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Uranium Reserve, Nuclear Fuel Cycle Delusion, CO2 Emission from the Sea, and Electricity Supply: Reflections after the Fuel Meltdown of Fukushima Nuclear Power Units

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Abstract

The Great Tohoku-Kanto earthquake and resulting tsunami has brought considerable attention to the issue of the construction of new power plants. We argue in this paper, nuclear power is not a sustainable solution to energy problems. First, we explore the stock of uranium-235 and the different schemes developed by the nuclear power industry to exploit this resource. Second, we show that these methods, fast breeder and MOX fuel reactors, are not feasible. Third, we show that the argument that nuclear energy can be used to reduce CO_2 emissions is false: the emissions from the increased water evaporation from nuclear power generation must be accounted for. In the case of Japan, water from nuclear power plants is drained into the surrounding sea, raising the water temperature which has an adverse affect on the immediate ecosystem, as well as increasing CO_2 emissions from increased water evaporation from the sea. Next, a short exercise is used to show that nuclear power is not even needed to meet consumer demand in Japan. Such an exercise should be performed for any country considering the construction of additional nuclear power plants. Lastly, the paper is concluded with a discussion of the implications of our findings.

Keywords: Uranium Reserve, Nuclear Fuel Cycle, CO2 Emissions, Electricity Supply, Fukushima Nuclear Power Plants

1. Introduction

The main purpose of this commentary is to discuss several fundamental issues associated with nuclear power generation plants that are a critical component of any discussion on sustainability. Before going into the core of our discussion, it is useful to review the present situation of the Fukushima nuclear accident in Japan.

The Great Tohoku-Kanto Earthquake that struck Japan on March 11, 2011 and the huge tsunami that followed put the Fukushima nuclear power generation plants in a dangerous situation. On April 12, Japanese authorities notified the International Atomic Energy Agency (IAEA) of their decision to upgrade from an INES 5 (The International Nuclear and Radiological Event Scale) to an INES 7. As a result of this re-evaluation, the total amount of discharged iodine-131 is estimated at 1.3×10^{17} becquerels, and caesium-137 is estimated at 6.1×10^{15} becquerels according to the Nuclear and Industrial Safety Agency in Japan (Yomiuri Online 2011.04.12). *Becquerel* is the quantity of radioactive material in which one nucleus decays per second. The scale of INES is mainly based on the amount of discharged iodine-131 *per second*, so the scale of INES does not help us to evaluate the long-term effects of cumulative radioactive materials released from the Fukushima nuclear power plants on land and into the sea. In fact, much of the radionuclides released into the environment around Fukushima have been a result of water leakages that were flushed into the ocean, rather than attached to carbon and other aerosols from a burning reactor moderator. Thus, the situation of the Fukushima nuclear power plants is entirely different from that of the Chernobyl accident with the same INES 7 rating that occurred almost exactly twenty-five years earlier in 1986. The Fukushima disaster could perhaps be much worse in the long-run since the disaster has yet to be stabilized.

