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Commentary

Uranium reserve, nuclear fuel cycle delusion, CO_2 emissions from the sea, and electricity supply: Reflections after the fuel meltdown of the Fukushima Nuclear Power Units

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ABSTRACT

The Great Tohoku–Kanto earthquake and the resulting tsunami have brought considerable attention to the issue of building new nuclear power plants. In this paper we argue that nuclear power is not a sustainable solution to energy problems. First, we explore the stock of uranium-235 and the different methods, fast breeder and MOX fuel reactors, developed by the nuclear power industry to exploit this resource. Second, we show that these fuel reactors are not feasible. Third, we show that the claim 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 effect 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 needed to meet electricity 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 paper.

1. Introduction

The main purpose of this commentary is to discuss several fundamental issues associated with nuclear power generation plants, which are a critical component of any discussion on environmental 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 peril. On April 12, 2011 Japanese authorities notified the International Atomic Energy Agency (IAEA) of their decision to upgrade from an INES 5 to an INES 7 on the International Nuclear and Radiological Event Scale. As a result of this re-evaluation, the total amount of discharged iodine-131 is estimated to be 1.3×10^{17} Bq, and caesium-137 is estimated to be 6.1×10^{15} Bq according to the Nuclear and Industrial Safety Agency in Japan (Yomiuri Online 2011.04.12). A *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 onto the land and into the sea. In fact, much of the radionuclides released into the environment around the Fukushima plant 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 which had the same INES 7 rating almost exactly twenty-five years earlier in 1986. The Fukushima disaster could 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 and well known as a strong advocate of the nuclear industry as an economic development tool, 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 on May 24 by the Tokyo Electric Power Company (TEPCO) where, based on their updated data analysis, they found that in addition to Unit 1 melt down on May 12, the nuclear fuels in Unit 2 and Unit 3 were melted down through the reactor vessels (Yomiuri Online 2011.05.24). For melt down to occur, the temperature of UO_2, uranium dioxide, must

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reach a temperature of approximately 2800 °C. TEPCO also acknowledged that the containment structure of these three units, with a thickness of 3 cm of steel (the temperature to melt steel is approximately 1600 °C) must already have been breached. Therefore, radioactive nuclear fuel is 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 fuel to the state of a cold shutdown. The only practical *temporary* solution now available would be to construct a structure that *completely* contains all three units to prevent radioactive substances from eventually flowing into the adjacent sea.

The remainder of this paper is organized as follows. Section 2 examines the stock of uranium-235, a fissile type of exhaustible primary energy. The proven reserve of uranium-235 has been shown to be limited. Due to the limited reserves of uranium-235, nuclear power generation supporters tried 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 (plutonium dioxide) and UO_2 (uranium dioxide). Section 3 shows that, to date, the *Nuclear Fuel Cycle* is not possible. Section 4 examines the issue of CO_2 emissions resulting from sea water evaporation caused by increased sea water temperatures triggered by hot water released from the nuclear power plants into the sea. This negative aspect of nuclear power generation is rarely examined. Thus, approximations of CO_2 emissions from evaporated sea water are calculated in this section. The estimates provided are dependent on many factors, but we believe that the values are within the negligible range of the most reliable values that have been calculated elsewhere. 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 the paper.

2. Uranium Reserve as an Exhaustible Primary Energy Source

Uranium is an exhaustible primary energy source like oil and coal. The total estimated amount of proven reserves of any type of exhaustible primary energy source has to be updated regularly to account for changes in technological and economic factors. However, *the relative size* of the estimated amount of several different *proven reserves* has not changed much. Therefore, examining 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 is instructive (2010). There are three types of energy (electricity, fuel and heat) used for different tasks and goals produced from various forms of primary energy sources. As a first approximation, the proven reserves of each one of these primary energy sources must be converted into Joules. Then, the number of years that each type of primary energy source can last is estimated and compared with the amount of total primary energy used in the year 2008, 474 EJ (4.74×10^{20} J) shown in Table 1. The data and the conversion coefficients are taken from the Teramura Research Lab (2007) and the World Nuclear Association (2009, 2010).

Table 1
"Guestimated" life span of three primary energy sources in terms of the total primary energy use in the world in the year 2008.

	Proven reserves	Joules	Life span (years)
Coal	860 billion tons	252.2×10^{20}	53.2
Crude oil and natural gas liquids	1239 billion barrels	76.4×10^{20}	16.1
U-235	6.3 million tons (U_3O_8)	30.7×10^{20}	6.5

Compiled from World Energy Council (2010).
The total primary energy use in the year 2008 in the world $=4.74\times10^{20}$ J.

