# "Energy Perspective and Nuclear Role after Fukushima Daiichi Accident"

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**Abstract**

The technical insight about "Energy Perspective and Nuclear Role after Fukushima Daiichi Accident" will be presented from the engineering viewpoint. The Fukushima Daiichi Severe Accident is described and the direction for nuclear power after the accident is discussed. Energy mixture formation against global warming is also further examined. Taking the effort for energy-saving as major premise, carbon capture and storage for fossil fuel, renewable energy and nuclear energy should be altogether developed, which means energy best mix should be achieved, under the constraint of keeping CO2 concentration in the atmosphere around 450ppm.

## 1. Introduction

The technical insight about "Energy Perspective and Nuclear Role after Fukushima Daiichi Accident" will be presented from the engineering viewpoint (1-2). The Fukushima Daiichi Accident is described and the direction for nuclear power after the accident is discussed. Energy mixture formation against global warming is also further examined. The following six issues will be explained in the paper.

Chapter2: What happened in the Fukushima Daiichi Nuclear Power Plant?
Chapter3: Rethinking nuclear power plant safety issues
Chapter4: Countermeasures
Chapter5: What should be done to improve the safety?
Chapter6: Long-term global energy vision
Chapter7: Role of nuclear energy after the Fukushima Daiichi Accident

## 2. What happened in the Fukushima Daiichi Nuclear Power Plant?

The Earthquake of Magnitude (Mw) 9.0 occurred at east coast of north Japan on March 11, 2011, which is ranked 4th largest in the world. There were over five hundreds earthquakes larger than Mw 5 during around 1 month. The huge tsunami wave was observed one hour later after the earthquake, whose affect is more severe than earthquake.

Causalities count over 30,000 people, which include dead over14,000, missing over 9,000 and injured over 5,000. Furthermore evacuee counts over 118,000, which will have the most severe psychological problem.

All 15 plants located east coast of north Japan suffered Earthquake, while every plant was successfully shutdown as same as Kashiwazaki plants at west coast of north Japan suffered large Earthquake in 2007. However every off-site power had been lost completely at this time (3). All plants were attacked by Tsunami, while observed Tsunami height only in Fukushima Daiichi Site is slightly over actual ground level, which is higher than design height, and therefore Total Loss of Power phenomena occurred in 3 plants in the Daiichi site. As the total safety function status, plants were successfully shutdown, while cooling and containment functions were damaged.

INES, International Nuclear and Radiation Event Scale rating of three major accidents are compared as shown in Fig.1. Fukushima is assessed as Level 7 by Japanese government but release amount is one order less than Chernobyl even three units damaged. The reason why Fukushima and TMI is less release than Chernobyl is due to reactivity control capability and fission product containment potential in the water because of water reactor type.