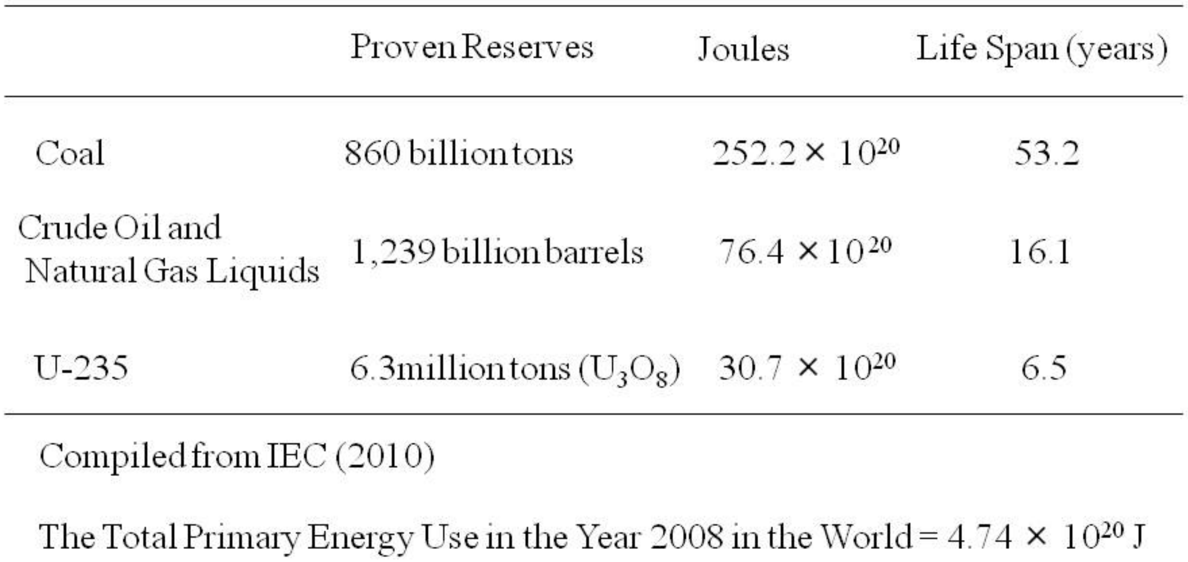
Despite the plausible serious long-term environmental and health problems associated with the Fukushima accident, Sergei Kirienko the Director General of the Russian state corporation Rosatom, well known as a strong advocate of the nuclear industry for economic development, strongly questioned the decision of the Japanese government to upgrade the disaster from INES 5 to INES 7 (Asahi.Com. 2011.04.13).

However, a significantly worse report was released by the Tokyo Electric Power Company (TEPCO) on May 24 where they described, based on their updated data analysis, that not only did Unit 1 melt down on May 12, but also the nuclear fuels (the melting temperature of UO_2 is about 2800°C) in Unit 2 and Unit 3 were melted down through the reactor vessels (Yomiuri Online 2011.05.24). TEPCO also acknowledged that the containment structure of these three units with 3cm width of steal (the melting temperature is about 1600°C) must already have several holes. Therefore, nuclear fuels full of radioactive substances are believed to have reached deep within the concrete situated under the containment structures. The most serious concern now is that it is impossible to construct a water circulation system that will cool down the temperature of the nuclear fuels to the state of a cold shutdown. The only practical *temporary* solution now available would be to construct a structure that *completely* contains the whole three units preventing radioactive substances from eventually flowing into the adjacent sea area.

The remainder of this paper is organized as follows. Section 2 examines the stock of uranium-235 that is a fissile type of exhaustible primary energy source. The proven reserve of uranium-235 has been shown to be surprisingly limited. Under these circumstances what was the reaction of the nuclear power generation supporters? Their reaction was to try to establish a so-called *Nuclear Fuel Cycle*; attempting to invent and construct a fast breeder reactor (FBR) that uses MOX fuel (Mixed Oxide) consisting of P_uO_2 and UO_2. Section 3 shows that, to date, this dream turned out to be a delusion. Section 4 presents the issue of CO_2 emissions through the nuclear power generation process within a reactor due to an increase in sea water temperature. This negative aspect of nuclear power generation has not been paid due attention thus far. Calculation of CO_2 emissions from the sea water is made in this section. The numbers given in this section are dependent on many factors of course, but we believe that the possible discrepancy from the most reliable values is within the negligible range. Section 5 discusses the capacity utilization of various electricity generation plants in Japan, showing that it is possible to supply electricity, in particular the peak demand of electricity, without resorting to the operation of nuclear power plants in Japan. Section 6 concludes this short piece.