The estimates of life span for four common primary energy sources, coal, crude oil, liquid natural gas, and uranium are calculated as follows:

(1) Coal: 1 TCE $=2.933\times10^{7}$ kJ;
(2) Crude oil and liquid natural gas: 1 TOE $=4.187\times10^{10}$ J; 1 barrel = 159 l;
1 kl $=0.925\times10^{3}$ TOE
(3) Uranium-235; 1 g of U-235 $=82\times10^{6}$ kJ

Triuranium octaoxide (U_3O_8), often used in nuclear power generation because it is readily available in nature and kinetically and thermodynamically stable is not directly usable as a fuel for a nuclear reactor without additional processing. This additional processing is necessary to obtain usable nuclear fuel. Only 0.7% of natural uranium is the fissile, or capable of undergoing fission, U-235 necessary to produce energy in a nuclear reactor while the remaining 99.3% 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 1 g of U-235 is 82×10^{6} kJ. So the total energy from the proven reserves of uranium is equal to $(82\times10^{6}\text{ kJ})\times(10^{3})\times(37{,}392.39)\times(10^{6})=30.7\times10^{20}$ J.

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

If the following two points are taken into consideration, the low proven reserve levels of uranium are clear:

(1) According to an estimate for 2030, primary energy demand in Asia reaches a level that is double (6.2 billion TOE) the year 2004 level (3.1 billion TOE), reflecting on the expected high economic growth rate (Ito, 2007). This projected energy demand would be almost 40% of the total projected energy demand in the world by 2030.
(2) There are three uses of energy for final consumption, fuels, heat, and electricity. Electricity that is partially produced from nuclear power generation plants using U-235 is only a small fraction of that used in final consumption. Moreover, of the three uses of energy electricity is only 23% of the final energy consumption in Japan (EDMC 2011).

3. Nuclear Fuel Cycle: A Delusion

The left part of Fig. 1 is a schematic representation of the process of mining, milling, enriching, and fabricating for a thermal neutron reactor. Spent fuel usually contains 1% of plutonium. The current stock of separated plutonium stored for Japan amounts to more than 45 t, equivalent to the potential production of about 4000 atomic bombs of the type dropped on Nagasaki in WWII. Plutonium is easily transformed into nuclear weapons. Therefore, under the nuclear non-proliferation treaty, Japan is prohibited from possessing plutonium in a pure form. 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, natural uranium consists of 0.7% of the fissile U-235 and 99.3% of U-238 which is not fissile and cannot be used directly in a light water reactor as fuel. Plutonium-239 and U-238 are supposed to be disposed of as radioactive nuclear waste. However, if U-238 is successfully transformed into plutonium within a fast breeder reactor (FBR), almost 60% of the uranium (both U-235 and U-238) could theoretically be utilized as nuclear fuels. Thus, the actual stock of proven uranium reserves would be more than 60 times as much as the current stock of U-235! This imaginative idea is the basis of establishing the *Nuclear Fuel Cycle*, depicted schematically on the right part of Fig. 1. There are four phases leading to

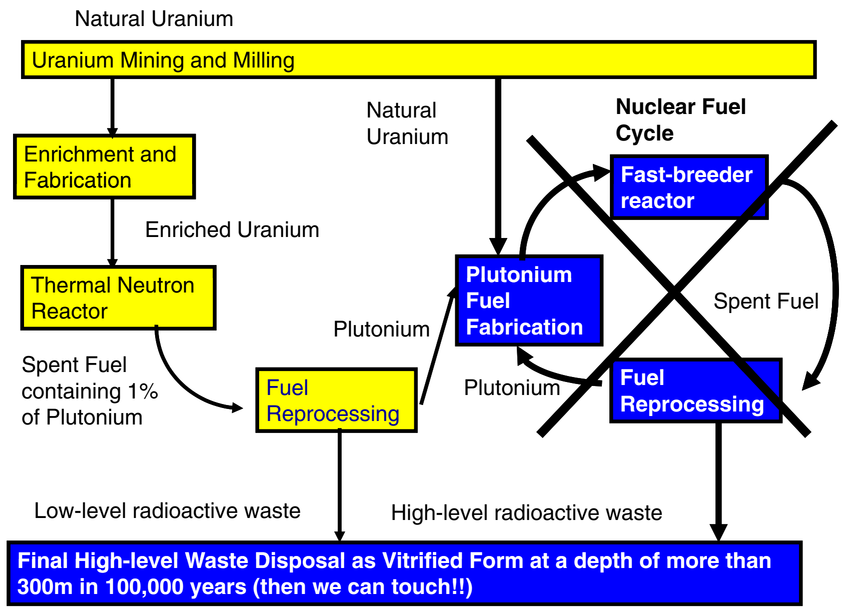

Fig. 1. Nuclear fuel cycle (based on a slide prepared by Prof. Koide).

constructing a commercially operating a 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 a FBR is perhaps a delusion, a serious misconception that hampers the proper planning for energy safely in the long-term. Since it might be impossible to establish a nuclear fuel cycle based on a FBR, MOX is now being used in the thermal-neutron reactor (not in a FBR) such as the Fukushima Unit 3, the fuel of which has reportedly melted down. It should be noted, however, that no nuclear power plants in Japan are currently operating right now with MOX fuels except the Ikata nuclear power generation station located in Shikoku Island, only 210 km away from Tokushima.