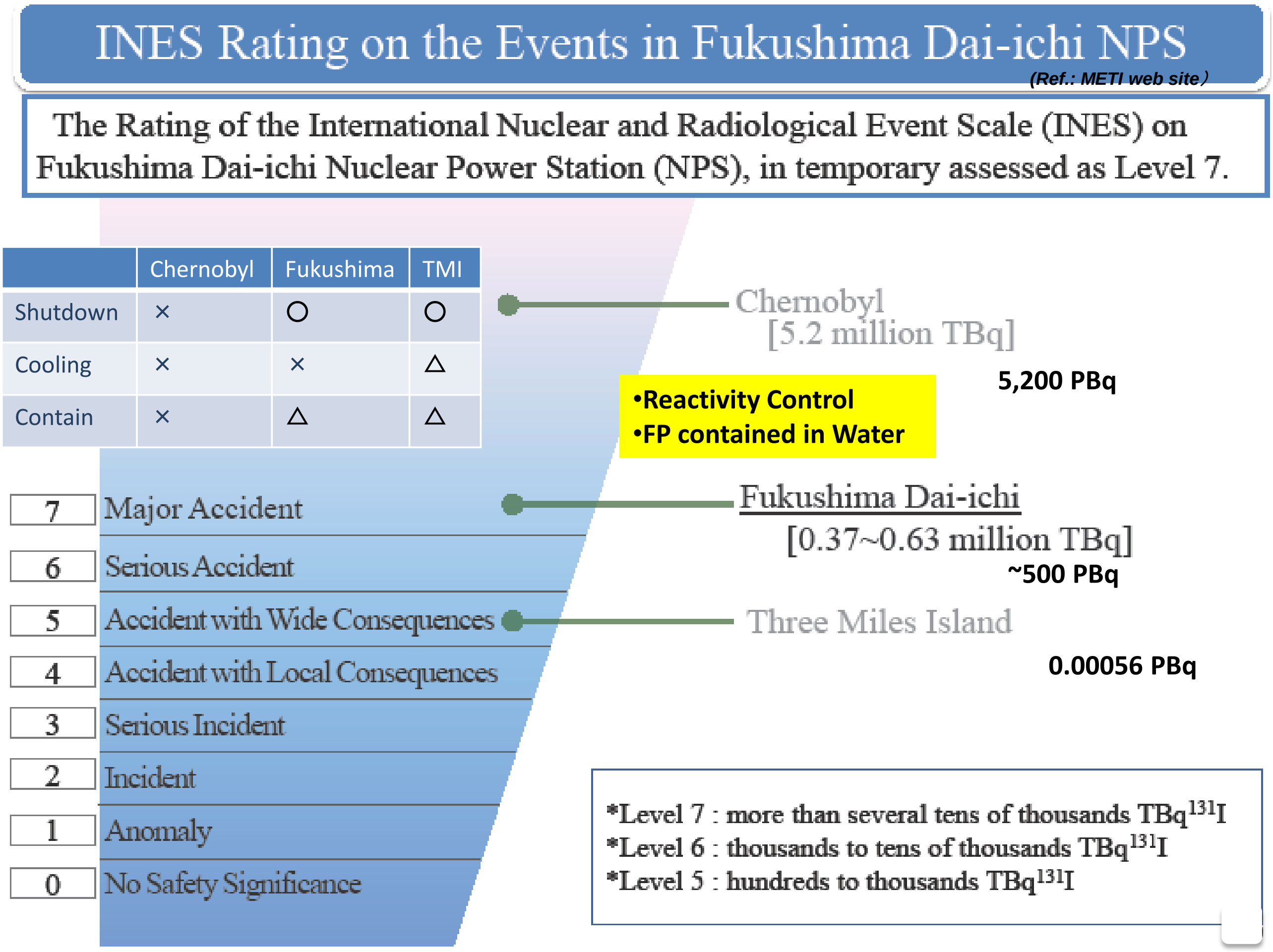


Fig.1 International Nuclear and Radiation Event Scale rating of three major accidents.

Risk (Frequency-Consequence) Curves only for early fatalities in the Severe Accidents are compared in various energy chains in Fig.2, in OECD countries during 1969-2001 (4). Even in the Chernobyl accident case of the largest accident in nuclear field, the risk is very small than other energy industries, and we cannot plot Fukushima or TMI accidents because no fatalities (no people death) occurred. The issue to be care in near future would be psychological problem such as Posttraumatic stress disorder for evacuating people, as appeared in Chernobyl case. Other large and long-term problems are plant recovery, long-term and low dose human radiation exposure affect, soil decontamination, and so on.

