별첨 3. 영문보고서

NUCLEAR FUTURE FORESIGHTCAST AND COUNTERMEASURES

2020 DECEMBER 31

KOREA NUCLEAR SOCIETY

Preface

This is the final report of the project which was conducted by the Committee of Nuclear Future Foresight in Korean Nuclear Society (KNS). The results had been presented in General Congress of KNS.

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Summary

The energy situation is changing rapidly due to the promotion of energy conversion and demand for carbon free energy sources. Under this circumstance, the domestic nuclear power plant industry is looking for short- and long-term countermeasures to avoid the collapse of technologies, supply chain and human resources. In this report, we examined global and domestic prospects and policies for energy, economy, and nuclear power plants. The main purposes were to draw implications from them and to prepare nuclear policy and R&D promotion plan to respond to changes in the future society's environment and technology demands. The adopted approach in the analysis was the scenario development method among future forecasting methodologies. As the political decision making and energy mix priorities critically impact the role of nuclear energy in the future, three scenarios were considered; the status quo scenario, united harmony scenario, and the confrontational scenario. Future megatrends were taken into account such as the climate change, pandemic, fourth industrial revolution, space technology innovation, change in the WTO system, etc. The established strategic direction of domestic nuclear technology development for the analysis include enhancing international cooperation for world nuclear power, development of small modular reactor and microreactors, marine applications of nuclear power, nuclear hydrogen production, etc. In particular, prospects of the potential nuclear applications were analyzed.

In accordance with the three scenarios, the direction of change in nuclear technology was presented. In the status quo scenario, the key words of future nuclear energy would be the energy storage, dispatchability, distributed System, low capital cost, innovative small reactor development, development of multipurpose micro reactor technology, development of next-generation power conversion system, and space reactors. In the united harmony scenario, proposed were the application of fourth industrial revolution technology to nuclear, virtual nuclear power plant, development of unmanned equipment, radiation damage restoration and resistance control, quantum FAB technology development, and future new material core technology-development. In the confrontational scenario, transition to nuclear science and technology would be required, such as activation of nuclear science application fields, development of technology to reduce the environmental burden of spent nuclear fuel, eco-dome spent fuel research center, coastal seabed rock disposal, etc. For mixed configurations of the three scenarios, this analysis result can be used as a broad image of the role of future nuclear energy.

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1. Introduction

● Background

- The energy situation is changing rapidly due to the promotion of energy conversion.
  - The nuclear power plant industry is experiencing severe trials such as declining sales, manpower loss, and a sluggish local economy due to the policy of leaving nuclear power plants, cancelling planned nuclear power plants, prohibiting the continued operation of nuclear power plants, and considering new nuclear power plants as an alternative for future power supply.
- Looking for short- and long-term countermeasures for the nuclear power plant industry.
  - Domestic nuclear power plant outlook or global nuclear power plant outlook, short-term response, or long-term preparation
  - What can or should be done to avoid the collapse of the domestic nuclear power industry?
- Comparing global and domestic prospects and policies for energy, economy and nuclear power plants to draw implications from the domestic nuclear power plants.
  - Use it as a basis for preparing for an uncertain future
  - Preparation of nuclear policy and R&D promotion plan to respond to changes in the future society's environment and technology demands
- Lastly, the current pandemic situation from COVID-19 is dramatically changing the global environment and initiatives including energy plans as well as nuclear energy sustainability.
  - What, how and why will Nuclear Energy be?

- **Review Technique and Application Plan**
  - Approaching Method: Future Forecasting Methodologies for a Scientific Approach such as delphi, cross-impact analysis, scenario, expert panels, environmental scanning, trend extrapolation, etc.
    - Future society prospects do not use only one method, but several methods comprehensively

- **Reasons for Selecting a Scenario Technique Among Forecasting Ones**
  - Assumptions about future forecasts
    - It is difficult to predict how all the factors associated with contributions will evolve in the future since factors are correlated to affect each other
    - Desirable to imagine the step-by-step development of expected situations within a scenario (a plan based on a consistent set of assumptions)
      - ✓ The valid scenario, as generated, when the underlying assumptions are widely met
      - ✓ Easy to deploy from the time of the event

    (Example) The outlook for the natural gas market from the time of the two oil crises
    to the present was difficult to predict at the time of a major shock in the
    energy sector, but it was used as a countermeasure assuming it could occur
    at a certain point in the future in the long run.

- **Direction and Key Considerations**
  - Prospects for the role of nuclear energy in the future: To draw the future of nuclear energy based on the goals set by a country and/or the world, and the policy scenarios that can be selected to lead the energy market on a path to achieve those goals.
  - Goal: To develop a domestic sustainable energy mix that considers the direction of the world's energy mix in the future changes in international society.
    - Energy direction for sustainable economics
    - Future energy mix considering safety, efficiency and security situations
  - The future prospects of nuclear energy are not just a prediction of the future of the energy and nuclear market.
    - A view of future nuclear energy based on the goals set by a country and the world, and the policy scenarios that can be chosen to lead the energy market, including nuclear, on a path to achieving those goals
      - ✓ Climate goals to curb greenhouse gases, the biggest crisis of the time
      - ✓ Sustainable Development Goals (SDG) for progress and growth

- **Variability in Future Nuclear Energy Forecasting**
  - Widely changed by various assumptions about political/economic and technological policies that each country chooses and the degree of development of energy technology.
    - Depending on the political position of the prospecting entity, the scope of this view is expressed in extremes
      - ✓ Differences from realistic future predictions (needs to be excluded)

    (Example 1) Greenpeace's projections that nuclear energy will be eliminated from the energy mix by 2050

    (Example 2) The World Atomic Energy Association forecasts nuclear energy use to triple by 2050

2. Consideration of Future Contributions

2.1 Correlation Between Energy Demand Forecast and International Society Forecast Scenario

- Political decision making and/or energy mix priorities in the international community considering technological/economic factors are critical to the impact of the role of nuclear energy in the future (adopting scenario deployment methods[1] as follows)
  - **Status Quo (SQ) Scenario**: Pursued without major changes in currently predicted economic trends and policies
  - **United Harmony (UH) Scenario**: In the case of innovative efforts by the international community to implement the same policy in solving global sustainability issues
  - **Confrontational (CF) scenario**: When international relations between countries are in conflict and their interests are a major factor in policy
- The overall energy demand outlook can be predicted regardless of the scenario direction, but the composition of the energy mix is estimated to differ greatly.
  - The energy mix in the international community devoted to global warming will be presented as a significant expansion of low-carbon energy and minimization of fossil energy use.
  - In the case of conflicts between countries or an international community focused only on national interests, the direction of the energy mix is expected to focus on energy security.
  - The sustainability of nuclear energy should be evaluated depending on the weight and role of nuclear energy in the energy mix for each scenario.

2.2 Future Energy Demand Forecast[2]

[1] Modified scenarios as described in the Reference M

[2] The data used in this section is referenced from Reference B.

- When forecasting the future energy demand in a situation where energy consumption and economic growth are desynchronized, the decisive variable is the regulation of greenhouse gas emissions due to energy consumption, or the carbon price.
- World energy demand will be -0.3% to 1.2% on average annually by 2040
  - Electricity demand is projected to increase by 0.4% to 1.2%.
    - Nuclear power plants are expected to increase by 1.1% to 2.2%
- Domestic energy demand will decrease slightly to -0.1% annually by 2040, and electricity will increase by 0.6%
  - Nuclear power forecasted to decline by -0.01%

2.3 Future International Community Prediction Scenarios

- The future international community will change according to political decisions and technological/economic ones about future growth roles (adopted scenario development method)
- The combination of the policy direction of each country according to political and technical/economic decision making is largely considered in three categories and categorized into three scenarios, **SQ, UH** and **CF** as below:
  - **SQ scenario**: Maintaining the status quo of international relations and policies currently maintained by each country
  - **UH scenario**: Innovation in the agreement and implementation of international relations and policies closer to the extent that the earth is compared to a country
  - **CF scenario**: When the interests of each country are extremely prioritized due to conflicting international relations between countries
- The future world may be somewhere in the middle of scenarios **UH** and **CF**, but from a certain point of view, it can sometimes be expressed as **UH** and sometimes as **CF**.
  - At the time of the Paris Agreement, the world was in a clear rosy area of **UH**.
  - After that, the emergence of the Trump administration in the United States, which prioritized the competitive interests of the country, or the realization of Brexit in the

UK, is a situation where the world has largely shifted to **CF**.