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. This section is concluded 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. CO_2 Emission from the Sea: The Case of Nuclear Power Generation Plants

Light water reactors are the most common type of thermal neutron reactor. Currently, two types of light water reactors are widely used: the pressurized water reactor (PWR) and the boiling water reactor (BWR). More than 80% of nuclear power generation units in the world in the year 1999 were light water reactors (JA.Wikipedia, 2011). The United States and Japan are the two countries that intensively use light water reactors. In the year 2008 all 103 nuclear power generation units in the United States were light water reactors (Settle, 2011) and in the year 2007 all 55 commercial nuclear power generation units were light water reactors in Japan (JA.Wikipedia, 2011). Currently, all commercially operating nuclear power plants in Japan are either PWRs or BWRs. These types of reactors are constructed near the sea because they require a lot of water for their operation, since water is used for the neutron moderator. All three units of the Fukushima power generation station that melted down are BWRs.

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. 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. Therefore, *as a first approximation*, an exercise aimed at investigating the order of magnitude of this temperature increase mechanism in terms of CO_2 emissions is provided. The numbers used in the exercise are dependent on many factors, but any discrepancy from the most reliable values is believed to be within the negligible range. Readers 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 $(2)\times(331.35\times10^6\ \text{kWh})\times(3.6\ \text{MJ})=2.39\times10^{12}$ MJ. The specific heat of 1 g of water is equivalent to 4.2 J. Thus, the amount of water that can be raised by 1 °C is $(2.39\times10^{12}\ \text{MJ}\times10^6\ \text{J})/(4.2\ \text{J/g})=0.569\times10^{18}\ \text{g}=0.569\times10^{12}$ t.

We can also examine how the amount of CO_2 in 1 l of water (mol/kg) varies with the temperature. A 1 °C increase in the surface sea water induces a 2% increase in CO_2 released from the sea.[1] Suppose that the average sea water temperature around Japan is 20 °C. According to the Japan Meteorological Agency (2011), the CO_2 concentration within the sea area around Japan is approximately 340 ppm. Therefore, the total amount of CO_2 that could be released from the sea is $(0.569\times10^{18})\times(340\times10^{-6})\times(0.02)=3.87$ million tons.

[1] According to Henry's Law a 1 °C increase in the surface sea water would result in a 4% increase in CO_2 released. However, since there are many factors that contribute to the release of CO_2 from the sea, such as pH level and plant life, that are not accounted for in Henry's Law, we use 2% as a conservative estimate of the CO_2 released into the atmosphere.

According to the Kyoto Protocol, Japan is supposed to reduce CO_2 emissions by 6% of their 1990 level which was 1144 million tons. Therefore, the required CO_2 reduction is 68.6 million tons. The total amount of CO_2 emissions *due to the operation process of electricity generation* from nuclear power generation plants in Japan is 5.6% of the required reduction of CO_2. This amount is not negligible and 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 sources of 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; and 5) the final disposal process that has never been envisioned properly. In addition to the CO_2 emissions 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 by Georgescu-Roegen, 1975 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 many more nuclear power plants due to high oil prices and, ironically, to fight global warming.

5. Reality Check: Electricity Supply and Peak Demand

Readers of this commentary might suspect that Japan can never produce a sufficient supply of electricity if all their nuclear power plants are eliminated, particularly since the country obtains 29% of its electricity from nuclear power (The Economist, 2011). Surprisingly, it is in fact possible for Japan to supply enough electricity to meet demand without relying on nuclear power plants. Fig. 2 shows the full capacity and the operation ratio for each type of electricity generation method together with private electricity generation in the year 2005 in Japan. Japan can safely secure the necessary electricity demand without nuclear power generation plants 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 with a capacity of 3.8 million kW) 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 operated by 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 rely on the possible electricity supply that could come from 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.

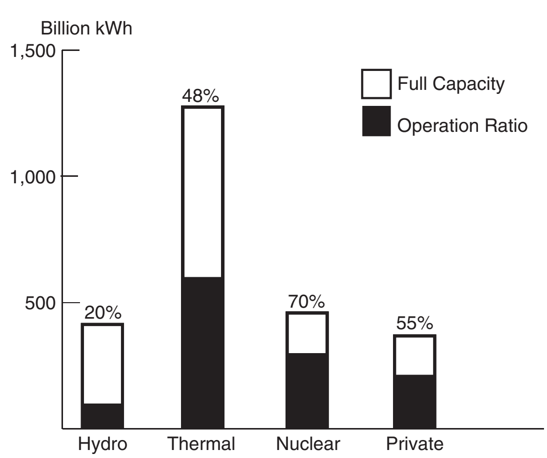

Fig. 2. Full capacity and operation ratio for electricity generation in Japan in the year 2005 (compiled by Prof. Koide from the date at Federation of Electric Power Companies of Japan, 2011).

