"GENESIS Project" and High-Temperature Superconducting (HTS) DC Cable –Keen Use of Ultimately Sustainable New Energies–

Ryosuke HATA

The world population has overpassed 6.6 billion in August, 2007, and is expected to reach 9 to 10 billion by the middle of this century. The International Energy Agency expects that the world electricity demand will grow by 50% by the year 2030 accordingly. In terms of all primary energies, the growth of demand between 2000 and 2050 is expected to be as high as 200%. Since greenhouse gas emissions increase along with the expansion of energy consumption that will bring about environmental degradation, it is pointed out that the irreversible world catastrophe would suddenly occur before energy resources become depleted. Recently, there exists an opinion that more nuclear energy that emits no CO_2 gas should be used, and today there are a lot of plans for building nuclear power stations in China and other developing countries in addition to Japan, the U.S. and Europe. One problem of uranium, however, is that it is only temporarily available and its reserve will last no more than 60 years. Another serious problem is that once the present generation consumed uranium, future generations should take care of radioactive wastes during around 100 years of interim storage and more than 10 thousands years of final storage. These problems show that nuclear energy is not the ultimate solution. Academic people are saying that making an artificial sun on earth through nuclear fusion should be the solution. However, it is presently predicted that it will take over centuries to realize artificial sun, meaning that at this point in time nuclear fusion is not the solution. In this paper, the author strongly insists that, in this impasse, the only ultimate solution that the present-day engineers can propose is the "GENESIS Project" that combines new solar-oriented recyclable energies such as photovoltaic power, wind-turbine power or hydraulic power with high-temperature superconducting power cable that has recently become technologically practical. In addition, the author also describes the importance of applying PPLP solid DC submarine cable to the international interconnection of electric power systems so as to realize the "Global Electric Power Network" and finally accomplish the "GENESIS Project".

1. Introduction

The world's population reached 6.5 billion in February 2006 [22] and was reported to have exceeded 6.6 billion in August 2007 [65]. It is expected to rise to between nine and ten billion by the middle of the 21st century [23]. Meanwhile, according to International Energy Agency (IEA) experts, worldwide demand for energy will expand by 1.5 times by 2030 [15]. In terms of electricity alone, demand is estimated to grow 2.6 times by 2030 [16]. Total demand for primary energies will double between 2000 and 2050. Assuming that generation of greenhouse gas emissions would increase along with expansion of energy consumption, which could have adverse impacts on the environment, there is potential for a sudden, irreversible catastrophe to occur prior to the exhaustion of natural resources such as crude oil and natural gas (40-60 years of reserves). In light of these considerations, Japan, the U.S., and Europe have recently been advocating an expansion of nuclear power generation, which uses uranium and does not emit carbon dioxide, while China and other developing countries have announced plans to construct a large number of nuclear power plants [16]. Uranium, however, is a transient resource of which reserves are projected to last no longer than 60 years [(1)-(3)]. Another serious issue is that after the current generation of humans have utilized the available uranium stocks, successive generations will have to manage 100 years of intermediate storage of radioactive waste, to be followed by as long as ten thousand years of ultimate storage [16, 17]. These issues indicate that, while there is a clear demand for more nuclear generation capacity right now, nuclear energy should not be regarded as the ultimate solution to energy, resource and environmental issues. Development of nuclear fusion reaction technology, in other words creating an artificial sun on Planet Earth, has been proposed by some academics since many years ago. However, completion of development of such a technology would take centuries according to a recent projection based on technical evaluation, and still provide no lasting solution. This paper sets out to argue that, given such an impasse, the only ultimate solution that present-day engineers can propose is the "GENESIS Project." This proposal combines new, solar-derived, recyclable energies, such as photovoltaic power, wind-turbine power, and hydraulic power, with the high-temperature superconducting power cable on which sufficient progress has recently been made to enable it to be put to practical use. The paper also describes the importance of application of PPLP Solid DC submarine cable to international interconnection of electric power in order to materialize the "global electrical network," which will enable the ultimate accomplishment of the "GENESIS Project".

Note: The description of the GENESIS Project is based largely on references (1) through (14), although they are not always cited.