- The coronavirus pandemic crisis, which suddenly hit the world in 2020, leads the world to a rapid **CF**.

2.4 Future MEGATRENDs

- Changes in the global environment
  - Climate environment
    - Decarbonized global environment / fine dust reduction
  - COVID-19 related environment
- Changes in science and technology
  - Fourth Industrial Revolution
  - Space technology innovation
- Changes in economic activity
  - Maintain or change the WTO system
  - Whether the multilateral economic system is activated or not

2.4.1 Climate Environment

- Climate change
  - Statistically significant climate fluctuations lasting decades or more
  - Global warming → rising global temperatures

    According to the latest Inter-Government Panel on Climate Change (IPCC) fifth report, global average temperatures have risen by 0.85°C over the past 133 years (1880-2012). The rise in global temperatures has been steeper than in the past 10,000 years, when global temperatures have never changed above 1°C.
  - Rise in sea level

Global warming melts glaciers around the world, causing sea level rise. According to a report from the Asian Development Bank (ADB), as of February 2016, the global average sea level increased by 74.8 mm from 1993.

- Future forecast

  If the earth's average temperature rise is maintained as it is today, the global average temperature will rise 3.7°C by the end of the 21st century. From 2080 to 2100, sea levels were expected to rise by 63 cm, flooding 5% of the world's residential area.

  Rapid temperature rise frequently causes heavy rainfall and typhoons, causing massive casualties and property damage.

- Preventive direction of climate warming

  The IPCC report says 40 to 70 percent of 2010 emissions should be reduced by 2050 to keep global average temperature rises below 2°C. To this end, it is necessary to shift the paradigm toward a low-carbon economic society, centering on industry. In the new climate system, both developed and developing countries are obligated to reduce greenhouse gases, so the overall economic structure such as energy use, industrial production methods, and transportation methods can be affected. Therefore, it is necessary to establish a preemptive response strategy.

2.4.2 COVID-19 Environment

- Covid-19 has spread globally since March, raising concerns about its impact on the global economy. Rapid contagion and increased anxiety have a negative impact on the economies of major countries.

  - The impact on the global economy is expected to be unprecedented in the future amid high uncertainty about the propagation of COVID-19. Demand and supply shocks due to migration controls, social distancing, etc. in each country have a negative impact on the real economy as follows.

    (1) Sluggish economies of major countries

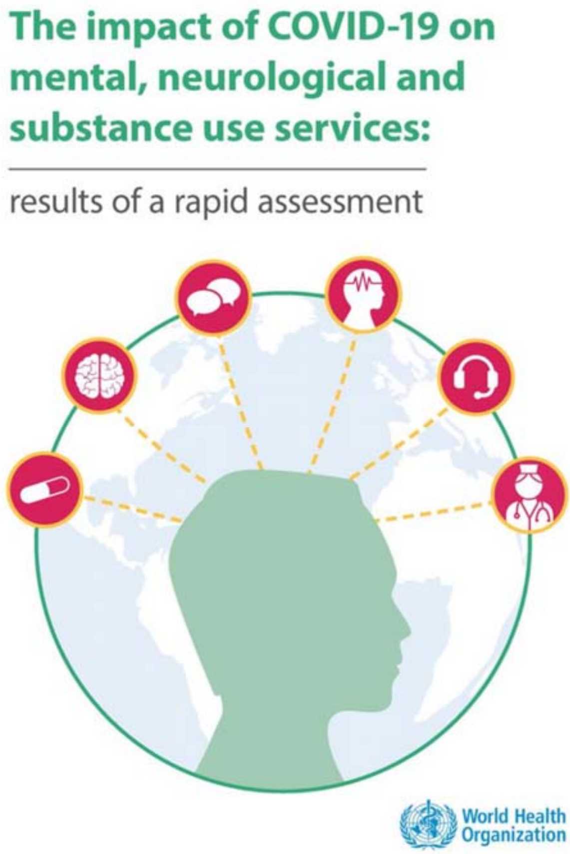
    (2) Great slowdown in trade in goods

(3) Reduced human resource exchanges

(4) Supply chain damage

(5) Boosting the crisis through the financial sector

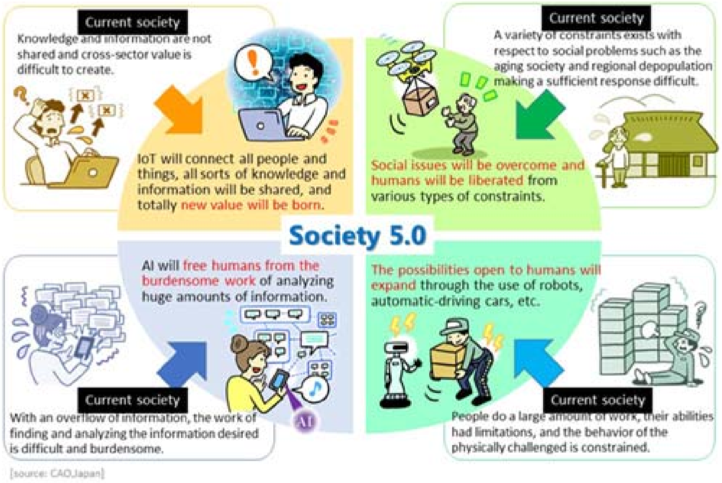
- The spread of COVID-19 has not only caused a global recession, but also changes in the lives of economic players. Households are expected to see increased risk as the pandemic poses a threat to livelihoods and safety, and companies are expected to add great value not only to efficiency, but also to resilience and flexibility as they experience unexpected production failures. As the incentives for non-face-to-face activities of households and businesses increase, the transition to a digital economy is expected to accelerate, and the trend of deglobalization is expected to be boosted by strengthening trade protection and weakening human resource exchanges.
  - Global trade growth slowed more than before due to the spread of deglobalization
  - Expanding information and communication technology (ICT)-based trade by accelerating the digital economy
  - Promote smarter manufacturing and accelerate the transition to non-face-to-face industries, ICT services, and eco-friendly, bio-health-focused industrial structures
  - The creation of various types of jobs mainly in non-face-to-face industries while employment in occupations with a high amount of face-to-face work decreases



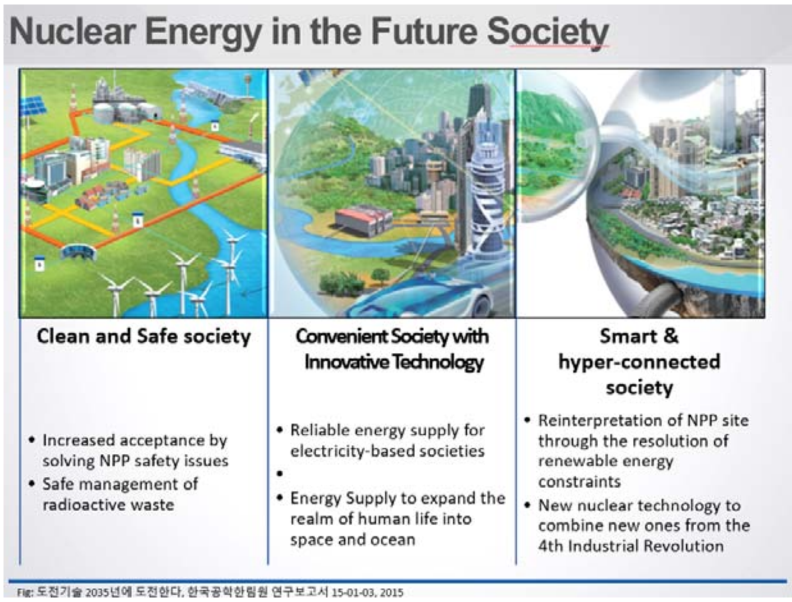
- Bio-Industry (Diagnosis, Cure & Vaccine), Non-Face-to-Face Technology and Service and Stable Supply of Energy are rapidly growing.