2. Uranium Reserve as an Exhaustible Primary Energy Source

Uranium is an exhaustible primary energy source like other primary energy sources such as oil and coal. We know that the total estimated amount of proven reserves of any type of exhaustible primary energy source has been updated because of changes in technological and economic factors. However, *the relative size* of the estimated amount of several different *proven reserves* has not been changed much. So, it is instructive to examine the relative size of proven reserves of uranium in comparison with those of coal, crude oil, and liquid natural gas based upon data provided by the World Energy Council (2010). There are three types of energy carriers (electricity, fuel and heat) used for different tasks and goals produced from different forms of primary energy sources. What we have done here is, as a first approximation, to transform the proven reserves of each one of the primary energy sources into Joule values. Then, we "guestimate" the number of years that each type of primary energy source can last in comparison with the 474 exajoules (4.74×10^{20} Joule) that was the total primary energy use in the year 2008 (Table 1).



	Proven Reserves	Joules	Life Span (years)
Coal	860 billion tons	252.2×10^{20}	53.2
Crude Oil and Natural Gas Liquids	1,239 billion barrels	76.4×10^{20}	16.1
U-235	6.3million tons (U_3O_8)	30.7×10^{20}	6.5

Compiled from IEC (2010)

The Total Primary Energy Use in the Year 2008 in the World = 4.74×10^{20} J

Table 1. "Guestimated" Life Span of Three Primary Energy Sources in terms of the Year 2008 Total Primary Energy Use in the World

The guestimates of life span are calculated as follows:

(1) Coal: 1TCE=2.933 ×10^7 kJ;
(2) Crude oil and Liquid Natural Gas: 1TOE=4.187 × 1010J; 1 barrel=159 litres;
1k litre=0.925 × 103TOE
(3) Uranium-235; 1g of U-235 =82 × 106kJ

The uranium oxide product (U_3O_8) of a uranium mill is not directly usable as a fuel for a nuclear reactor and additional processing is required. Only 0.7% of natural uranium-235 is "fissile", or capable of undergoing fission, the process by which energy is produced in a nuclear reactor. The remainder is uranium-238 (U-238). So the average weight of U_3O_8 is 841. Only 0.59% of the total U_3O_8 is U-235. The heat equivalent of 1g of U-235 is 82 × 10^6kJ. So the total energy from the proven reserves of uranium is equal to 82 × 10^6 × 10^3 × 37392.39 × 10^6 = 30.7 × 10^{20} J.

From Table 1 we can recognize that how tiny of the uranium proven reserve in comparison with other exhaustible primary energy sources. Judging from this preliminary examination of uranium reserves we are not surprised to see that *starting 1991, the production of uranium in terms of contained uranium had been less than reactor requirement of uranium up until now* (WEC 2010, p. 204, Fig. 6.3).

3. Nuclear Fuel Cycle: A Delusion

The left part of Figure 1 is a schematic representation of the process of mining, milling, enriching and fabrication for thermal neutron reactor. Spent fuel usually contains 1% of plutonium. The current stock of separated plutonium stored for Japan amounts to more than 45 ton. This stock is equivalent to potential production of about 4,000 atomic bombs of the type dropped on Nagasaki in WWII. Plutonium is easily transformed into nuclear weapons. Therefore, it is prohibited to possess plutonium in a pure form for Japan under the nuclear non-proliferation treaty. The only law-abiding way for Japan to possess plutonium is to create a MOX (Mixed Oxide) form consisting of P_uO_2 and UO_2.