2. Increasing Population and Energy Consumption, and Energy Reserves

Figure 1 shows global population growth from the year 1 A.D. to recent times. **Figure 2** shows historical energy consumption, which began to grow very rapidly from the time of the Industrial Revolution in the late 18th century, when humanity acquired the capacity to use fossil fuel resources. Population followed the explosive growth function shown in the middle of **Fig. 1**, passing a point of no return and rising from less than 3 billion in 1945 to more than 6.6 billion in 2007 [(22), (65)], and is projected to reach 7 billion in 2030, and 9 billion in 2045 [(23)]. Energy consumption likewise skyrocketed, as shown in **Fig. 2**, and by 2030 is projected to be five times the current level (see **Fig. 15**).

Figure 3 presents a comparison of the growth of energy demand in developed and developing countries, showing that electricity demand has been growing markedly faster in the developing countries, and its growth trend is contributing substantially to energy-related problems. **Figure 4** charts installed electrical generation capacity per capita (which has risen extremely rapidly in China, to 0.45 kW per capita in 2007). If the level of 1 kW per capita, which Japan reached during the 1970s, is taken as the steppingstone to developed nation status, then the people of every country of the world may be said to have the right to enjoy a capacity of

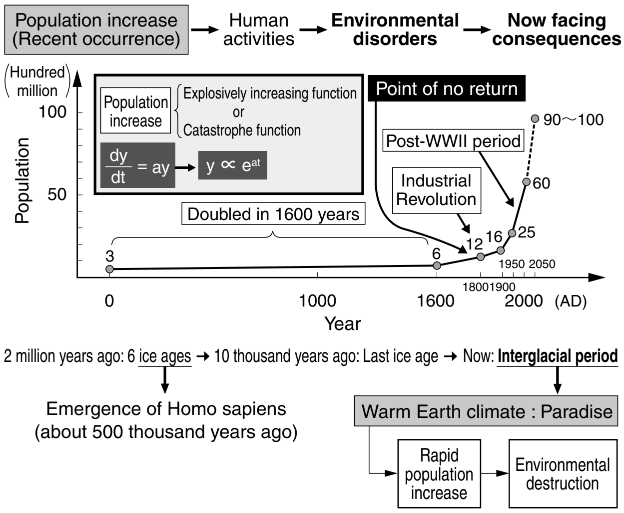
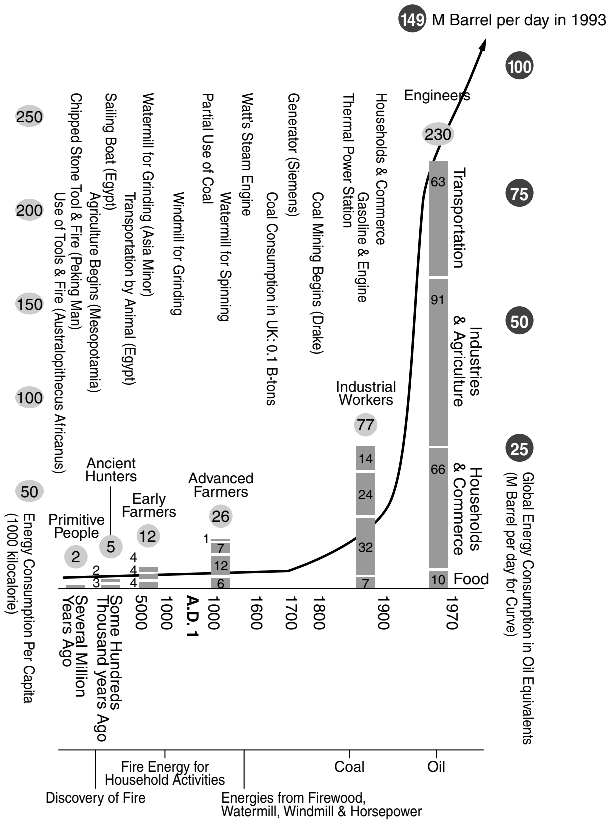
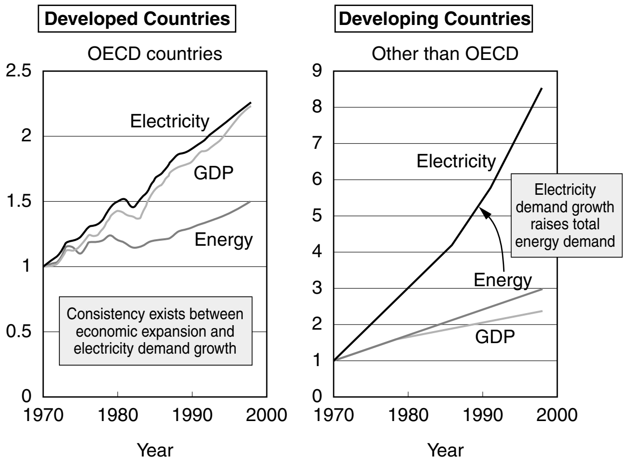