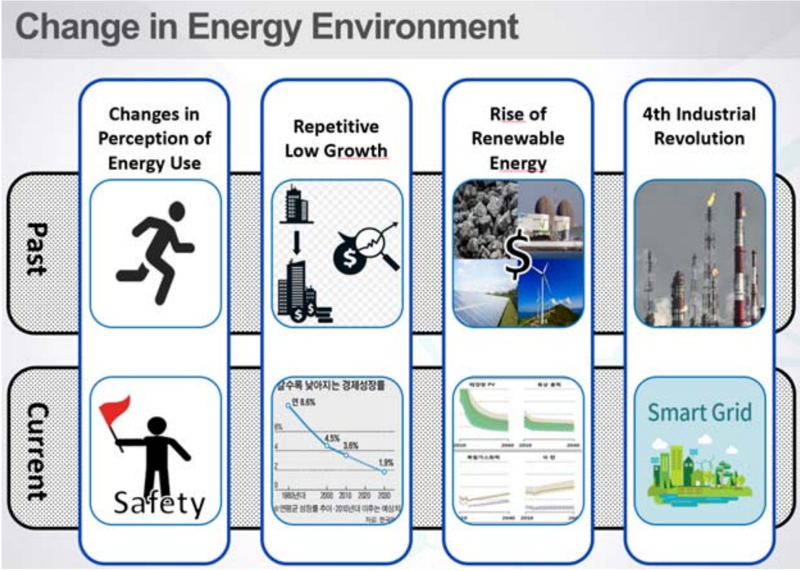
2.4.3 Technology Changes and Nuclear Energy

- The direction of change in technology
  - Future society due to technology changes



◆ Nuclear energy in the future society





- Future Trends in Space Technology
  - Own Reliable Long-term Energy Supply Including Express Transportation
  - Completely Isolated and Safe Human-Friendly Environment
  - Virtual Reality to Propose Rapid Communication Such as Face-to-Face Meetings

- Nuclear Energy Associated with Space Technology
  - Nuclear energy will be a very safe and reliable long-term energy source.

2.4.4 Changes in Economic Activity

- Whether the WTO system is changed and/or whether the multilateral economic system is activated are relevant to the future energy mix.
- Under the GATT and WTO systems after World War II, the 22% tariff rate dropped below 3%, and trade-to-GDP that was 27% in 1970 is 60% today.

- Trump's protection trade policy is a real threat to the global trade order that the world has been working on for 75 years.
    - The U.S.-China tariff war reduced U.S. GDP by 0.3% and Chinese GDP by 1.9%.
- COVID-19 restricts exports, not imports
    - Create a world trade version that includes exceptional risks such as COVID-19.

2.5 Strategic Direction of Domestic Nuclear Technology Development

2.5.1 Enhancing International Cooperation for World Nuclear Power

2.5.1.1 Current Status and Prospects of World Nuclear Power

- Continuous expansion of new generation capacity is necessary to meet the increasing demand for electricity caused by economic growth and changes in lifestyle
- The decarbonizing trend of energy consumption such as using solar energy, hydro and nuclear power, wind power, etc. is expected to continue to fulfill the Paris Agreement for Climate Change
- Continuous growth in nuclear power generation by restarting and continued operation after stagnant generation caused by the Fukushima accident
    - In spite of the accident, Japan has established its share of nuclear power generation as 20~22% in its 2030 Long-term Energy Supply Plan
- Increase in new nuclear plants to comply with the increase in demand for low-carbon energy sources
    - Necessity for an annual increase of 25 GWe of nuclear power capacity from 2021
    - New construction of 15 units in India and 16 units in the UK by 2030
    - Preparations for new nuclear plants in the U.S., France, China, Turkey, Philippines, Czech Republic, Vietnam, South Africa, Poland, etc.

Type	Unit	Capacity (MWe)	Country	Source
Operation	441	390,113	31	IAEA
Construction	54	57,441	20	IAEA
Planning	153	156,882	22	WNA
Decommissioned	188	83,961	21	IAEA

World Nuclear Power Status (from KAIF)

- The share of nuclear power in the nation's power generation is expected to decrease in accordance with the Korean government's Energy Conversion Policy
  - Expected decrease in nuclear power to 11.7% installed capacity and 16.6% generation by 2030
  - No additional plans for new plants besides the four units currently under construction

2.5.1.2 Implications from Current Status of World Nuclear Power

- Notwithstanding the increasing demands for low carbon generation, several countries that operate nuclear power or are planning new construction are still facing the following pending issues. The necessity to enhance international cooperation on such issues is continuously increasing.
  - Large scale enhancements for nuclear safety
  - Reasonable regulation system for nuclear power
  - Engineering and technology upgrade for high performance, effective O&M and decommissioning of nuclear power plants
  - Establishing spent fuel management policy and acquiring public acceptance for nuclear

power

- Maintaining a supply chain and skilled human resources for the nuclear power industry

2.5.1.3 International Cooperation Areas for the Sustainable Development of the Global Nuclear Industry

- Safety and Security
  - Continuous improvements in nuclear security as well as safety performance
  - Recognizing the importance of the nuclear security/safety interface
  - Ensuring that nuclear safety and security measures are designed and managed
  - Enhancing security culture and improving the state of cyber security, etc.
- Back-end Fuel Cycle Policy
  - Requiring a long period to determine the national policy for permanent disposal and reprocessing
  - Requiring various technologies and experiences
  - Considering the restrictions and public acceptance of each nation
- Technology Enhancement and Sharing
  - Continuous investment in technology development to enhance safety and operation performance
  - Sharing experience and peer reviewing the best practices of each country
- Public Acceptance of Nuclear Power
  - Greatest obstacle for the sustainable development of nuclear power
  - Requiring wisdom and collaboration on a global level
  - Fulfilling social responsibility by improving welfare and boosting the economy of local communities

- Nuclear Industry Supply Chain and Human Resources
  - Securing the nuclear industry supply chain with a high-quality assurance program and competitive prices

    Securing high-level skilled human resources for new plants and stable operation of nuclear power

2.5.2 Development of Small Modular Reactor (SMR) and Gen-IV Ones

- Utilization of SMR
  - Explores small-scale power market (remote power/heat supply, remote island/polar/military base distributed power supply, offshore plant power/heat supply)
  - Serves as a small distributed energy source for supplying power and process heat to marine plants
  - Contributes to GHG reduction by replacing fossil fuels that are used for power generation in remote areas
- Assess potential market size with SMRs
  - Canada valued the global SMR potential market at $150 billion Canadian dollars per year between 2030 and 2040
- Benefits of SMR
  - Small investment, small power grid
    - Due to its small size and compact properties, the system can be simplified to minimize construction costs as most are manufactured in a factory.
  - Utilization in various fields other than power generation

2.5.3 Development and Future Applications of Micro Reactor

- Introduction to Micro Reactor
  - Micro Reactor: A small plug-and-play reactor system under about 25 MWe

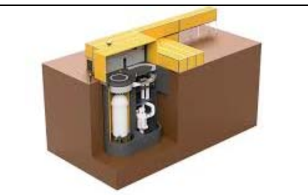
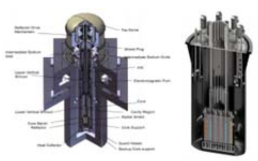
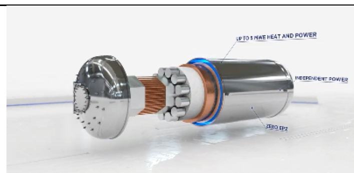
        - Not just a tiny, small modular reactor
    - Design Features
        - Factory fabrication: Quick installation and removal, reduced capital cost
        - Small size: Transportable by truck, aircraft or shipping vessel
        - Self-regulation: Minimal specialized operators, removal of any potential for severe accidents, improved resiliency
        - Long core lifetime and minimized moving parts in reactor
- Applications
    - Niche markets where the energy cost is very high: off-grid, diesel-dependent communities
    - Hybrid energy system with renewable energy within microgrids
    - Transportable energy system for forward/remote military bases
    - Civilian communities and mining in remote areas
    - Emergency restoration of power to natural disaster areas
    - Independent, stable energy system

Arctic Mining

Military Base

Remote Community

- Micro Reactor under Development
    - Non-LWR based on Gen IV and space reactor technologies
    - U.S. DOD's micro reactor development for permanent domestic military installation by 2027: three contracts in March 2020 GCRs, one HPR)
    - CNL's micro reactor demonstration by 2026 for remote mining and communities
    - In March 2020, Oklo Inc. submitted a combined license application to the U.S. NRC for a 1.5 MWe Aurora powerhouse (heat pipe reactor)

Reactor Type	Name/Capacity/Developer	
Gas-Cooled Reactor (GCR)	U-battery / 4 MWe / Urenco Starcore / 10~20 MWe / Starcore Holos / 3~13 MWe / Hologen MMR / 5 MWe / USNC	
Liquid Metal Reactor (LMR)	Gen4 Module / 25 MWe / Gen4 Sealer / 3~10 MWe / LeadCold 4S Nuclear Battery / 10 MWe /Toshiba ANGSTREM / 6 MWe / OKB Gridropress	
Heat Pipe Reactor (HPR)	Evinci / 0.2~5 MWe / WEC Aurora / 1.5 MWe / Oklo NuScale Micro / 1~10 MWe / NuScale	