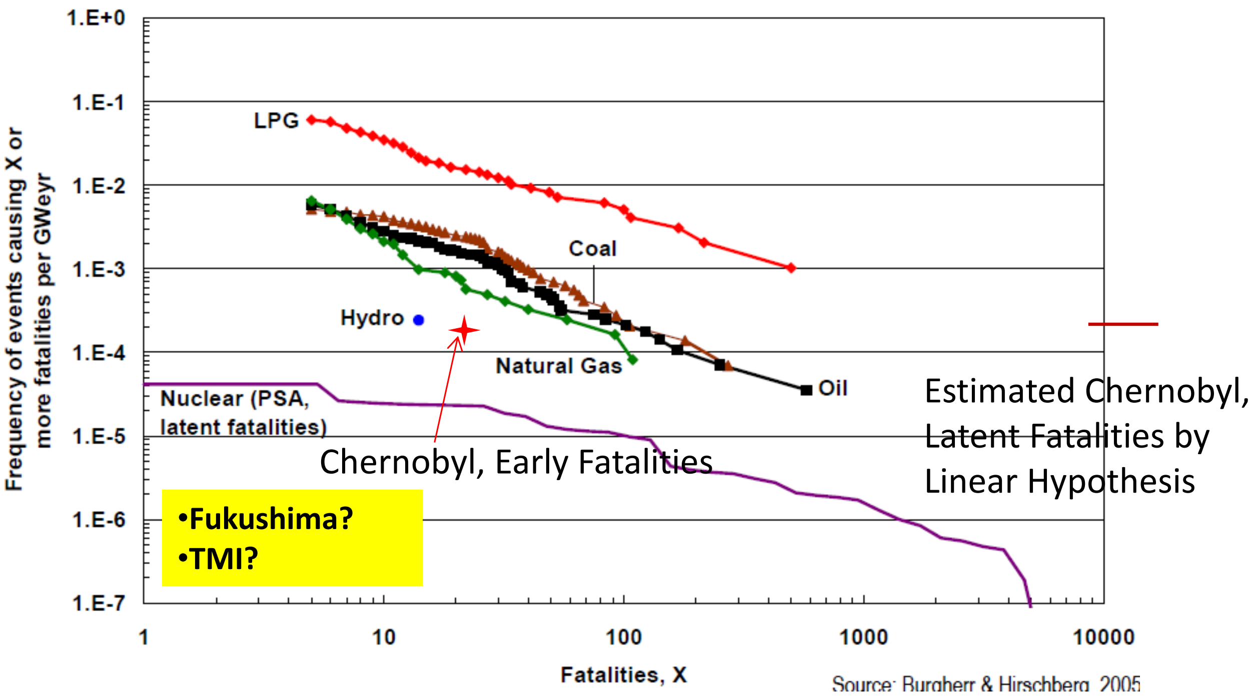


Fig.2 Frequency-Consequence Curves for Severe Accidents in Various Energy Chains OECD, without Allocation: 1969-2001.

## 3. Rethinking nuclear power plant safety issues

First of all, Fukushima Daiichi Accident issues can be characterized by “Unexpected event” or "Assuming while not considering such event." That is the phrase to represent the Fukushima Daiichi Accident problem. First priority for safety related personnel is that Human Factor and Common Mode Failure (CMF) problems are always worth keeping in mind; e.g. Station Blackout due to CMF of Loss of offsite Power and of Emergency DGs failure, and Site with multiple units problem with Earthquake and Tsunami multiple events, etc. Issues behind are that Imagination lack on risk or severe condition by responsible personnel is observed. Additionally everything would be considered and performed completely, while by formalism. Responsible persons should have studied deeply safety issues.

There are two items to be discussed, which are considered to be root cause of the Accident. One is “Rare Event” treatment; the other is “Crisis Management” problem, while both are due to lack of imagination by responsible personnel. Rare Event is high consequence with low frequency. Low consequence with high frequency event is easy to treat by commercial reason, while it is very difficult to handle the rare event even the risk is just the same. Unexpected event has been used frequently, but it is the risk-benefit issues to assume or not. Tsunami Probabilistic Risk Analysis has been carried out and safety related personnel knew the severity of the affect well. Regardless of the initiating event, lack of measures to "Complete Loss of Power" is to be asked.