Fig. 1. Population increase, energy consumption increase, and Earth's environment



(Source: Japanese Ministry of the Environment)

Fig. 2. Historical trend of global energy consumption



Source : Mohan Munasinghe – World Energy Council Journal (Dec 1991)
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Fig. 3. Relationship between GDP growth and increase in total energy or electricity consumption

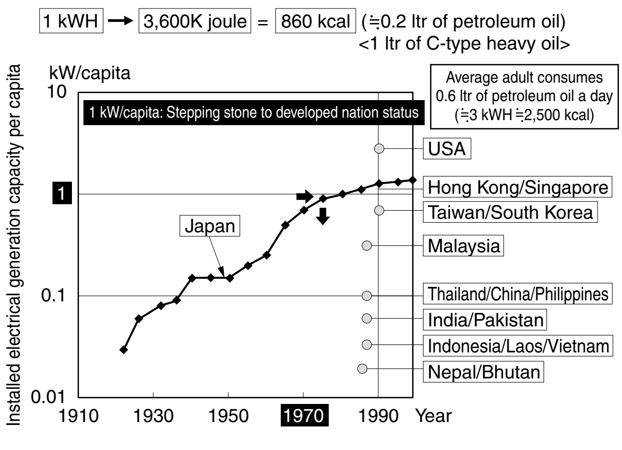


Fig. 4. Increase of electric power generation capacity in Japan and other Asian countries

at least 1 kW per capita. Let us take as a standard unit the situation of Japan, which has the world's third largest total electricity capacity of 250 GW (a little more than one third of which is generated from 55 nuclear power plants). If there is to be 1 kW per capita for the current world population of 6.6 billion, and if we divide that total by the Japan unit of 250 GW, the world would have about 26 zones equivalent to Japan, which has the world's second largest GDP. Indeed the population problem will continue to be one of the gravest problems that humanity faces in the future.

From the standpoint of energy, although there is a strongly rooted idea that distributed generation and consumption of electricity may change the picture in the future, megalopolitan areas of more than one million people are rapidly proliferating through the world, as shown in **Fig. 5**, and it is clear that urban areas will continue to develop more and more intensively, as in Japan where the three largest metropolitan areas of Tokyo, Osaka and Nagoya have now (as of 2007) come to include more than 50% of the total population [18]. Thus the reality is that if the combination of enormous power generation, enormous power transmission and enormous power consumption cannot be maintained, it will be impossible to sustain civilization as we know it. As for distributed electricity generation, wind turbines generated a grand total of 74 GW in 2006 (equivalent to about seventy-four 1 GW nuclear power plants) [19], and photovoltaic generation amounted to 3.7 GW in 2005 (equivalent to about three point seven 1 GW nuclear power plants) [20], and these sources are steadily growing. However, distributed use will not be the ultimate solution for human energy use, as in all likelihood distributed use will remain limited to first-stage use of new energy resources, or complementary use.

The major sources of energy are the fossil fuels–petroleum, natural gas, and coal–and the non-fossil fuel, uranium. **Figure 6** shows the current reserves of those fuels [21]. Coal stands out with a reserve/production ratio of more than 200 years, and it is vital to recognize that the others, with reserve/production ratios of just 40 to 60 years, are transient resources. It is also vital to recognize that the reserve/production calculations rely mainly on the population-related denominator, so even if the numerators of the ratios improve there is no theoretical basis for a meaningful major expansion of reserves. [See the Author's Note II after Section 7 "Conclusion."]