As examined in Section 2, fissile uranium-235 consists only of 0.7% of the total uranium; 99.3% of it is uranium-238 which is not fissile and cannot be used directly in a light water reactor as nuclear reactor fuel. plutonium-239 and uranium-238 are supposed to be disposed of as radioactive nuclear waste. However, if uranium-238 is successfully transformed into plutonium within a fast breeder reactor (FBR), almost 60% of uranium (both uranium-235 and uranium-238) could theoretically be utilized as nuclear fuels. In this way the actual stock of proven uranium reserves would be more than 60 times as much as the current stock of uranium-235! This imaginative idea is the basis of establishing the *Nuclear Fuel Cycle*, depicted schematically on the right part of Figure 1. There are four phases leading to constructing a commercially operating FBR: (1). Experimental Reactor; (2). Prototype Reactor; (3). Demonstration Reactor; and (4). Commercial Reactor. Japan has reached only the second phase and is now *planning* to construct a commercial reactor in 2050! In our view, establishing a nuclear fuel cycle based on FBR is perhaps a delusion, a serious delusion that hampers the proper planning for energy safely in the long-term. Since many people started realizing that it might be impossible to establish a nuclear fuel cycle based on FBR, MOX is being used in the thermal-neutron reactor (not in FBR!) such as the Fukushima Unit 3, the fuel of which has been reportedly melted down. It should be noted, however, that no nuclear power plants in Japan are operating right now using MOX fuels except the Ikata nuclear power generation station located in Shikoku Island, only 210 km away from Tokushima.

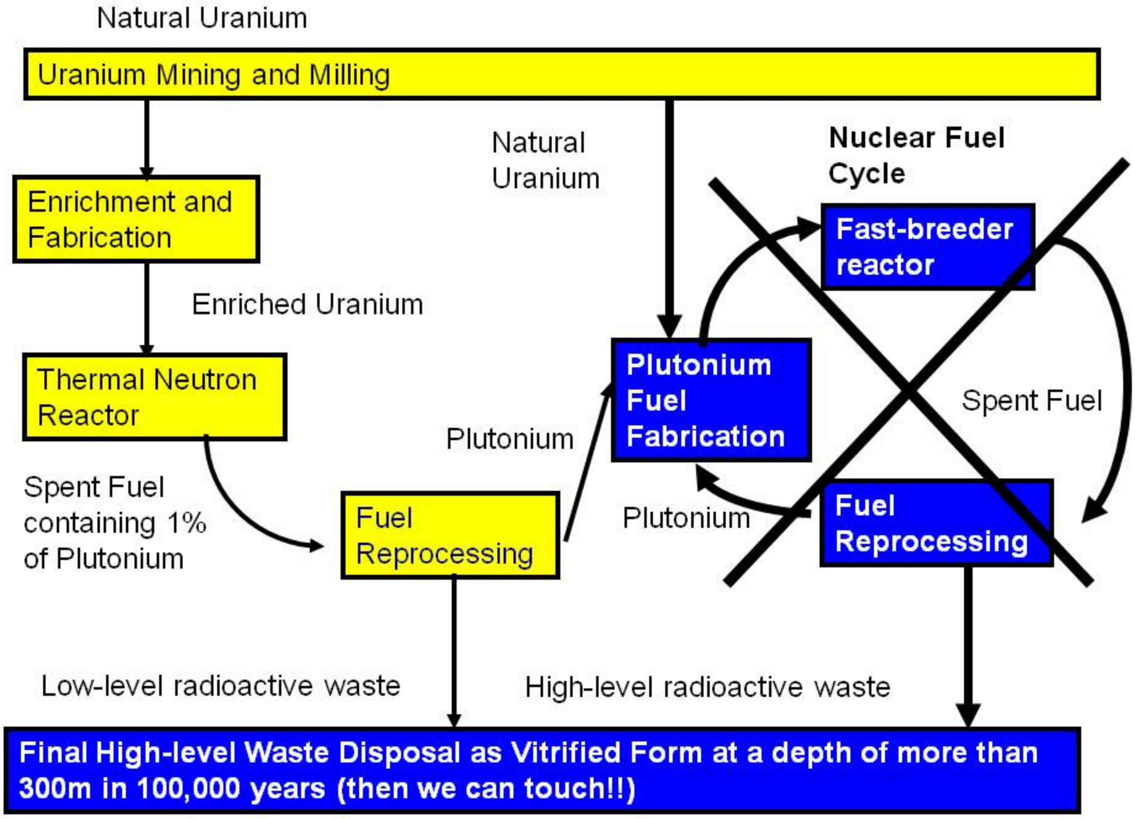


Fig. 1 Nuclear Fuel Cycle (based on a slide prepared by Prof. Koide)

Making mistakes is the only way for humans to acquire proper understanding of the nature and rational behind any technology. In the case of nuclear power generation, the learning process mechanism seems to be very difficult to establish, perhaps beyond the reach of humans. We would like to conclude this section with Soichro Honda’s famous quote to understand the nature and characteristics of nuclear power generation technology: “technology that does not take people seriously into account is not technology at all” (Honda 2009).