As shown in this paper, the peak electricity demand in Japan can be met without resorting to nuclear power generation plants. Furthermore, to reduce the need for additional capital investments in power generation to fulfill the peak demand during the summer Japanese consumers could shift or average out their peak electricity demand. Moreover, Japanese industries could also be encouraged to average out their peak electricity demand. For example, after the earthquake and tsunami the Japanese people responded by turning off lights, turning down the air conditioning, worked from home, and factories moved shifts to nights and weekends when demand for electricity was lower. As a result, peak electricity in the Tokyo region decreased by almost 20% from the previous year (The Economist, 2011). 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 rising 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. Price oriented policies could also be used 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 as well.

The reader might wonder why Japanese electric power companies are promoting the construction of additional nuclear power plants. The reason is very simple: nuclear power is more profitable than any other method of electricity generation for the power companies, as guaranteed by the Electric Utilities Industry Law in Japan. Despite a 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, constructing as many nuclear power generation plants as possible is very profitable for any Japanese electric power company. There also exist bureaucratic networks and political interest groups that facilitate electric power companies to take advantage of the Electric Utilities Industry Law. 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, where “Amakudari” is the practice whereby bureaucrats retire into lucrative posts for corporations in industries they had overseen. The electric power companies are no exception for this very bad practice of Amakudari.

Another question to be raised is whether or not the cost of electricity produced by nuclear power plants is really cheaper than the cost of electricity produced through other types of generation. Following the pioneering work done by T. Murota (1993), K. Oshima (2010) tried to identify the real cost of electricity generation based on the financial reports issued by all the Japanese power generation companies. According to his result the real cost of electricity produced by nuclear power plants is higher than the costs of other types of electricity generation. It must be noted that Oshima's calculation does not include the substantial amount of subsidies provided by the Electric Power Development Taxation Law (0.375 yen/kW), the compensation cost in the case of a nuclear accident and the long-term management cost of the radioactive waste that have been piled up near the nuclear power generation plants.

6. Conclusion

Japan started operation of nuclear power generation in 1970. The reactor vessels are designed to last about 30 years for PWR and 40 years for BWR. Since neutrons are used as a moderator for these reactors, once the quantity of neutron radiation within the reactor vessel exceeds a certain threshold, the reactor vessel becomes extremely fragile. According to H. Ino's recent study (2011), Japan has seven nuclear power units that have considerably high Ductile Brittle Transition Temperatures (DBTT). Genkai Unit 1 in Saga Prefecture, Kyushu is reported to have the highest DBTT at 95 °C. If the temperature of the reactor vessel is cooled below the DBTT, then the probability that the reactor will shatter on impact, especially in the case of cold shutdown operation, instead of bending or deforming, increases. The aging of nuclear power plants is a serious threat for the Japanese people.

Several key issues associated with nuclear power electricity generation that are fundamentally important for a discussion on sustainability have been examined in this paper.

Yet, there is another deep theoretical and practical challenge associated with the quality and quantity of a primary energy source. That is, 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 bulk matter required for energy extraction, transformation, and transportation to support modern industrial society. The conclusion that fossil fuels are superior in terms of a 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.” Therefore, 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 a large amount of matter is necessary for high-intensity energy, such as thermonuclear energy, because high-intensity energy must be contained and controlled within a stable boundary.

After the melt down of the nuclear fuels in the three units of the Fukushima nuclear power station, a cold shut down became impossible to reach. As already suggested, the only plausible temporary remedy would be to contain all three units completely. One should remember 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 leaking into the 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). Remember, 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 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 claim, the high pressure coolant injection system within the reactor building in the Fukushima station was destroyed immediately after the earthquake itself, proving their statement to be false. 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, who is supposed to protect children from radioactive contamination as much as possible, raised the minimum allowable contamination level for children up to 20 mSv per year. This level is the maximum contamination legally allowed for a professional radiologist; a totally unacceptable decision. At this moment what the Japanese government must do is construct a containment structure and stop promoting another Granfalloon 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, there is no safe level of exposure to radiation: even very low doses can cause cancer (National Research Council, 2006). Second, 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 the Aomori Prefecture in Japan, and this plant is yet to be operational. Every year about 1000 t of spent fuel is produced in Japan and the stock of spent fuel that has not been processed properly is accumulating. 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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