We live now in the era of a shift from metallic to non-metallic infrastructure components, as shown in **Fig. 7** [3]. (The figure does not include the replacement of iron and steel structures by carbon-fiber reinforcement plastics [62].) In electronics, vacuum tubes (metal electrodes) have been replaced by silicon-based semiconductors; in telecommunications, copper wire is being replaced with glass-based optical fiber; and in

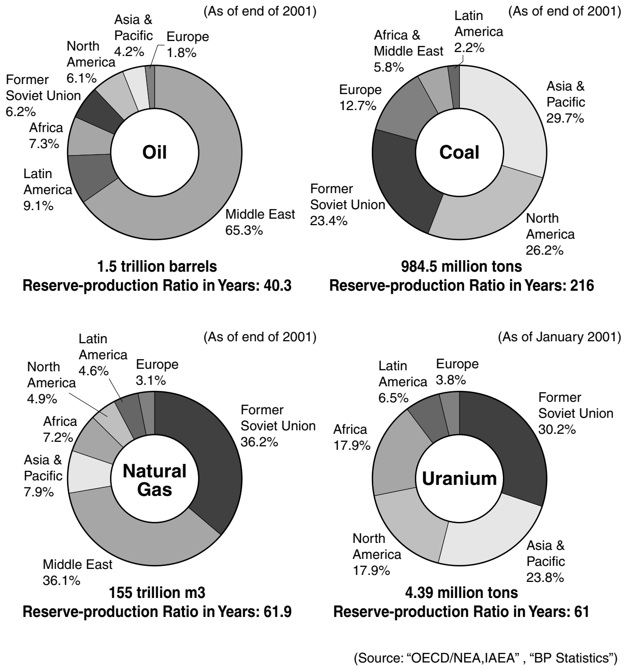
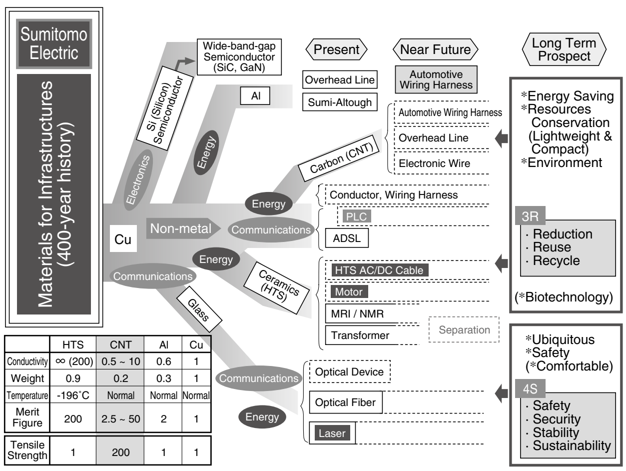


Fig. 6. World energy resource reserves



	HTS	CNT	Al	Cu
Conductivity	∞ (200)	0.5 ~ 10	0.6	1
Weight	0.9	0.2	0.3	1
Temperature	-196˚C	Normal	Normal	Normal
Merit Figure	200	2.5 ~ 50	2	1
Tensile Strength	1	200	1	1

Fig. 7. Change and progression from metals to non-metals

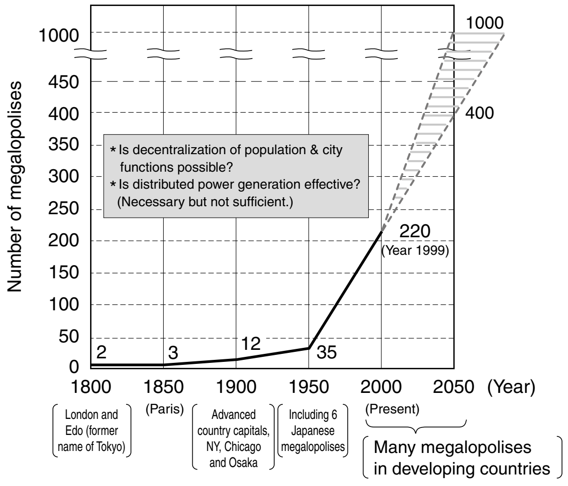


Fig. 5. Number of megalopolitan areas (over 1 million people) in past, present and future (1800-2050)

electricity transmission, ceramics-based high-temperature superconductors (HTS) are emerging as a replacement for copper cable [(24)-(27)]. Also in motors, one of the largest categories of electrical energy use, there is a trend away from copper wire and toward ceramic HTS wire [(28)]. The shift to non-metallic components indeed seems inevitable in the energy-related field as well.

Copper is actually still used in large quantities as the mainstay of electricity transmission and motors. The electricity infrastructures of the 30 developed nations in the OECD are made up chiefly of copper, yet if heavily populated developing nations including BRICs continue to rely chiefly on copper materials for their infrastructure expansion, copper reserves will eventually be exhausted. Furthermore, before the point of exhaustion is reached, easily accessible copper deposits will be mined out, forcing the development of new mines with more serious environmental impacts. Thus over the long term, weaning the electricity infrastructure from its mainstay material of copper, or in other words making electricity infrastructure non-metallic, will become more and more important. Already the remarkable pace of development in China alone has created such an unprecedented surge in copper consumption that steep jumps in the price of copper are becoming the norm [(29)].

