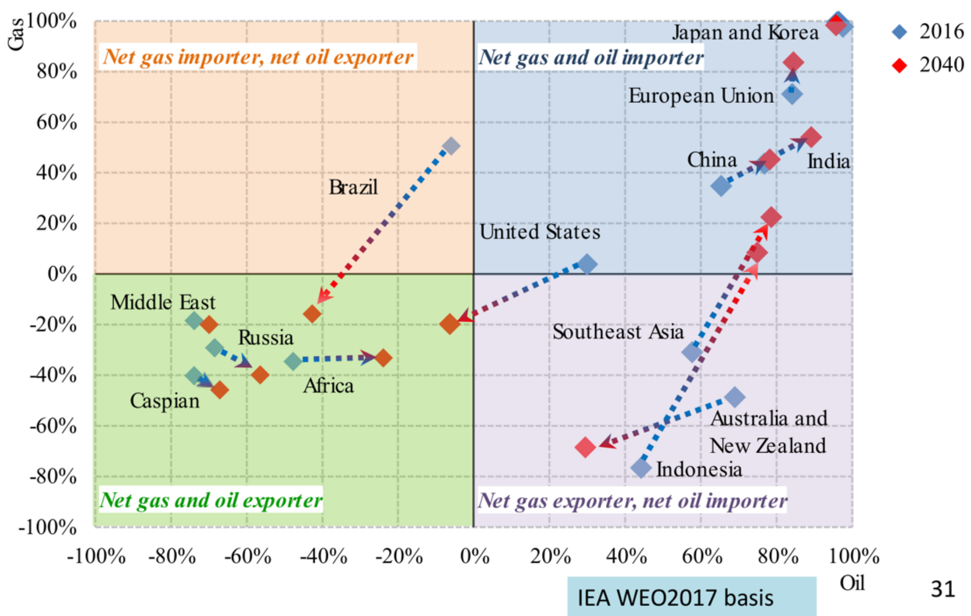


Oil major BP shocked the world by predicting that demand will peak earlier than expected.



This is a catastrophe for countries that depend on oil and natural gas production. As symbolized by the efforts of US President Trump who went as far as to broker a deal between Saudi Arabia and Russia to cut oil production as oil demand evaporated due to lockdowns amid the coronavirus, oil and gas producing countries will do whatever is in their power to maintain their conventional energy dominance. Meanwhile, Europe and China will endeavor to attain energy self-sufficiency by making maximum use of renewable energy. Just as Covid-19 has caused societies to polarize into the rich and the poor in domestic politics, the world of energy is likely to polarize further into fossil fuel-dependent and renewable energy-based countries (Fig. 3). Will opposite sides start crashing with one another, just as in domestic politics? Or is there a different path?

Possible polarization of post-Covid energy self-sufficiency strategies: The US will form an oil and gas producer coalition with Russia and Saudi Arabia, while China and the EU will opt for renewable energy. What should Japan do?



About five years ago, I was invited to a board meeting of Saudi Aramco with Daniel Yergin and was asked, “When will oil demand peak?” This question would be absolutely normal today, but back then, I was shocked and was not sure if it was a serious question. However, I soon realized that they had good reason to be worried, with electric vehicles (EVs) and hydrogen fuel cell vehicles (FCVs) starting to be seen on the streets and with countries ramping up their emission reduction commitments ahead of COP21. For Saudi Arabia and other oil producers, peak oil demand is a nightmare. The curve for peak oil was first discoveredby Hubbert in 1956, but it was based on production. In reality, oil fields were developed one after another and although costs increased, the peak never came. Thanks to high oil prices, the United States could boost production through technological innovation and return to the helm of global oil production after the shale oil revolution. However, producers can do nothing about peak demand. I recall the words of Saudi Arabia’s former petroleum minister, Zaki Yamani: “The Stone Age did not end, because we ran out of stones.” In response to that question from Aramco five years ago, I answered “2030 or earlier,” which was earlier than 2035 widely accepted in the oil industry back then, because at COP21 in Paris both the US and China were keen to reach peak CO_2 emissions by 2030. Thereafter, China continued to build large numbers of solar PV and wind power plants, shift to EVs and FCVs, and has begun to suggest that oil demand will peak in 2025. And now the coronavirus pandemic is likely to cause the oil era to end even earlier.