- Micro Reactor Prospects
    - For on-grid application with microgrids connected to the main power grid, existing large LWRs will be useful to stabilize the grid for a long time.
    - For off-grid application, the micro reactors would replace diesel generators in remote areas to reduce greenhouse gas emissions.
    - The micro reactor would first be utilized for special purposes in arctic mines and military bases.
    - After the demonstration of its safety and economy, its application range will be extended to commercial independent energy sources in the remote mines and communities.
    - Finally, because of their design features, micro reactors could be a perfect fit for local, reliable and low carbon microgrids.
    - The average fossil-fueled power was 1.8 MWe in 290 Canadian off-grid communities (government of Canada, 2011).
    - Australia had 1,000 off-grid communities across island and microgrids (Energy Supply

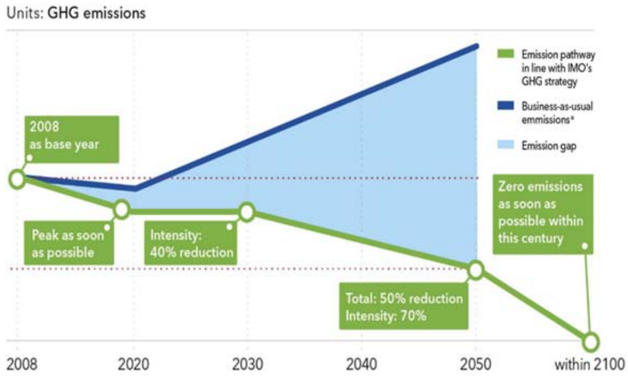
Association of Australia, 2015).

- UK BEIS projected a global market for around 570 units of an average 5 MWe by 2030, for a total of 2850 MWe (NUVIA, 2016).

- Required Technologies and Policy
  - In the case of gas-cooled reactors and liquid metal reactors, GenIV reactor technologies can be used to design the micro reactor.
  - A heat pipe reactor requires R&D for technology, but its simple design eliminates a large amount of R&D funding and long period of research as the early stage of the existing GenIV reactors.
  - Since the existing LWR licensing process and criteria cannot be used for the micro reactor, it's uncertain how long the licensing process will take in either country.
  - A new licensing policy should be developed for the micro non-LWR.
  - The first design review of the NRC and CNSC is very important for revitalizing the micro reactor market in the future.
  - The licensing and demonstration process should be transparent enough for the public to trust the safety and economy of the micro reactors.

- Development and Future Applications of Marine Nuclear Reactor
  - Background
    - Shipping is estimated to be responsible for 2.7-3.3% of annual global carbon dioxide emissions. IMO's decarbonizing strategy: a 40% reduction of the average carbon intensity by 2030 and a 70% reduction by 2050, compared to 2008 levels.
    - The rising importance of global availability of alternative fuels and energy sources in marine engineering. The answer to this challenge can be nuclear power.

◆ The success of KILOPOWER (space nuclear reactor) development and a handful of microreactor designs under development in the United States can diversify nuclear reactor types for marine applications.



<IMO strategy on reduction of GHG emissions (source: DNV-GL)>

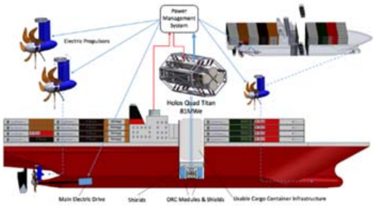
■ Potential applications

◆ Nuclear-powered container ships

◆ Nuclear-powered icebreakers for Northern Sea Route

◆ Floating nuclear reactors, floating base for deep-sea mining, deep-sea exploration

◆ Floating port, sea steading, very large floating structures, floating production storage and offloading (FPSO)

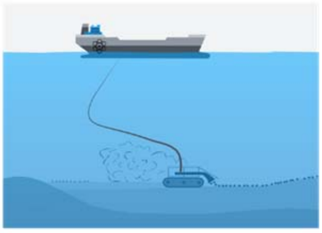


<Concept of nuclear-powered container ship (source: Holos)>

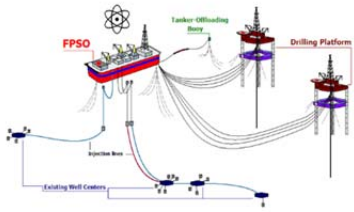
<Concept of nuclear-powered Icerbreaker ***Lider*** (source: Rosatom)>

<Concept of floatinig seaport (source: publicdomainarchitects)>

<Concept of floating NPP BANDI-60s (source: Kepco E&C)>



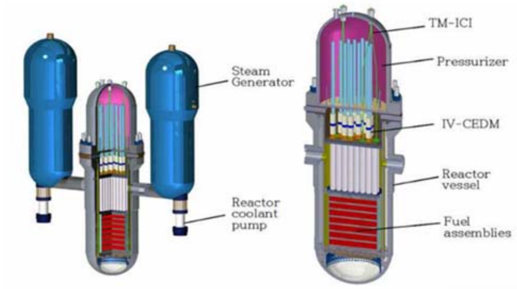
<Concept of seabed mining (source: dw.com)>



<Concept of FPSO (source: Wikipedia)>

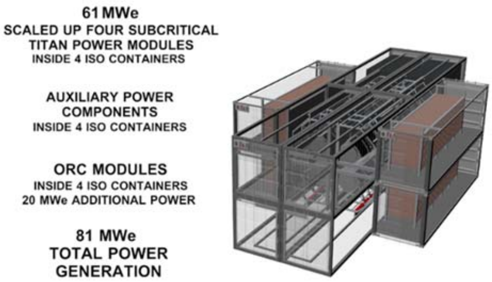
■ Marine nuclear reactors under development

Name	Developer	Power	Type
Bandi-60s	Kepco E&C	60 MWe	PWR/floating reactor
ACPR50S	CGN	50 MWe	PWR/floating reactor
ACP100s	CNNC	125 MWe	PWR/floating reactor
m-MSR	Corepower	23-81 MWe	Molten chloride fast reactor/propulsion
Holos Titan	HolosGen	80 MWe	Gas cooled reactor/propulsion
KLT-40S	OKBM	35 MWe	PWR / floating reactor (in operation)
RITM-200M	OKBM	50 MWe	PWR / icebreaker, floating reactor (in operation)
VBER-300	OKBM	325 MWe	PWR / floating reactor
ABV-6E	OKBM	9 MWe	PWR / multipurpose floating reactor
SVBR-100	JSC AKME	100 MWe	Molten lead-bismuth fast reactor / multipurpose
Shelf	Nikiet	6.6 MWe	PWR / underwater energy source



<Bandi-60s (source: Kepco E&C)>

<ACPR-50s (source: CGN)>



<HOLOS Titan (source: Hologen)>

<m-MSR (source: Corepower)>

■ Required Technologies and Policies

- ◆ PWR type marine reactors are based on proven technologies. The nuclear navy has logged more than 5,400 reactor years of accident-free operation and travelled over 130 million miles on nuclear energy. Thus, the civilian shipping industry should adopt the nuclear navy's protocols and procedures.
- ◆ If non-LWR micro reactors are deployed in the late 2020s, the installation of multiple megawatt-level micro reactors would be a promising option for marine applications of nuclear power with their compact size, convenient installation and removal, and enhanced safety.
- ◆ As marine reactors require various types of power, a micro reactor portfolio from 100 kW to a few MW needs to be prepared. A scalable concept is desired.
- ◆ Port access and public acceptance can be bigger issues than safety. Hybrid operation of nuclear and battery (battery operation near a port) can be an option for lowering public concern.

- If the technology for floating seaports or mobile harbors advances, nuclear-powered ships can be used merely for transportation across oceans and battery-powered ships for transportation between coastal ports and floating ones.
- In Korea, development led by the government is indispensable. Icebreakers for the Northern Sea Route, offshore plants for underwater mining, underwater drones for deep-sea exploration, etc. can be a target system for government projects.
- Cooperation between land-based micro reactor development and offshore reactor development would reduce costs and time.
- A new licensing policy should be developed for marine reactors since they can be exposed under moving and inclined conditions and have different external hazards than conventional reactors.
- International collaboration for legislation that can provide a framework under which nuclear-powered ships operate.
- The issue of disposal of spent fuel is a prerequisite for the marine application of nuclear power.