3. Increasing Energy Consumption and Environmental Problems

The rapid increase in global population and energy consumption since the Industrial Revolution was noted in the previous section. **Figure 8** shows the trend of emissions of carbon dioxide (CO_2), which is one of greenhouse gases, discharged into the atmosphere for the past 200 years [(21)]. The increase in CO_2 emissions naturally corresponds to the growth of energy consumption seen in **Fig. 2**. CO_2 emissions notably increased since 1945, as the explosively increasing function in **Fig. 1** has pushed it past the point of no return. Currently, global CO_2 emissions amount to approximately 6 billion tons of carbon (C) equivalent per year, about half of which is reduced to oxygen (O_2) through solar-driven photosynthesis, while the other half or so remain in the atmosphere, causing an ever greater accumulation [(21)]. As a result, environmental change is occurring on a global scale [(31)] and according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) released in 2007, there is a strong possibility that the global environment will dramatically deteriorate during this century [(30)]. **Figure 9** is a newspaper article presenting one possible scenario of environmental deterioration [(31)].

Figure 10 shows the CO_2 emissions for the various types of electricity generation that serve mainly to support technically advanced civilization (about one third of CO_2 emissions in the OECD countries is from electricity generation) [(21)]. The levels of CO_2 emissions from the coal, crude oil and liquefied natural gas (LNG)-

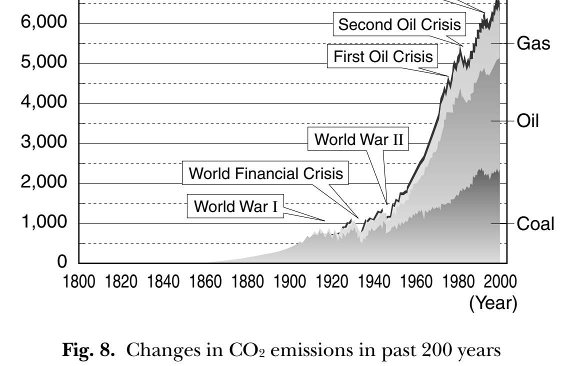


Fig. 8. Changes in CO_2 emissions in past 200 years


温暖化の地球史⑤

今世紀末、生物の危機再び？

国立環境研究所の研究チームがこんな予想をまとめた。江守正多・温暖化リスク評価研究室長は「温暖化は遠い将来の問題ではない。近い未来でも深刻な影響をもたらす」と警告する。

世界に深刻な被害

2030年代
（平均気温が0.5～1.5度上昇）
- 夏の「暑い夜」が増え、冬の「寒い昼」が減少
- サンゴの白化が増加
- 洪水と暴風雨による損害拡大
- 数億人が水不足に直面する

白化したサンゴ
（沖縄・石垣島、環境省提供）

2050年代
（平均気温が1～3度上昇）
- 感染症の媒介生物の分布が変化
- 熱波や干ばつによる死亡率の増加
- 最大30%の種で絶滅リスクが拡大
- ほとんどのサンゴが白化

2080年代
（平均気温が1～5度上昇）
- 地球規模での生物の絶滅
- 世界の沿岸湿地の約30%が消失
- 穀物生産量が低下
- 毎年数百万人が新たな洪水の被害

洪水で水浸しになったニューオーリンズ（AP）

2100年までの気温上昇予測

度 4 3 2 1 0 -1
世界平均地表気温の上昇
石油などを使って経済成長を促進したケース
環境保全に配慮して経済発展と両立したケース
1900年 2000 2100
（予測のグラフと世界地図は、IPCCの資料を基に作成）