Second is that there are many Crisis Management problems as follows;

- Delay in initial response
- Delay in decision making
- Delay in external support request
- Poor collaboration among government (Prime Minister Kan), bureaucrats (Nuclear and Industrial Safety Agency and Japan Nuclear Energy Safety Organization), and interested party (Tokyo Electric Power Company)
- Poor information disclosure in emergency situation

After all, it is a matter of organizational culture called Safety Culture. Anyway, rare event occurred on one occasion, measures had to be taken. Fukushima Daiichi nuclear power plants as "National Privatization" destroyed by large-scale disasters should be treated same as infrastructure systems as a national policy. Commercial operation can be acceptable for infrastructure system in usual situation. However, if the unexpected severe event would occur such as huge earthquake and tsunami, the affect is easily over the private company's responsibility, therefore safety net should be prepared by government for such case.

## 4. Countermeasures

Countermeasures, which are lessons learned from the accident, are summarized here.

1. Against Station Black-Out

Cause of Fukushima Daiichi Accident is simple and primitive, and can be overcome. Main cause was lack of Water tightness of switchgear, and/ or lack of water proof of emergency diesel generator.

1) Ensuring the water tightness of essential equipment facilities, such as Metal-clad switchgears and Emergency Diesel Generators.

2) Secure power supply system through diversification of Power Supply sources, Fukushima Daiichi Nos. 5 and 6 were safe due to diversification.

3) Secure robust cooling functions of reactor and containment vessel.

2. Against Severe Accident

Severe Accident means core melting and damage of Containment Vessel. So far Severe Accident is considered as Beyond Design Basis Accident, those measures should be extensively evaluated, thorough Accident Management measures.

1) Enhancement of prevention measures of hydrogen explosion

2) Enhancement of Containment Venting system

The causes of accident and countermeasures of safety on the plants should be reconsidered on the aspects of regulations, designs and operations. To protect the Severe Accident under the station black out accident, safety design of NPP should be further examined once more.

Evolutions of safety technologies of nuclear power plants, such as emergency residual heat removal system have been in progress for this half a century. The future energy outlook should not be designed by technologies in 1960's. Now we are in the age of "Generation 3 Reactor" system, which have advanced safety features such as passive safety characteristics, power supply diversification and so on.

## 5. What should be done to improve the safety?

Safety design principle is "Defense in Depth" concept, which should be further reconsidered reflecting the accident causes.

- Preventing damage
- Failure expansion mitigation: autonomous characteristic, inherent safety (intrinsic safety)
- Incident prevention: a fail-safe, fool-proof, redundancy, diversity
- Incident expansion mitigation: confinement, control release
- Environmental effects mitigation: evacuation

Usual systems focus on the forefront function, such as preventing damage, expansion mitigation, or incident prevention, while safety critical systems increases attention to back-up function, if it has a large enough impact on the environment. Common Mode Failure, such as External Initiating Event, which is usually Rare Event, or auxiliary systems failure is difficult to install to Defense in Depth design.

- Earthquake & Tsunami, Off-site Power & EDG & Buttery
- Sea Water Cooling

According to the "Defense in Depth" concept reflecting Fukushima accident, we should consider three level safety functions; usual normal system, usual safety system, and newly installed emergency system including external support function. Anyway the diversity is significantly required for not only future reactor concept but also existing plant back-fit activities.

Swiss Cheese Model proposed by Reason, J indicates operational problem. Fallacy of the defense in depth has frequently occurred recently because plant system is safe enough as operators becomes easily not to consider system safety. And then safety culture degradation would be happened, whose incident will easily become organizational accident. Such situation requires final barrier that is Crisis Management.

Concept of "Soft Barrier" has been proposed here. There are two types of safety barriers, one is Hard Barrier that is simply represented by Defense in Depth. The other is Soft Barrier, which maintains the hard barrier as expected condition, makes it perform as expected function. Even when the Hard Barrier does not perform its function, human activity to prevent hazardous effect and its support functions, such as manuals, rules, laws, organization, social system, etc. Soft Barrier can be further divided to two measures; one is "Software for design", such as Common mode failure treatment, Safety logic, Usability, etc. The other is "Humanware for operation", such as operator or maintenance personnel actions, Emergency Procedure, organization, management, Safety Culture, etc.