One of the possible solutions is hydrogen. Aramco had high hopes for hydrogen even back in 2015 when I received the question. It is possible to produce clean hydrogen by extracting hydrogen from oil and re-injecting the carbon dioxide into geological formations for enhanced oil recovery (EOR). Such hydrogen is currently called “blue hydrogen” and is distinguished from green hydrogen, which is sourced from renewable energy. Saudi Arabia has begun to work on trials of both types of hydrogen. For example, it plans to build a plant near the futuristic city of Neom, which will generate green hydrogen through electrolysis using solar power and convert it into ammonia. Furthermore, a plan is under way with Japan to convert blue hydrogen into ammonia and export the product.

Japan has long relied on imports for fossil fuels. However, the country diversified its sources of energy after the oil crises to promote coal- and gas-fired thermal power, nuclear, and energy conservation. Fifty years ago, Japan developed a business model to liquefy natural gas, a cleaner fossil fuel, to transport the gas in liquid form, and LNG has now become Japan’s specialty. However, natural gas does emit CO_2, though in relatively smaller amounts. If Japan were to decarbonize, the key would be hydrogen, as in Saudi Arabia, rather than LNG. Energy will be traded by transporting decarbonized oil, coal, natural gas as blue hydrogen, converting and transporting renewables-sourced electricity as green hydrogen, or importing electricity directly by connecting power grids; this can be the fresh vision of energy trading. Hydrogen can be transported, in addition to ammonia, as an organic hydrate (methylcyclohexane, MCH) or as liquid hydrogen, and Japan is the world’s frontrunner in both these technologies. The IEA considers that decarbonizing existing hard-to-abate sectors and facilities is the most difficult challenge, and the challenge is particularly relevant in Asia where many plants are still young. One solution might be for Japan to promote clean ammonia co-firing in coal-fired thermal power plants, a technology Japan is currently considering, to consumer countries in Asia and Middle East oil-producing countries. Singapore intends to use MCH as the Asian hub of the hydrogen trade. Australia plans to export blue hydrogen generated from brown coal and green hydrogen from solar PV. It also plans to connect its power lines to Singapore. If society actually achieves carbon neutrality, the marginal cost of fossil fuel for the power sectors should become zero, to match those of wind power and solar PV. Gas resources underground acquired value by being converted into LNG, but in future, value will be created by converting gas into hydrogen. Oil demand slumped due to the coronavirus pandemic, and oil prices became negative at one point. Covid-19 will usher in an era where demand determines the form of supply. This could be a tremendous opportunity for Japanese companies depending on the way they choose.

Writer's Profile

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Mr. Tanaka is the Distinguished Fellow at the IEEJ. He is the chairman of the Steering Committee of Innovation for Cool Earth Forum (ICEF). As Executive Director of the International Energy Agency (IEA) from 2007 to 2011, he initiated a collective release of oil stocks in June 2011. He also played a crucial and personal role in the strengthening of ties with major non-Member energy players, including China and India. He began his career in 1973 in the Ministry of Economy, Trade and Industry (METI), and has served in a number of high-ranking positions, including Director-General of the Multilateral Trade System Department. He was deeply engaged in bilateral trade issues with the US as Minister for Industry, Trade and Energy at the Embassy of Japan, Washington DC. He has also served twice as Director for Science, Technology and Industry (DSTI) of the Paris- based international organization, OECD. He is currently CEO of Tanaka Global, Inc. He is also former Chairman of the Sasakawa Peace Foundation and serves as a Board member or an auditor at some corporations.

脱炭素化とエネルギー地政学

田中　伸男 *

菅総理が我が国も 2050 年に実質炭素排出ゼロ（カーボンニュートラル）を目指すと宣言した。EU も脱炭素を目指す野心的なグリーンディールを去年発表していたのに続き、この 9 月には中国の習近平主席が 2060 年を目標にすると宣言し世界を驚かせたばかりであった。更に米国にバイデン政権が生まれれば米国も脱炭素に本格的に取り組むと考えられる。国際エネルギー機関（IEA）も最新の世界エネルギー見通し（WEO2020）の中で従来の持続可能シナリオに加え 2050 年ネットゼロケース（NZE2050）を提起した。

従来であればとても考えられなかったシナリオが語られるようになったのには理由がある。第一に EU や欧州諸国を中心として多くの政府が 2050 年ネットゼロを宣言していること。これに日米中も足並みを揃えることになる。第二に太陽光風力など再生可能エネルギーのコストが大幅に落ちてきたこと。IEA は太陽光が発電分野の新しい王様だという。第三にコロナで加速するデジタルトランスフォーメーションの旗手であるメガテク企業が次々に脱炭素を打ち出していること。アップルが典型だが自分だけでなく部品のサプライチェーンを含めて 2030 年までの脱炭素化を宣言している。アップルと取引したければ世界中どこに位置する企業だろうとネットゼロを目指さざるを得なくなる。私はこれを需要サイドが先導するエネルギートランスフォーメーションと呼んでいる。第四にコロナ危機からの脱出のために多くの政府がグリーン回復策を打ち出しており危機の中で停滞する化石燃料と対照的に再エネ投資は堅調だからだ。IEA 事務局長のファティ・ビロル氏が「私は（脱炭素化に）楽観的だ」と言うのを聞いてたまげたが変化のスピードは確実に速まっている。