4. CO2 Emission from the Sea: The Case of Nuclear Power Generation Plants

Light water reactors are the most common type of thermal neutron reactor. For example, more than 80% of nuclear power generation plants in the world in the year 1999 were light water reactors. Currently, two types of light water reactors are widely used: the pressurized water reactor (PWR) and the boiling water reactor (BWR). All commercially operating nuclear power plants in Japan are of these two types. For this reason, these plants are constructed near the sea because a lot of water is needed for their operation, since water is used for the neutron moderator. All three units of the Fukushima power generation station that have melted down are BWRs.

It is well known that *only one-third* of the total heat generated by light water reactors is transformed into electricity due to their low level of thermal efficiency. Therefore, boiling water from a light water reactor must be discarded into the sea. Thus, the sea water temperature in the surrounding marine ecosystems must rise considerably. Yet scientists concerned with the issue of climate change have not paid due attention to this highly plausible reason for increasing sea water temperatures. The IPCC (2011), for example, has never mentioned this type of mechanism for increasing sea water temperatures, only focusing on the absorbing capacity of the ocean. So it will be a nice exercise, *as a first approximation*, to investigate the order of magnitude of this temperature increase mechanism in terms of CO_2 emissions. The numbers we go through are dependent on many factors of course, but we hope that the possible discrepancy from the most reliable values is within the negligible range. Readers of this short piece are encouraged to investigate further on this problem.

In the year 1998 the amount of electricity generation was 331.35 billion kWh. As already mentioned, the average thermal efficiency of light water reactors in Japan is one-third. Therefore, the total heat discarded into the surrounding sea is $2 \times 331.35 \times 10^6 \times 3.6$MJ = 2.39×10^{12} MJ. The specific heat of 1g of water can be regarded as 4.2J. Thus, the amount of water that can be raised by one degree Celsius is $2.39 \times 10^{12} \times 10^6$ J/4.2 J = 0.569×10^{12} ton.

We can also examine how the amount of CO_2 to be resolved in 1 lire of water (mol/kg) varies with the temperature. Then a 1°C increase in the surface sea water induces a 2% of CO_2 release from the sea. Suppose that the average sea water temperature around Japan is 20°C. According to the Japanese Meteorological Agency (2011), the CO_2 concentration within the sea area around Japan is approximately 340ppm. Therefore, the total amount of CO_2 that could be released from the sea is $0.569 \times 10^{18} \times 340 \times 10^{-6} \times 0.02$=3.87 million ton.

According to Kyoto Protocol, Japan is supposed to reduce CO_2 emissions by 6% of their 1990 level that is 1,144 million tons. So the required CO_2 reduction is 68.6 million ton. Therefore, the total amount of CO_2 emission *due to the operation process of electricity generation* from the nuclear power generation plants in Japan is 5.6% of the required reduction of CO_2. This amount is not a negligible amount at all. It must be emphasized that this amount of CO_2 emissions comes only from the operation process of electricity generation. There are many other possible CO_2 emissions if we take other processes of nuclear power generation and radioactive waste, already suggested in Section 3, into consideration: (1) mining and milling; (2) enrichment and fabrication; (3) dealing with depleted uranium ore; (4) low-level radioactive waste management; (5) the final disposal process that has never been envisioned properly. In addition to the CO_2 emission issue, there are of course other biological hazards, including human health problems that could ensue for an incredibly long period of time.