- **Implications: Based on a number of technologies for large-sized NPPs, research reactors, and SMART reactors that have been secured for more than 40 years, it is necessary to build and operate a domestic SMR for the demonstration of SMRs and entry into the global market. Additionally, there is a need to play a leading role in the commercialization of Gen-IV type reactors to maintain the superiority of nuclear technology.**

2.5.4 Nuclear Hydrogen Production

- Global Hydrogen Economy Prospects

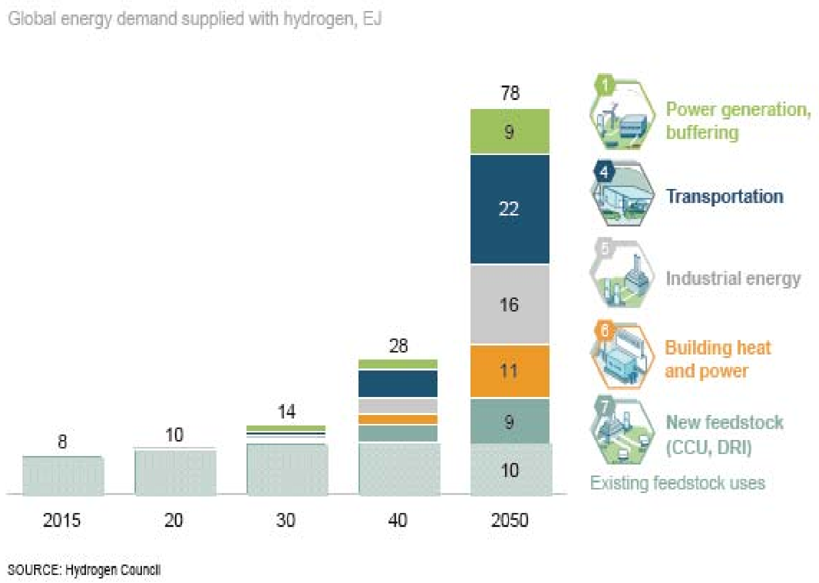
■ Projected global demand and roles for hydrogen in 2oC global warming scenario[3]

◆ **A global hydrogen economy by 2050 will play key roles to**

✓ contribute to 18% of final energy demand

✓ abate 6Gt of CO2 annually

✓ make annual revenues of > $2.5 trillion dollars



✓ create > 30 million jobs

■ Gaining momentum toward a global hydrogen society

◆ Thirty-two countries including China, the EU, Japan and Korea announced that they would achieve carbon neutrality by no later than 2060

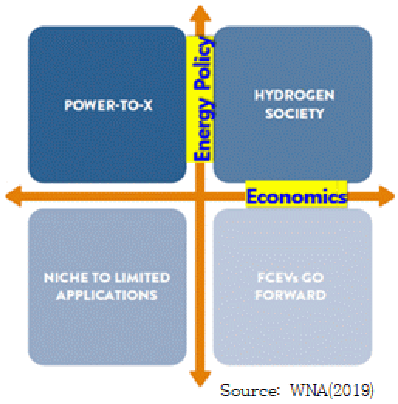
◆ Eighteen countries comprising 70% of global GDP established strategic hydrogen road map

✓ EU ('20. 7): 6 GW and 2X40 GW electrolyzer capacity by 2024 and 2030, respectively

3 Hydrogen Council, "Hydrogen scaling up: A sustainable pathway for the global energy transition," November 2017

- ✓ USA (President-elect Biden): establish ARPA-C to develop clean hydrogen technology competitive with grey hydrogen, and SMR at half the construction cost
- ✓ Japan ('17. 12): 900 hydrogen stations, FCV 800K, FC buses 1.2K by 2030

◆ The cost of solar and wind power decreased by 80% over the past decade and continues to fall, which could make green hydrogen cost competitive soon in regions like Saudi Arabia where solar and wind resources are plentiful



Source: WNA(2019)

■ Achieving a global hydrogen society is very likely owing to:

◆ Worldwide recognition of hydrogen as an indispensable solution to climate change, keeping the energy policy favorable

◆ Scale-up with innovation leading to favorable economics

● Prospects of Nuclear Hydrogen in Korea

■ A series of policy announcements for ramping up a hydrogen economy

◆ Roadmap for vitalizing hydrogen economy (2019. 1)

◆ Roadmap for development of hydrogen technologies (2019. 10)

◆ Promulgation of hydrogen-related act (2020. 2)

◆ Korean Green New Deal (2020. 7)

◆ Carbon neutrality by 2050 (2020. 10) : clean hydrogen > 80%

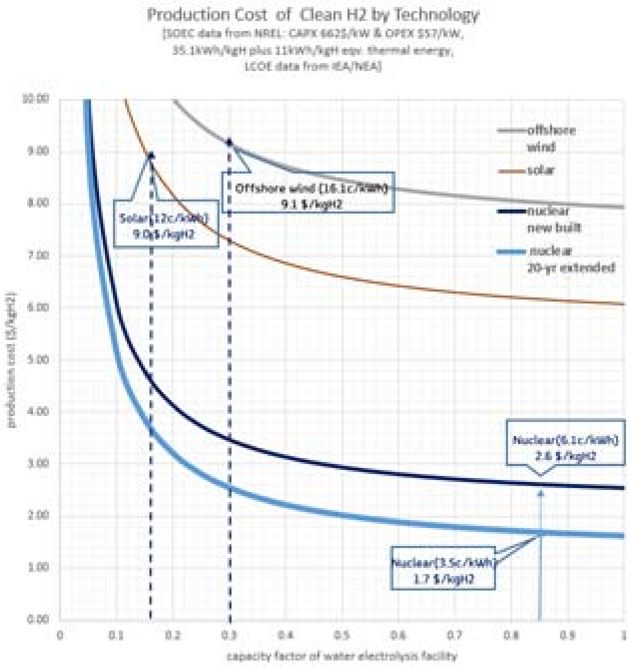
	2022	2030	2040
Demand	470K(ton-H_2)	1.94M(ton-H_2)	5.26M(ton-H_2)
Supply	① Byproducts ② Extraction ③ Electrolysis	① Byproducts ② Extraction ③ Electrolysis ④ Import ② : 50%	① Byproducts ② Extraction ③ Electrolysis ④ Import ② : 30%
Price	₩6,000/kg-H_2	₩4,000/kg-H_2	₩3,000/kg-H_2
FCV	81K		620K
FC Power	1.5GW		15GW

Source: Hydrogen technology roadmap

- Economic viability of clean hydrogen options: Can the goals be met?
  - Extraction with CCS: uncertain depending on LNG price and CCS cost
  - Imports including CCS, liquefaction, shipping, import terminal: unlikely
  - Renewable electrolysis: highly unlikely due to high electricity cost and low capacity factor
  - High temperature electrolysis with nuclear heat and electricity: very promising

If 20-year extended operation is allowed for existing NPPs, 16.4 GW nuclear capacity will be available in 2040, enough to supply ~3.5 million ton-H_2 of clean hydrogen at a cost of ~$1.7/kg-$H_2$.

- Nuclear hydrogen could play an essential role in making the dream of a Korean hydrogen society come true by:
  - mass provision of clean hydrogen at a target price
  - reduction of renewable curtailment through a nuclear-renewable hybrid system via hydrogen
  - contributing to greenhouse gas reduction by providing hard-to-abate sectors like steelmaking with affordable clean hydrogen


Production Cost of Clean H2 by Technology
[SOEC data from NREL: CAPX 662$/kW & OPEX $57/kW,
35.1kWh/kgH plus 11kWh/kgH eqv. thermal energy,
LCOE data from IEA/NEA]
offshore wind
solar
nuclear new built
nuclear 20-yr extended
Solar(12c/kWh) 9.0 $/kgH2
Offshore wind (16.1c/kWh) 9.1 $/kgH2
Nuclear(6.1c/kWh) 2.6 $/kgH2
Nuclear(3.5c/kWh) 1.7 $/kgH2
production cost ($/kgH2)
capacity factor of water electrolysis facility
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
0.1
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1