しかしその実現には過激なまでの技術革新とインフラ投資が必要だ。再生エネルギーの活用をさらに進めるために IEA が注目するのが 4 つの新技術、即ち水素、バッテリー、二酸化炭素の分離利用貯蔵（CCUS）と小型モジュラー原子炉（SMR）である。インフラ投資も巨大になる。例えば太陽光では現在世界最大のソーラーパークを二日に一つずつ作り、水素では最大の水電気分解プラントを毎時間ごとに建て続け、巨大 CCS 基地を毎週一箇所作るくらいの投資が必要である。またこれから十年以内に新車の半分以上が電気自動車になる必要がある。また消費者の行動変化も必要だ。航空輸送では 1 時間以内のフライト利用の停止、3km 以内の自家用車利用をやめ自転車か徒歩にシフト、全世界で二割の人が 3 日在宅勤務する、住宅の暖房温度（冷房）を三度下げる（上げる）など生活全般にわたる行動変化が必要だ。これだけの変化を起こすのには大幅な炭素課税か炭素取引市場を作るのみならず政府の規制強化が必要になるだろう。欧州の多くの国や中国、カリフォルニア州が 2035 年までにガソリン車の販売禁止を決めている。

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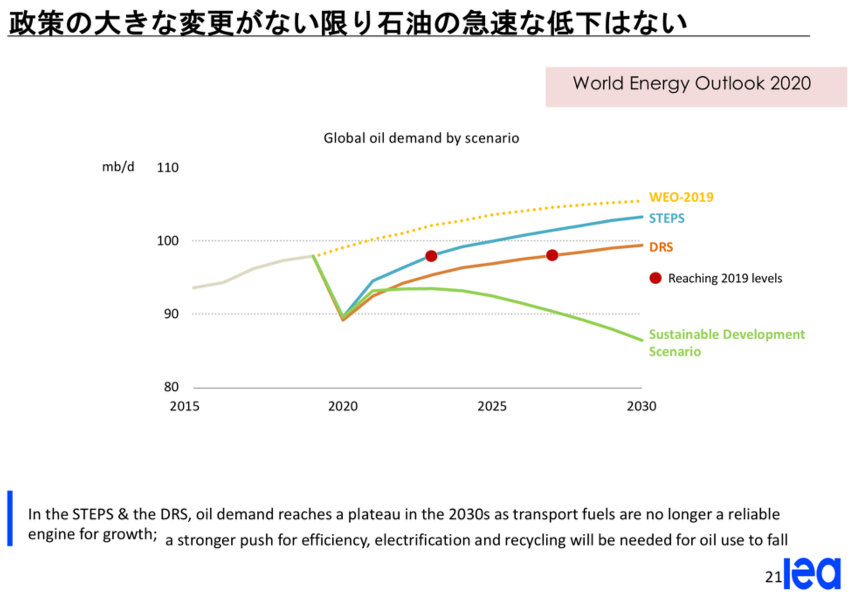
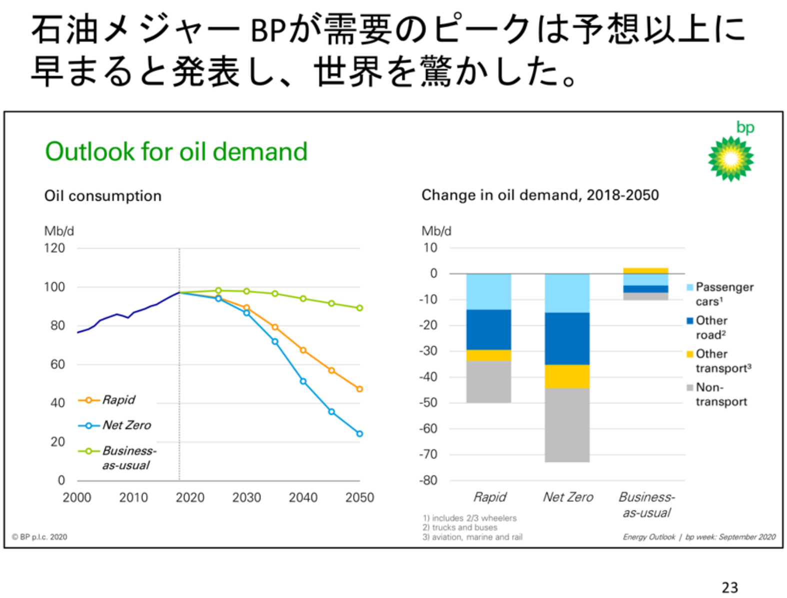
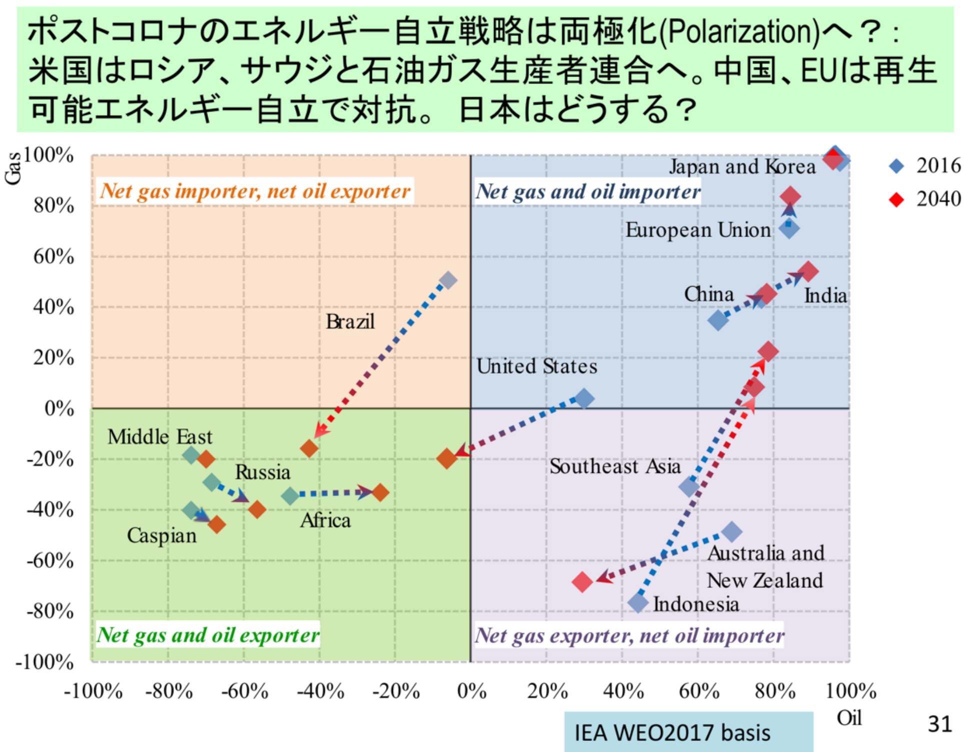