The following statement in 1975 by Georgescu-Roegen deserves special attention with respect to the threat of heat pollution created by nuclear power generation at a fundamental level: “The *additional* heat into which all energy of terrestrial origin is ultimately transformed when used by man is apt to upset the delicate thermodynamic balance of the globe in two ways. First, the islands of heat created by power plants not only disturb the local fauna and flora of rivers, lakes, and even coastal seas, but they may also alter climatic patters. One nuclear plant alone may heat up the water in the Hudson River by as much as 7°F. Then again the sorry plight of where to build the next plant, and the next, is a formidable problem. Second, the additional global heat at the site of the plant and at the place where power is used may increase the temperature of the earth to the point at which the icecaps would melt—an event of cataclysmic consequences. Since *the Entropy Law allows no way to cool a continuously heated planet*, *thermal pollution could prove to be a more crucial obstacle to growth than the finiteness of accessible resources*” (the second italics part is added, Georgescu-Roegen, 1975, p. 358). This quote is very valuable for our debate on sustainability. Georgescu-Roegen argues that nuclear power plants could be a real threat to global warming. We must recall that some countries such as China and Russia are planning to launch the construction of even more nuclear power plants due to high oil price and – ironically – to fight global warming.

5. Reality Check: Electricity Supply and Peak Demand

We believe that the readers of this commentary might suspect that Japan can never produce a sufficient supply of electricity if all their nuclear power plants are eliminated. Surprisingly, it is in fact possible to supply enough electricity to meet demand. Figure 2 shows full capacity and the operation ratio for each type of electricity generation method together with private electricity generation in the year 2005 in Japan. It is easy to recognize that without nuclear power generation plants Japan can safely secure the necessary electricity demand without any problems if the idle capacity of other types of electricity generation plants are used more intensively, in particular, thermal electric power generation plants. It is also possible to supply peak electricity demand in summer evenings without any difficulty. According to Asahi.com (2011.05.12), the Hirono Thermal Plants (five units of 3.8 million kW capacity) in the Fukushima Prefecture that were shut down after the earthquake will be operational again starting in mid-July 2011. So the peak electricity demand (55 million kW) can be supplied without any problem. Furthermore, according to Nikkei.com (2011.05.16), in the year 2011 for example, the full capacity of private electricity generation amounts to 60 million kW. Out of this amount, 16.4 million kW of electricity can be supplied to the district of TEPCO. At this moment, the present maximum capacity of TEPCO is 56.2 million kW. So if electricity is properly distributed, there would be no electricity shortage. If this is the case, then why don't TEPCO and other Japanese electric power companies refer to the possible electricity supply that could come from the private electricity generation? The answer is that they are afraid of the possible separation between the generation and distribution of electricity, which will cause TEPCO and other Japanese electric power companies to lose their monopolistic power over the electricity market.