3. Future Forecasting by Scenario Development

3.1 Deployment of Three Response Scenarios

- **Status Quo (SQ) Scenario**: Share policies with countries or institutions with great international influence
  - Policy execution based on NDC commitments made by countries around the world in the Climate Convention results as follows:
    - NDC forms the root of energy industry change
    - Market-optimized, subsidy-free investment environment assumptions
      - ✓ Mandatory standards and regulations also play an important role in coexisting with market forces to make consumer decisions
      - ✓ The development of economical low-carbon energy technologies maintains market autonomy instead of man-made market intervention
  - Maintaining conflict structures in countries or institutions
    - The tendency to focus on resolving internal conflicts related to maintaining international cooperation has been exposed
    - The amount of international trade remains the status quo
  - Continuation of a key policy maintaining international economic power
    - Focus on protecting your country's technology and securing your own technology
  - International geopolitical framework of **SQ Scenario**
    - Change based on national policy decisions rather than the flow of international policy
      - ✓ Reflects the interests of countries and private economies strengthened by policy decisions
    - Regional geopolitical tensions at a non-severe level of damage
      - ✓ Raises questions about U.S. global leadership

    - ✓ Continuing local and regional conflicts in the Middle East
    - ✓ Europe continues to be preoccupied with the intra-country challenges raised by Brexit and concerns about the collapse of the EU
    - ✓ Weakening of China and Russia's attempts at a challenging global role

- ■ Reasons for each internal challenge related to demographic, economic, environmental and political development
  - ◆ Weakened policy consistency
    - ✓ Need to work on international issues such as terrorist attacks and refugee states
    - ✓ Maintaining order with international organizations; continuous research and development and technology development are independent of geopolitical development
- ■ Economic growth in **SQ Scenario**
  - ◆ Global GDP growth has been slowing below average for the past 25 years and is expected to be significantly lower than in the five years before the 2008 financial crisis
    - ✓ The global population increases, especially in developed countries, and the growth rate decreases over time.
  - ◆ Their growth potential continues as emerging economies catch up with advanced economies by improving productivity.
  - ◆ From the mid-2030s, global warming and extreme climate events will shrink economic activity somewhat, and the impact is expanded in the 2040s.
  - ◆ Oil and gas demand rises early in the forecast period based on low-cost fossil fuels and a variety of NDC requirements by country.
- ■ Operation of Eu Emissions Trading System (EU ETS) and other national and regional carbon pricing schemes
  - ◆ Carbon taxes remain unlinked with countries
  - ◆ Continuation of low-level carbon tax delays large-scale launch of carbon capture

and storage (CSS)

- ✓ CCS is relatively underdeveloped, weakening its role as a major climate risk mitigation tool

- ■ Energy system in **SQ Scenario**
  - ◆ The average annual improvement in energy quality is 1.9%, more than double the improvement rate shown over the past 25 years.
  - ◆ Achieved through various policy measures, including fuel efficiency standards in vehicles, and advances in technologies related to buildings, industries, power and the entire energy subsector.
    - ✓ The energy mix is mainly gradual, but changes from carbon fuels to green energy technologies
- ■ Accelerate the transformation from the power sector to green energy technology after securing competitive prices for electric vehicles
  - ◆ Technological changes in light vehicles accelerate the electrification of automotive vehicles around the world.
    - ✓ Regulatory incentives and subsidies for wind and solar energy and electric vehicles are expected to gradually be phased out and turned into profitable clean energy technologies
- ■ Continued global GDP growth is expected to slowly increase energy demand
  - ◆ Slow transition to carbon-free fuel slowly reduces CO2 emissions
- ■ **Lack of sustainable scenarios in the long term**

- **United Harmony (UH) Scenario**: Maximizing international cooperation and coexistence of environment and energy
  - ■ Maintaining order of international organizations, international legal systems and trade agreements
    - ◆ Emerging economies such as China, Brazil and India also join the international order.

- International cooperation creates a policy-led geopolitical and political environment.
- Multiple sectors work together to achieve their goals.

■ Prevention of global warming by compliance with Paris Convention

- Prioritizing the goal of complying with the global warming mitigation requirement of 2℃.
    - ✓ Allows reconfiguration of the overall sector, including the energy mix, to meet goals
    - ✓ Target to limit global energy sector cumulative CO_2 emissions slightly below IEA's 450 scenario level by 2040
- Meet global temperature 2°C compliance target by 2050
    - ✓ Countries carry out commitments of the Paris Agreement (in compliance with 2°C targets)
    - ✓ Each national policy agenda is formed by realizing that the threat of global warming requires radical action, and the seriousness of the necessary policy requires a joint, coordinated response

■ Practical development and growth of developed and emerging countries through energy efficiency improvement by avoiding dependence on fossil fuels (coal and oil, etc.) and diversifying energy

- Rapid abolition of fossil fuel subsidies
- Promote high carbon prices and investments and technology transfers relevant to the development of international carbon markets
- Rapid propagation of added value for building an eco-friendly energy system
    - ✓ Radical electrification of key sectors

■ Early global economic growth to be low

- Initially, investments are made in the green economy to achieve agreed targets for reducing global CO_2 emissions rather than short-term economic returns.

- After that, high returns from green investments will increase economic growth.
  - ✓ Energy growth < economic growth → CO_2 emissions related to energy
- Unprecedented pace of energy efficiency growth superior to the impact of economic growth

  (Example) Encouraging the development and distribution of large-scale CCS, etc.

  (Example) Reduced cost of renewable technologies and automotive batteries, widespread availability of electric vehicle charging points, technological maturity and low prices of large-scale electric storage devices, smart grids, substantial strengthening of transmission networks and significant amounts of home and public building item modifications, etc.

- **Confrontational (CF) scenario**: Disabling the international order according to the political decisions of each country
  - Priority on popular fascism, nationalism, and domestically oriented and short-term policies
  - Rising skepticism about the adverse effects of climate warming
  - Raising the priority of national interests rather than seeking international common interests
    - As the growth rates of individual countries continue to diversify, conflicts between countries can intensify.
  - Economic inequality between countries weakens social and international cohesion
  - Abandonment of existing international politics and principles and the rise of protectionism
    - Continued geopolitical disputes due to the neglect of additional management of emerging military powers among the areas not under the control of existing military powers.
    - Exposing limits of international institutions such as the United Nations to mediate global problems.

- ✓ The end of the pursuit of peaceful globalization that existed after the Cold War

◆ The geopolitical situation of confrontation between countries hinders international trade and the deployment of new technologies.

- ✓ Political and economic resources are used for less-productive purposes
- ✓ Crisis of failure to fulfill the Paris Agreement's commitment to mitigating climate change

■ Continued low economic growth

◆ Continued use of high-cost energy due to long-term low investment in new technology production capacity and increased demand for fossil fuels.

- ✓ Rising energy prices
- ✓ Increased volatility associated with insecurity in energy-producing countries

◆ Operation of the carbon price system is ranked lower in the policy agenda.

- ✓ Minimal investments in the transition to carbon-free fuels
- ✓ New CCS development projects are not considered

■ Policy and regulatory interest in local environmental issues is maintained, but there is increased indifference to environmental issues around the world

■ Rising awareness of anxiety about energy security

◆ Interest expressed in energy efficiency and local renewable energy

◆ Visualization of the policy to use domestic fossil fuel resources

◆ Continued dependence on fossil fuels in areas with plentiful coal, oil or gas

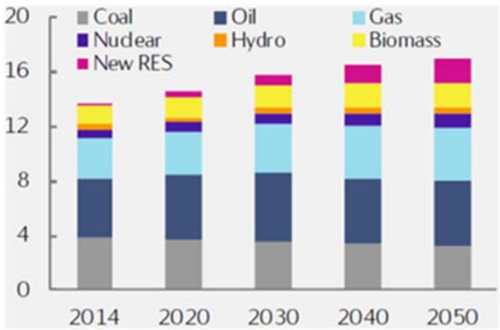
◆ Significant delay in electrification of automobile vehicles worldwide

3.2 Energy Mix Forecasts According to Scenario Development

- **Status Quo (SQ) Scenario**

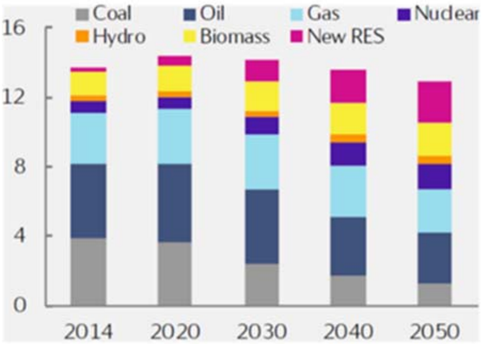
■ Nuclear power increases by 1.2%/year annually by 2050

- In 2050, the world's power generation rate is 15%, with 3840 TWh
- Demand increases by 44% during the period
- Expected economic growth is due to lack of technology exchange and cooperation between regions
- Less capital, but nuclear power is necessary because of lack of international trade and the need for supply security due to protectionism.