IEA は世界の石油需要のピークは今後 10 年は来ないというが、NZE2050 なら 2019 年がピークだ。（グラフ 1）オイルメジャーの一角 BP は最近発表したエネルギー見通しの中で政府が脱炭素化に向けて積極的な政策を打てば去年が石油需要のピークになり、そうでないとしても需要は 2019 年レベル以上には上昇せず頭打ちになると言って世界を驚かした。（グラフ 2）この春に大規模な石油資源の減損を決めた BP であるがその裏にはこのような見方があったのかと納得させられた。右肩上がりの需要を前提にして限られた資源を地下から少しずつ掘り出し高いレントで売ることが従来の石油のビジネスモデルであった。高いレントを可能にしたのがオイルメジャーによる寡占と OPEC 生産国カルテルである。需要が今後低下するならこのビジネスモデルは回らない。石油の需要は減り国際卸売り価格は下がるが二酸化炭素の価格は先進国でトン当り 140 ドル（IEA の持続可能発展シナリオ）にもなり炭素価格込の消費者価格は高くなる。そしてレントは生産者から消費者に移る。欧州各国政府や EU の脱炭素政策への転換を





見た BP、トタル、シェルなど欧州系メジャーは大きく脱炭素へ向けて舵を切った。石炭を切り捨て、石油から天然ガスへと転換、更に水素や再生可能エネルギービジネスを増やしている。米国系メジャーは出遅れているがこれが未来のエネルギービジネスの世界標準になるだろう。