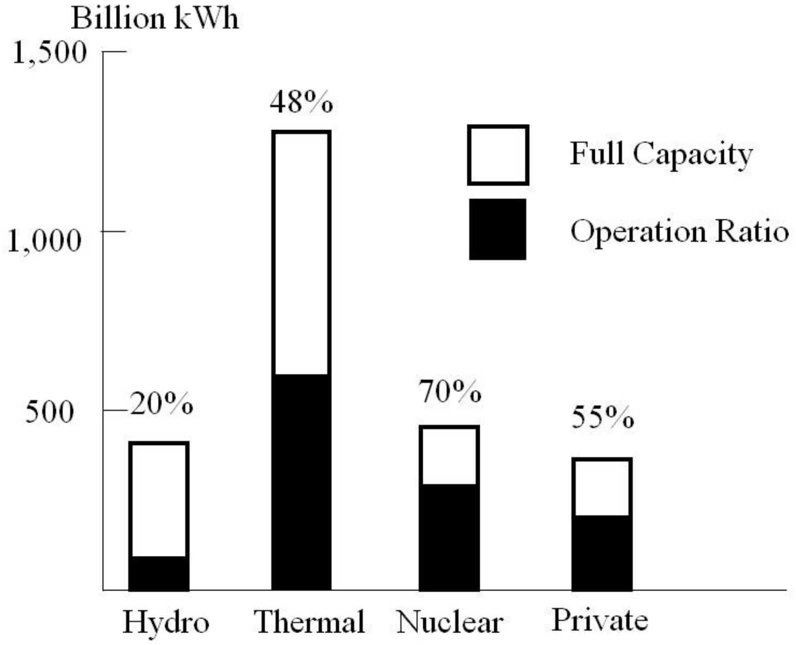


Fig. 2 Full Capacity and Operation Ratios for Electricity Generation in Japan in the year 2005 (compiled by Prof. Koide from the date at Federation of Electric Power Companies of Japan 2011)

As shown in this paper, it is possible to supply the peak electricity demand without resorting to nuclear power generation plants in Japan. Furthermore, to reduce the need for further capital investments in power generation to fulfill the peak demand for only several hours in a summer evening, it is better for Japanese consumers to try to shift or average out their peak electricity demand. This averaging out policy can be done with the cooperation of industries. This policy is also very useful to reduce wasteful energy use by pumped-storage hydroelectricity generation plants that have more than 30% loss of electricity due to the raising and dropping of water during the periods of demand shortages. The cost of pumped-storage hydroelectricity is ten times as much as those of thermal and normal hydroelectricity generation plants. It is also wise to use more price oriented policies to make demand management more flexible; for example, instituting a peak electricity price scheme for summer evenings. A more sophisticated way of demand management using market mechanisms are occasionally useful.

The readers might wonder why Japanese electric power companies promote even more construction of nuclear power plants in Japan. The reason is very simple: nuclear power is more profitable than any other method of electricity generation for the electric power companies, as guaranteed by the Electric Utilities Industry Law in Japan. Despite the change in this law in 1995 that allowed independent power producers to enter into the electricity generation market, electric power companies still enjoy favorable positions. The Electric Utilities Industry Law stipulates that electric power companies can determine the electricity price based on the three factors: (1) the total cost of electricity generation, electricity distribution, and electricity sale; (2) a business return rate (determined by the Electric Utilities Industry Law); and (3) the total asset value possessed by the electric power companies. The total asset value of a nuclear power plant and its components is much bigger than that of any other type of electricity generation plant, given the business return rate that is applied to any type of electricity generation plant. Therefore, it is very profitable for any electric power company to construct as many nuclear power generation plants as possible. There also exist bureaucratic networks and political interest groups that facilitate electric power companies to take advantage of various articles in the Electric Utilities Industry Law that are favorable to the electric power companies. In fact, for example, some of the top ranking officers of the Ministry of Economy, Trade, and Industry can take Amakudari jobs for the electric power companies: “Amakudari” is the practice whereby bureaucrats retire into lucrative posts in industries they had overseen. The electric power companies are no exception for this very bad practice that is still adopted by some companies overseen by Japanese government bureaucrats.

6. Conclusion

We have examined several key issues associated with nuclear power electricity generation that are fundamentally important for a discussion on sustainability.

There is yet another deep theoretical and practical challenge associated with the quality and quantity of a primary energy source. The metabolic pattern with the technological development of society based on the massive use of fossil fuels can be described in terms of an acceleration of energy and material consumption together with the dramatic reallocation of distribution of age classes, human time profile of activities and land use patterns in various sectors of the modern economy, *resulting in time and land saving in the energy and agricultural sectors* (Mayumi, 1991). Furthermore, fossil fuels are “optimal” in terms of the amount of matter in bulk required for energy extraction, transformation, and transportation to support modern industrial society. The conclusion that fossil fuels are superior in terms of material flow requirement, is sometimes called Georgescu-Roegen’s Fundamental Proposition (Kawamiya 1983; Mayumi 2001). Therefore, solar energy cannot easily support current fossil-fuel based manufacturing and consumption activities, as Georgescu-Roegen argues (1979, p. 1050): “It [the necessary amount of matter for a technology] is high for weak-intensity energy (as is the solar radiation at the ground level) because such energy must be concentrated into a much higher intensity if it is to support the intensive industrial processes as those now supported by fossil fuels”. This is the one reason why large scale agro-biofuel production from corn or sugarcane is not viable at all (Giampietro and Mayumi 2009). Concerning the feasibility of nuclear power generation, Georgescu-Roegen also argues that the necessary amount of matter is high for high-intensity energy such as thermonuclear energy because high-intensity energy must be contained and controlled within a stable boundary.