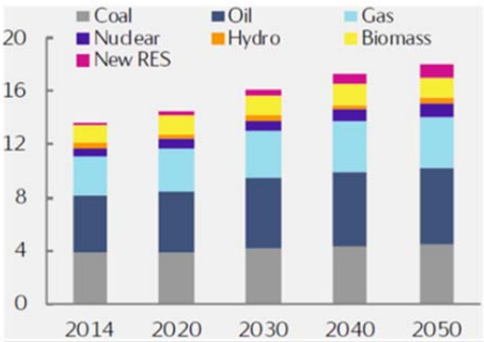
현상유지 시나리오의 세계 1차 에너지 수요 (Btoe) Statoil, Energy Perspectives 2017: Long-Term Macro and Market Outlook, Statoil ASA, Stavanger (2017).

- **United Harmony (UH) Scenario**
  - Nuclear power will increase to 2.3%/year annually by 2050, more than double the total growth of 124%
  - Nuclear power needs to replace fossil fuels and increase power demand to meet greenhouse gas emission reduction targets.
  - In 2050, nuclear power accounts for 16% of total electricity generation, and total nuclear capacity is 5,600 TWh.
  - It is an important part of the nuclear energy mix and a key part of the base load electricity.



화합 시나리오의 세계 1차 에너지 수요 (Btoe) Statoil, Energy Perspectives 2017: Long-Term Macro and Market Outlook, Statoil ASA, Stavanger (2017).

- **Confrontational (CF) scenario**
  - Energy security is a top priority due to the complex international political situation
  - Even under these conditions, the nuclear power forecast for 2050 is 3.64 PWh
    - This is similar to the prediction of 3.84 PWh in the **SQ Scenario**, which is a reference case.
    - Because nuclear power has a comparative advantage over other energy sources in energy security.
    - Similar to the 1970s and 1980s, when nuclear power was developed based on the importance of energy security.
  - Even in scenarios where there is no optimism about the global economy, such as low growth rates and increasing protectionism, nuclear power is expected to be used for hedges against the resulting energy security risks.



대립 시나리오의 세계 1차 에너지 수요 (Btoe) Statoil, Energy Perspectives 2017: Long-Term Macro and Market Outlook, Statoil ASA, Stavanger (2017).

Summary of Response Scenarios

Issue	**SQ**	**UH**	**CF**
Major Features	Passive NDC execution, Continuation of the present status of international order, Market-oriented without subsidies, Commercialization of low-carbon technology, Carbon pricing system not working	Compliance with 2°C limit, Development of global cooperation, Active decarbonization, Electric car market base ESS technology maturity, Strengthening T&D network linked with house and building renovation, Economy grows more than **SQ**	Breach of NDC, Priority on the national interest, Increased geopolitical conflicts, Globalization retreat with physical barriers and border control, Skepticism on Climate Issues, Much lower economic growth
Energy	Improving transportation and building efficiency, Expansion of electric vehicles, Gradually abolishing regulations, incentives and subsidies for renewable and electric vehicles, Growth rate of GDP > than that of efficiency improvement → Increased energy consumption, Energy source unit improvement of 1.9%/year, Energy consumption increased by 0.6% /year from 2014 to 2050 (24% increase in total)	The rate of reduction in energy source units overwhelms economic growth, Energy source units down 2.8%/year, 94% of 2050 Energy, Demand 2014 (6% reduction)	Increased demand for fossil fuels and rising energy prices, Increased volatility, Carbon prices move away from policy, Excludes incentives for new technologies (CCS squandered), Ignoring global climate issues, Slowing the pace of electric vehicle supply, Energy source unit improved by 1.1%/year, 32% increase in energy demand
Electricity	→ 2050 25%	→ 2050 30%	→ 2050 20%
Nuclear	Maintain 5~6% status	Increased to 11.5%	Maintain 5~6% status
Renewables	Expanding	Rapidly expanding	Expanding
CO_2	Stabilizing emissions, failing to achieve Paris Agreement target	Significant reduction in CO_2	Increased rather than **SQ**

4. Direction of Change in Nuclear Technology Forecasts

- **Status Quo (SQ) Scenario**: Keywords of the power system/market and nuclear technology
  - ■ Adaptation of new markets and development of new products
    - ◆ Energy Storage
      - ✓ The demand for energy storage devices rises as renewable energy expands significantly
      - ✓ Traditional batteries have limitations in high-capacity, long-cycle energy storage, and technology alternatives still have economic problems
      - ✓ New technologies based on nuclear engineering such as isotope energy storage and molten salt batteries need to be developed.
        - ➢ Development of energy storage technology suitable for nuclear power plants and for technical characteristics
    - ◆ Dispatchability
      - ✓ Increased demand for load-following capacity as renewable energy expands
      - ✓ Although limited, it is necessary to develop control algorithms and verify safety for the output control of existing nuclear power plants
        - ➢ If the output control of existing power originals is limited, consider combining with existing ESS to improve output control capabilities
      - ✓ A system capable of controlling the electric output from the secondary side to reinforce output control capability is possible
        - ➢ Future reactors must be designed to have power control capabilities
  - ■ Continued role in the energy market
    - ◆ Distributed System
      - ✓ Difficulty in building transmission and distribution networks, the increasing frequency of natural disasters such as wildfires, and decreasing reliability for large power companies are increasing the decentralization of power systems such as microgrids and

community choice aggregators.

- ➢ Need to develop reactor technology suitable for small distributed power systems (small, easy maintenance, high output control performance)

- ■ Low capital cost
  - ◆ The competitive power market was highly favored for LNG combined power generation with low initial capital investment costs due to uncertainty about future imports. As renewable energy expands in the future, the uncertainty of recovering capital costs is expanding further due to lower power market prices and increased price volatility.
  - ◆ Accordingly, even if the average power generation cost is low, it is difficult to select a power generation source with a high initial capital investment cost in the market.
    - ✓ Initial capital investment and waste costs for future reactors will have to be significantly reduced.
- ■ Nuclear energy technology (nuclear reactors)
  - ◆ Innovative small reactor development
    - ✓ Printed board-type steam generator
    - ✓ High-performance reactor coolant pumps
    - ✓ Multi-unit block concept intelligent autonomous operation
    - ✓ Reactor-seated valves
    - ✓ Optimization of passive safety system, etc.
  - ◆ Development of multipurpose micro reactor technology
    - ✓ Development of micro reactor system - supercritical CO^2 power conversion system
    - ✓ Construction and verification of reduced commercial devices for performance demonstration
    - ✓ Nuclear fuel design/manufacturing technology excluding serious accidents

and multipurpose heat source application technology, etc.

- Development of next-generation power conversion system
  - ✓ MW class supercritical CO_2 power generation system design with independent power available
    - Verification of key technology
    - Detailed design of plant-grade system
- Space reactors
  - ✓ Space-use nuclear-propelled engine
  - ✓ Space power supply

- **United Harmony (UH) Scenario**: Nuclear application of Fourth Industrial Revolution technology
  - Application of Fourth Industrial Revolution Technology
    - Growth in the energy market with the application of advanced production technologies such as artificial intelligence/deep learning, robots, autonomous driving, Internet of Things (IoT), new materials, and 3D printing
    - Expansion of technology area with product production technology in fields outside of radiation technology and nuclear power
  - Nuclear applications
    - Reactor system (micro reactor, autonomous driving, accident-resistant nuclear fuel)
    - Fluid system (device development, flow safety)
    - Safety (diagnosis, disaster, environment, security)
    - Waste/decommissioning (automation, adsorbent, disposal, dismantling, decontamination)
    - New materials (semiconductors, quantum computing, new functional materials)

- Medicine (diagnosis, treatment, dose assessment)
- Agricultural life (improvement, isotope)
- Nondestructive (automation) space (batteries, power generation technology)

- Virtual nuclear power plant
  - Establishing a virtual nuclear power plant integration platform and securing the world's best nuclear power plant abnormal condition prediction precision
  - Accident progress prediction and driver support technology based on precision simulation
  - To improve the reliability of diagnosis/prediction of abnormality/failure of pressure boundary device
  - Nuclear fuel safety evaluation technology using high-precision nuclear fuel analysis technology
  - Intelligent nuclear disaster response
    - ✓ Development of an intelligent decision support platform for optimal accident management/response
    - ✓ Accident progress evaluation and radioactive material emission reduction technology development
- Development of unmanned equipment to reduce the environmental leakage of radioactive materials, and personalized disaster response solutions according to the environmental release of radioactive materials
- Radiation damage restoration and resistance control modelling and simulation (M&S) technology research
  - Radiation damage restoration through radiation reaction M&S development research
  - Establishment of precision prediction technology and improvement of radiation immunity, product development efficiency improvement
  - Biomolecule recombination technology, cell factory implementation technology,

and natural polymer processing technology

- Development of radiation technology for precise safety diagnosis of social infrastructure and food
- Rescue safety diagnosis, food safety diagnosis, radiation safety and monitoring, etc.