**6. Long-term global energy vision**

Based on the history of Conference of Parties (COP) and towards to the COP17 that was held in the end of 2011, a new post-2012 climate regime was examined to be scientifically sound, economically and technologically rational, and politically pragmatic through The Canon Institute for Global Studies research project. Alternative and feasible global emission pathway has been proposed by scientific analysis based on target of global mean temperature rise. Global Emission Pathway, Z650 means that total accumulation CO2 emissions in this century is 650GtC, in which the global surface temperature rise to approximate 2 degree C compared to pre-industrial levels, the CO2 concentration decrease by zero emission after a peak over the target concentration as shown in Fig.3 (5).

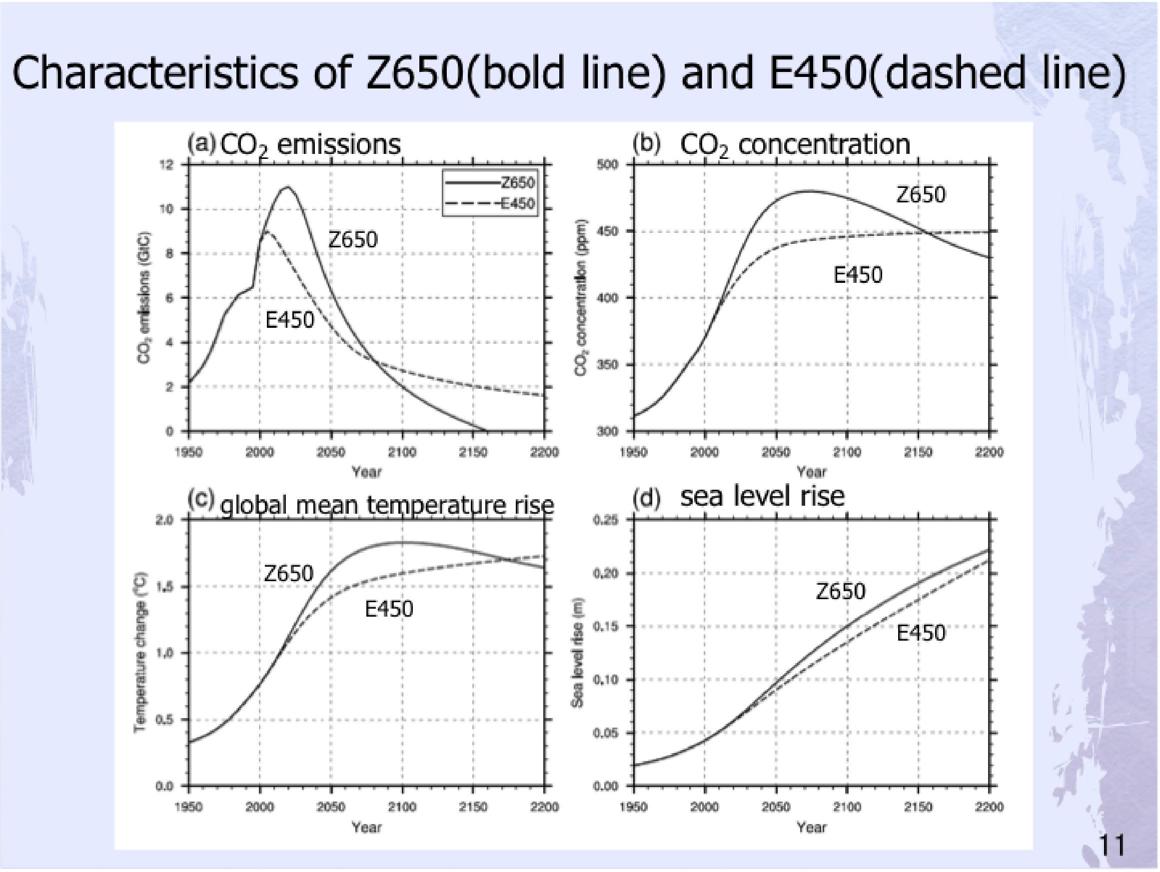


Fig.3 Proposed Global Emission Pathway, Z650 and E450.