After the nuclear fuels of the three units of the Fukushima nuclear power station melted down, it became impossible to reach the state of cold shut-down. As already suggested, the only plausible temporary remedy would be to contain all three units completely. It should be remembered that the containment strategy is nothing more than leaving nuclear fuels in the facility without putting the fuel into a cold shut down state. However, immediate action toward the construction of the containment structure is absolutely necessary at this moment, so that a lot of the radioactive waste can be prevented from flowing into the surrounding ocean. If Japan is not successful in achieving this temporary containment, serious irreversible biological effects would result, heavily damaging marine ecosystems and adversely affecting human health.

Under these circumstances, it is very sad to see that the draft prepared by International Atomic Energy Agency (IAEA) indicates that the nuclear power generation accident could have been prevented if a tsunami prevention measure was properly prepared (Asahi.com. Mini. 2011.05.31). We must remember that the IAEA was set up in 1957 as the world’s “Atoms for Peace” organization within the United Nations family. The Agency promotes safe, secure, and peaceful nuclear technologies. So one of the aims of the IAEA is to promote the nuclear power generation as much as possible! This draft plan by the IAEA was perfectly echoed in a new proposal made by some twenty Japanese politicians, including several former prime ministers, saying that nuclear power generation plants should be constructed underground (Sankei 2011.05.31). Despite their false claim, the high pressure coolant injection system within the reactor building in the Fukushima station was destroyed immediately after the earthquake itself. The IAEA and some Japanese politicians unfortunately misunderstand the nature and characteristic of nuclear power generation technology without grasping the deep meaning of S. Honda’s statement on the technology and its relation to the welfare of human beings. The IAEA and the politicians are trying to attribute the cause of the Fukushima accident to the tsunami, not to the huge earthquake that caused the tsunami and happen frequently in Japan. Furthermore, the Ministry of Education, Culture, Sports, Science and Technology which is supposed to protect children from radioactive contamination as much as possible raised the minimum allowable contamination level for children up to 20mSv per year. This is the maximum level of contamination legally allowed for a professional radiologist. This is indeed a totally unacceptable decision. At this moment what the Japanese government must do is to construct a containment structure as soon as possible, and should not promote another Granfaloon project without properly understanding the issues involved. Unfortunately, during the construction process of these containment facilities a vast number of workers must go through serious radiation exposure; a similar exposure level to those workers at Chernobyl.

We must emphasize three points associated with nuclear waste. First of all, there is no safe level of exposure to radiation: even very low doses can cause cancer (National Academies 2006). Secondly, it is almost impossible to safely operate large commercial plutonium plants for reprocessing spent fuels. For example, there is only one place, Rokkasho-Mura (Rokkasho village) of Aomori Prefecture, in Japan that is yet to be operated. Every year about 1,000 ton of spent fuels are produced in Japan and the stock of spent fuels that are yet to be processed is accumulating without being "processed" properly. Finally, concerning the high-level radioactive waste, final disposal sites, located underground, where the vitrified wastes are supposed to be buried for 100,000 years have not been determined. Given this information and, as we have shown, the fact that nuclear power is not needed to produce a sufficient supply of energy in Japan, any serious discussion of sustainability in Japan must be void of any argument for building additional nuclear power plants. Furthermore, the exercise performed in this paper for Japan should be carried out for other countries before they entertain any discussion of building new nuclear power plants. Only then can serious sustainability discussions occur.

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