■ Quantum FAB technology development

- Develop core technology for quantum fabs (design-synthesis-measurement-control-analysis) and establish a full-cycle quantum material research and development platform
- Multi-extreme environment fusion multi-scale complex quantum beam measurement technology development
- Quantum Computing/Quantum Functionality/Quantum Energy Material Development

■ Future new material core technology-development of complex functional future material technology using quantum beams

- Development of high-performance lightweight neutron absorbing material
- Gas separation membrane material development
- Development of material evaluation technology using neutron beams

- **Confrontational (CF) scenario**: Transition to nuclear science and technology

■ Nuclear Science and Technology

- All activities using reactor, accelerator, nuclear transfer/reaction, and irradiation

■ Activation of nuclear application fields

- Basic research (measurement, analysis technology)
- Environmental protection
- Securing water resources

- Medical (cancer diagnosis, treatment)
- New material
- Quantum technology (basic research)
- Industrial applications (process diagnosis, non-destructive inspection, etc.)
- Food agricultural life energy (RI, solar cell improvement)

- Development of technology to reduce the environmental burden of spent nuclear fuel
  - Securing technology to recover nuclear materials for disposal in connection with deep borehole disposal (DBD)
  - High radioactive nuclear material stabilization technology for DBD (solidified material manufacturing)
  - Securing long-term safety test data for solidified materials and use/management
  - Securing a plan for storing and managing heat-dissipating nuclides (Cs,Sr)
  - Secure environmental burden reduction technology safety/effectiveness/economy evaluation data and provide technology-intensive spent fuel safety management solution
- Eco-Dome Research Center
  - Developing a "future managed city for spent nuclear fuel" where the public can feel safe
  - Utilizing the "brown (green) field" from the dismantling of nuclear power plants
- Coastal seabed rock disposal

The concept of building a disposal area on the coastal continental shelf within 5 km as a way to improve the safety of in-depth disposal facilities and improve the acceptance of the community by mitigating the psychological nimby phenomenon.

5. Summary of Comprehensive Prospects

- Global energy demand is expected to increase by an average of -0.3% to 1.2% per year and power demand by 0.4% to 1.2% by 2040, depending on the scenario.
- Domestic energy demand will decrease slightly to -0.1% annually by 2040, and electricity will increase by 0.6%.
- For mixed configurations of the three scenarios, it can be used as a broad image of the role of future nuclear energy.
- Global energy demand will continue to grow, and the greenhouse gas mitigation scenario will continue to use nuclear power by 2050.

- Nuclear power is expected to play a role in the future from the time when there is the possibility of developing nuclear power as a non-climate change advantage, and there is energy security excellence and confrontation scenarios such as the coronavirus pandemic, etc.
- About 100 new nuclear power plant construction markets are expected by 2040, and a total of 300 new nuclear power plants are expected to be built in the long-term considering permanent remediation afterward. Therefore, it is necessary to maintain nuclear technology export competitiveness and establish a strategic cooperation system. To this end, it is necessary to maintain and develop nuclear power plant technology and the equipment supply industry, continuously strengthen nuclear power plant safety technology R&D, and foster and maintain abundant human resources.
- A variety of strategies for exporting nuclear power plants such as small nuclear power plants (SMART) and the latest technology medium-sized nuclear power plant (APR1000) are needed to strengthen the competitiveness of export models by building and operating them in Korea and securing portfolio products by developing new export targets.
- In order to maintain the superiority of nuclear technology, it is necessary to play a leading role in the commercialization of next-generation nuclear power plants with continuous investment in technology development. Pursuing green hydrogen production including nuclear hydrogen production is expected to usher in a hydrogen society.

- Nuclear power, which has excellent characteristics in the mitigation of greenhouse gases and energy security, is considered a sustainable energy source in the future, so it is necessary to strive for active nuclear growth.
- Notwithstanding the increasing demand for low carbon generation, several countries that operate nuclear power plants or are planning new construction are still facing the various pending issues. The necessity to enhance international cooperation on such issues is continuously increasing.
- When there are frequent global environmental pollution problems such as the coronavirus crisis...
    - Humanity will eventually be subdivided into reliable small groups, and
    - As the stability of distributed and independent energy sources emerges as a matter directly connected to the survival of humanity,
    - It is expected to pursue perfection in clean technology.
    - On the other hand, it is expected that non-face-to-face communication will grow significantly.
    - It is expected to lead to the development of technology that seeks a better environment than the current Earth.

6. References

A. International Atomic Energy Agency, Climate Change and Nuclear Power 2018 (2018),

http://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf

B. OECD International Energy Agency, World Energy Outlook 2019, https://www.iea.org/reports/world-energy-outlook-2019

C. International Panel on Climate Change, Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge (2013).

D. Emissions Database for Global Atmospheric Research (EDGAR), Global Emissions EDGAR v4.2 FT2012 (2014),

http://edgar.jrc.ec.europa.eu/overview.php?v=42FT2012

E. Paris Agreement, United Nations Framework Convention on Climate Change, Bonn (2015).

F. OECD International Energy Agency, World Energy Statistics and Balances (2018),

http://dx.doi.org/10.1787/data-00512-en

G. Greenpeace International, Global Wind Energy Council, Solarpower Europe, Energy [R]evolution 2015, Greenpeace, Amsterdam (2015).

H. Ram, M., et al., Global Energy System Based on 100% Renewable Energy – Power Sector, Study by Lappeenranta University of Technology and Energy Watch Group, Lappeenranta and Berlin (2017).

I. **Keramidas, K., Kitous, A., Global Energy and Climate Outlook 2017, European Commission Joint Research Centre, EUR 28725 EN, Publications Office of the European Union, Luxembourg (2017).**

J. **World Nuclear Association, The Nuclear Fuel Report: Global Scenarios for Demand and Supply Availability 2017-2035, WNA, London (2017).**

K. **International Atomic Energy Agency, Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, 2017 Edition, Reference Data Series No. 1, IAEA, Vienna (2017).**

L. **World Energy Council, World Energy Scenarios 2016, WEC, London (2016).**

M. **Statoil, Energy Perspectives 2017: Long-Term Macro and Market Outlook, Statoil ASA, Stavanger (2017).**

N. **OECD International Energy Agency, World Energy Outlook 2017, OECD Publishing, Paris (2017).**

O. **OECD International Energy Agency, World Energy Outlook 2014, OECD Publishing, Paris (2014).**

P. **OECD International Energy Agency, Energy Technology Perspectives 2017, OECD Publishing, Paris (2017).**

Q. **International Atomic Energy Agency, Going Long Term: US Nuclear Power Plants Could Extend Operating Life to 80 Years (2018),**

https://www.iaea.org/newscenter/news/going-long-term-us-nuclear-power-plantscould-extend-operating-life-to-80-years

R. **International Atomic Energy Agency, Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, Reference Data Series No. 1, 2018 Edition, IAEA, Vienna (2018).**

S. **Murphy, D., Berkman, M., Impacts of Announced Nuclear Retirements in Ohio and Pennsylvania (2018),**

http://files.brattle.com/files/13725_nuclear_closure_impacts_-_oh_pa_-_apr2018.pdf

T. **Advanced Nuclear Reactors: Technology Overview and Current Issues, Congressional Research Service (2019)**

U. **Advanced Nuclear Power Reactors (Updated Feb. 2020) WNA,**

https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx

V. **Nuclear Fuel Cycle Evaluation and Screening – Final Report, INL/EXT-14-31465(2014).**

W. **Transitions: Argonne's pioneering study of nuclear energy future(2019)**

X. **제2기 미래특별위원회, 한국원자력학회"원자력 미래 전망예측 및 대처방안",**