Compared with the IPCC 450ppm equilibrium stabilization scenario E450, the Z650 scenario allows relatively large emissions during the near short term. Therefore, the Z650 scenario will generate a higher CO2 concentration in the near future. The concentration will exceed 450ppm in a short period, but it will decrease and stabilize at a lower level. As the result, the Z650 scenario will cause a similar temperature rise with the IPCC 450ppm scenario (6). Multi gas GHG concentrations: max 2.3 degree C in 2100 and saturating 2 degree C towards 2200.

The key findings are summarized as the following (7).

(1) The proposed Z650, as shown in Fig.4, improves the possibility of international agreement compared with the G8 Summit proposal, which argued that the worldwide greenhouse gas emissions must be reduced by at least 50% in 2050 compared to the 1990 or recent year levels.

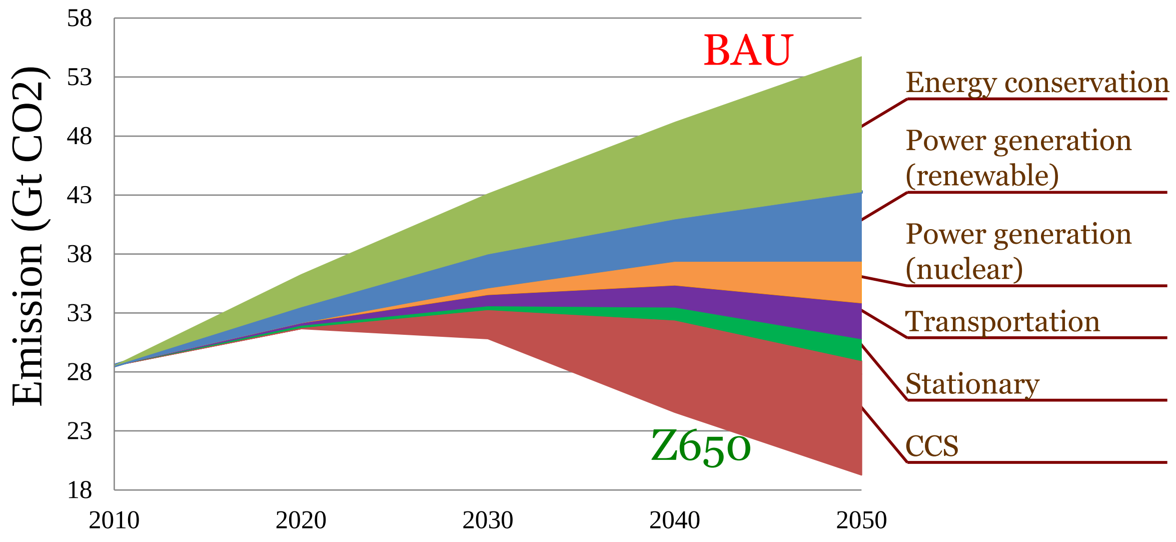


Fig.4 $CO_2$ emission reduction by sector.

Energy saving and renewable energy play an important role during the whole period, while nuclear, transportation and carbon capture and storage (CCS) play an increasing role during the later stage.

(2) A numerical experiment of global energy system optimization shows the technical feasibility of the Z650 scenario not only globally but also regionally. The obtained time series total primary energy mixes in Fig.5 suggest that the consumption of fossil energy will peak at 2030, and the clean energies, especially the renewable energy will play an essential role during the second half of the century. The resulted regional emission curves reflect the differences of financial and technical capability among areas. The industrialized countries will reduce their emissions by 50% in 2050 compared with 2005 levels, while the emissions of developing countries will increase by 10% at the same time. The results of individual industrialized countries fit with the national targets well. These results provide useful information for global harmony.