石油や天然ガス生産に依存する国にとっては大変な事態だ。コロナ危機での都市封鎖による需要消滅を受けてトランプ米大統領がサウジとロシアを仲介してまで石油生産削減を決めたのが象徴的だが生産国は必死で従来型のエネルギードミナンスを維持しようとするだろう。他方欧州や中国は最大限再生可能エネルギーを使ってエネルギー自立を図る。コロナは各国の国内政治をますます貧富両極化（ポラライズ）するがエネルギーの世界も化石燃料依存型と再生エネルギー型の両極化が進む可能性が高い。（グラフ 3）国内政治のように両極は激しい戦いを始めるのだろうか。それとも違う道があるのか。



5 年ほど前に東京で開かれたサウジアラムコの取締役会にダニエル・ヤーギンとともに呼ばれたことがある。受けた質問は石油需要のピークがいつ来ると思うかということであった。今なら驚かないが、その時は大変驚き、真面目に聞かれているのか耳を疑ったが、電気自動車（EV）や水素燃料電池自動車（FCV）が走り始めパリの COP21 を控えて各国の二酸化炭素削減約束が加速する中で極めてまともな心配をしていることが彼らの言葉から理解できた。サウジを始めとする産油国にとって石油のピークは悪夢である。1956 年にハバートが唱えたのが Peak Oil Curve だがこれは生産量のピークであった。実際は次々に油田が開発され追加コストは上昇してもピークは起こらなかった。シェール石油革命で米国が世界一の生産国に帰り咲いたのは高い価格に支えられ、技術革新で生産を増やすことができたからである。しかし需要のピークは生産者の力ではどうにもならない。昔サウジのヤマニ石油大臣が言った言葉が思い出される。「石器時代は石がなくなったから終わったのではない。」5 年前のアラムコの質問に私は石油業

界の常識である 2035 年ごろより前の 2030 年以前ではないかと申し上げた。パリの COP21 で米中が揃って 2030 年に二酸化炭素の排出ピークアウトに前向きだったからだ。中国はその後も太陽光や風力発電を大量に建設し、EV や FCV へのシフトを進め石油需要のピークは 2025 年だと言い出している。しかしコロナ危機で石油時代の終焉がさらに早まりそうなのだ。

答えの一つが水素だ。2015 年当時からアラムコは水素に期待していた。石油から水素を取り出し二酸化炭素を地中に石油生産回復（EOR）のために再注入すればクリーンな水素を作れる。今はそんな水素を再生エネルギー由来の緑の水素（Green Hydrogen）と区別して青い水素（Blue Hydrogen）と呼ぶ。サウジはこの両方を試験的に始めている。新都市ネオムのそばで太陽光発電の電気で水を電気分解してできた緑の水素をアンモニアにするプラントが構想されている。また日本と青い水素をアンモニアにして輸出する構想が動き出している。

日本は化石燃料を輸入に頼って来た。しかし石油ショック後は多様化を進め、石炭やガス発電、原子力、省エネなどを進めた。化石燃料の中でよりクリーンな天然ガスを液化して運ぶというビジネスモデルを開発し 50 年を経て LNG は日本のお家芸になった。しかし天然ガスも少ないとはいえ二酸化炭素を排出する。日本が脱炭素を目指すなら LNG ではなく、答えはサウジ同様水素にあると思う。今後は石油、石炭、天然ガスを脱炭素化し青い水素にして輸送するか、再生エネルギー起源の電気を緑の水素にして輸送、または電力線を連携して直接電力を輸入するのが未来のエネルギー貿易の姿だろう。水素の輸送方法はアンモニアに加え有機ハイドレート（メチルシクロヘキサン MCH）や液化水素があり、いずれも日本が技術において世界の先頭を走っている。IEA は既存の施設の脱炭素化が最も難しいという。まだ若いプラントの多いアジアの問題でもある。そこで例えば日本が考えている石炭火力でのクリーンアンモニア混焼を解決策としてアジアの消費国や中東の産油国に売り込んだらどうであろう。シンガポールは水素貿易のアジアハブに MCH を活用しようとしている。オーストラリアは褐炭からの青い水素や太陽光の緑の水素を輸出する計画だ。また電力線をシンガポールまで繋ぐ計画もある。脱炭素社会が来れば化石燃料の限界価格は風力太陽光のゼロに収斂するはずだ。地下に眠っていたガスは LNG にすることで価値が生まれたが、今後は水素にすることで価値が生まれる。コロナ禍で石油需要が消失し石油価格は一時マイナスになった。コロナによって需要が供給形態を決める時代が来る。これはやり方によっては日本企業にとって大変なチャンスが来ることになると思うがどうだろう。

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