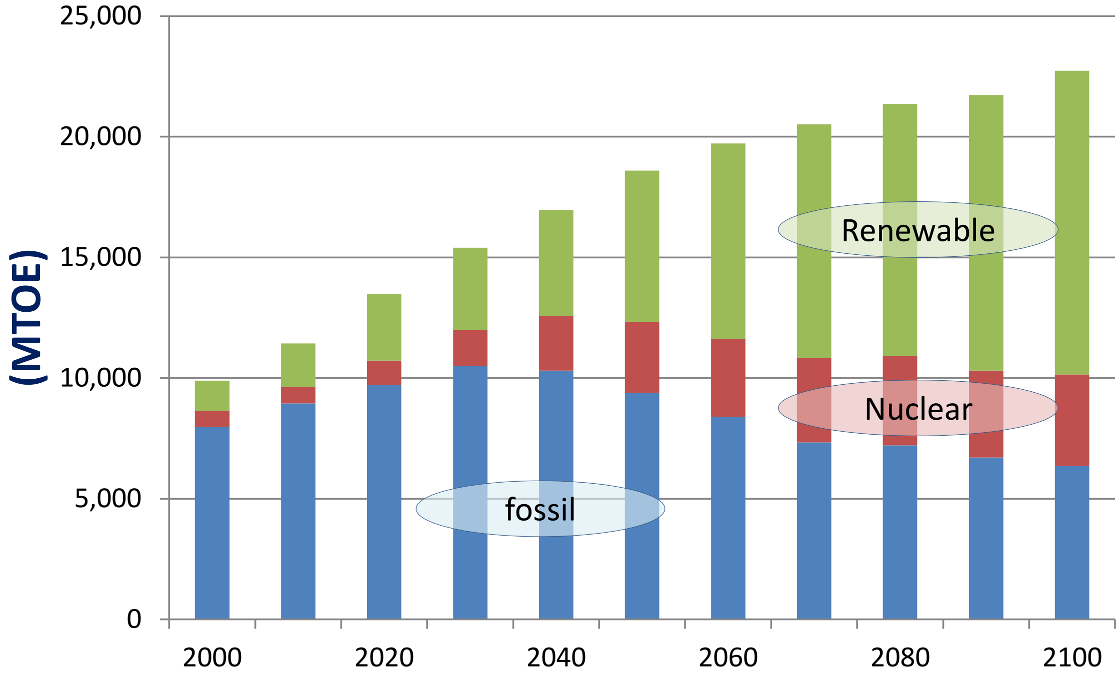


Fig.5 Total primary energy for Z650.

(3) The cost-effective analysis shows that the Z650 scenario is economically rational. Compared with the reference case, the additional investments in Z650 scenario could be covered by the fuel savings during the following 40 years (2010-50) both globally and regionally.

(4) Alternative approaches including high reduction targets of industrialized countries (80% by 2050 compared with 2005 levels), absence of CCS, and phase out of nuclear energy from 2020, were also examined. Each of them shows a poor economic performance with the cost-benefit balance destroyed.

## 7. Role of nuclear energy after the Fukushima Daiichi Accident

Premise here is that "Global warming and energy security are the invariant problems." The long-term energy demand and supply simulation to minimize the total energy system cost was conducted for energy prediction during the 21st Century in the world. Taking the effort for energy-saving as major premise, CCS for fossil fuel, renewable energy and nuclear energy should be altogether developed, which means energy best mix is required to be achieved, under the constraint of keeping CO2 concentration in the atmosphere around 450ppm.

In CO2 constraint case, idealized energy mix is obtained, well-balanced between investment and fuel saving. Nuclear phase-out scenario, in which new nuclear plant construction is prohibited, is possible even considering the issue of global warming from the simulation results shown in Fig.6.

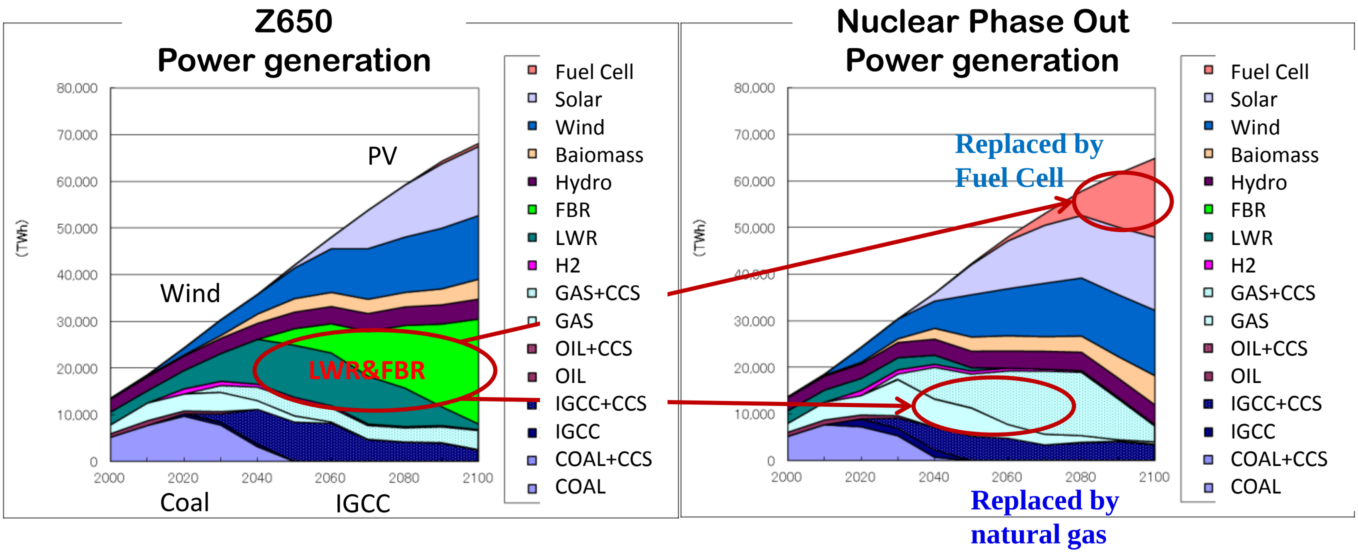


Fig.6 Z650 and Nuclear power phase out (no newly established since 2020)

The contribution of the fossil power declined, mostly replaced by natural gas until around 2050,and by large-scale introduction of the Fuel Cell since 2080. Nuclear phase-out scenario has two problems; one is increasing energy costs, and the other is little room for countermeasure and large uncertainties of technology. In Nuclear Phase Out case, unbalance between investment and fuels saving, and the burden on developing countries increases largely.

Therefore, rational use of nuclear power is requested, that is each country should make decision, Japan and several European countries would also become nuclear phase-out, while China, India and ASEAN countries will continue to massively introduce the nuclear power. If the large accident happens again anywhere in, it would become the global phase-out. Therefore, rational unified safety standards (organizational structure, design and operation, regulations) should be reviewed based on the Fukushima Daiichi Problem world-wide analysis and be established all over the world.

## 8. Conclusion

The feasible target for new emission scenario called Z650 (Overshoot & Zero-Emission) instead of traditional concept and energy mix against global warming has been proposed.

Taking the effort for energy-saving as major premise, carbon capture and storage for fossil fuel, renewable energy and nuclear energy should be altogether developed, which means energy best mix should be achieved, under the constraint of keeping CO2 concentration in the atmosphere around 450ppm. Nuclear power and renewable energy should be two wheels towards low carbon societies against global warming with economic growth.

It also demonstrated that international cooperation would enable the practical mitigation against global warming, based on cost minimum optimization over the world. It identified that innovative and useful technologies should be introduced over the world. International cooperation system against global warming should be reestablished on the basis of Science, Feasibility, and Fairness.

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