2090～99年の平均気温上昇予測
（1980～99年平均との比較）
0 1 2 3 4 5 6 7度
グラフィックス　デザイン部 田村明彦

六年前は気温上昇

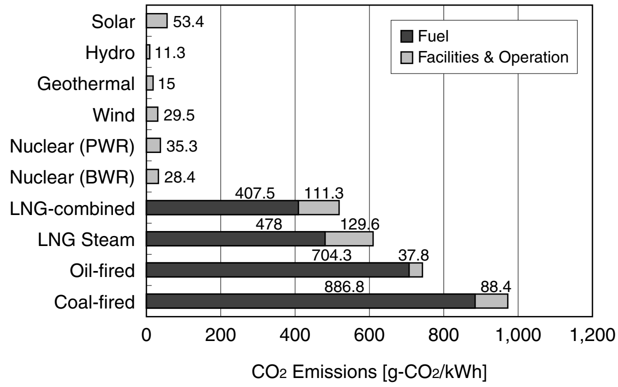
電など再生可能エネルギーを導

水や食

人類の

Nihon Keizai Shimbun (July 22 ,2007)

Fig. 9. Newspaper article on dangers posed to living creatures should global warming continue



(Source: OHM Nov. 2004 Issue)

Fig. 10. Comparison of CO_2 emissions among various electric power generation technologies

fueled thermal power station systems that provide the bulk of current power generation are overwhelmingly higher than the levels from the solar derived "new energy resources" or nuclear power generation. Therefore, in order to alleviate CO_2 and other greenhouse gas emissions, which is the crucial issue for this century, it will be necessary to make a shift as quickly as possible from fossil fuels (coal, crude oil and LNG) to new energy resources including nuclear power.

Under the Kyoto Protocol which came into force on February 16, 2005, Japan is committed to reduce greenhouse gas emissions from 2008 through 2012 to an average of 6% below the 1990 level, and toward that end the government of Japan has prepared a plan to decrease domestic CO_2 generation by 0.5% (21). It includes a set of voluntary restraints for power companies designed to realize a 20% unit reduction of CO_2 emissions (from 425 to 340 g per kW hour), which is expected to be achieved mostly through construction of new nuclear power plants and improvement of nuclear power plant utilization rates (21) (see **Table 1**). The government's basic policy for reducing CO_2 emissions is the encouragement of nuclear power (32), (33). There is a worldwide movement for the resurgence of nuclear power, including the US plan to build more than 30 new plants (34), and reported plans for building between 100 (34) and 200 (35) new plants in other countries, especially in China and India. However, considering the uranium reserve/production ratio in **Fig. 6** (less than 60 years), even though the necessity of nuclear power at the present time has to be respected, the question of whether or not a policy of urgently expanding nuclear power could provide a real solution to problems of energy, resources and the environment must be answered in the negative (see the next section).

The problems of population growth and environmental degradation are worsening the world food situation. In the 1980s the global grain inventory was more than 35% of the consumption level, but in 2005 it had fallen to 17.7% (23). In recent years global warming has led to persistent drought conditions in the grain belts of the US, Australia, southwest Europe and northwest China, and harvest levels are declining. Water resources are also under pressure, as demand for water increased during the "oil century" (the 1900s) by a factor of six, twice the rate of population growth (36), (37). There are some 60 countries, mainly in Asia and Africa, that have less than the human survival requirement of 50 liters of water per day per capita (37), while the IPCC predicts that as global warming progresses, there will be two extreme regions of drought regions and large-scale flooding regions. Some oil-producing countries have drawn up plans for utilization of new energy resources and large-scale seawater desalination (38), (39).

Meanwhile, as a means to reduce CO_2 emissions, there is rapidly increasing production of biomass fuels sourced mainly from grains such as corn (40), and this is considered likely to have the negative effects of reducing food inventories and increasing the demands for agricultural water (40), (64).

Table 1. Self-imposed CO_2 emissions reduction target of Japan's power generation industry

CO_2 Emissions in Power Generation Industry		2002: 350 M ton-CO_2/year (27%) 2003: 363 M ton-CO_2/year (32.4%)
Self-Imposed Reduction Target		20% Reduction in unit power generation 425 g-CO_2/kWh in 1990 ⇩ 340 g-CO_2/kWh in 2010
Electricity Growth Rate and CO_2 Emissions		Electricity growth rate: 37% (from1990 to 2010) CO_2 Emissions: 1.37 × 0.8 = 1.096 (CO_2 Emissions increase by 10%)
Measures for 20% CO_2 Reduction in Unit Power Generation	(1) Newly Installed Nuclear Power Stations	5 stations ×▲3%/station =▲15% (7-8 M ton-CO_2 reduction/station /year)
	(2) Increase of Coefficient of Utilization of All Nuclear Power Stations	3% increase for each of 53 stations →▲3%
	(3) Increase of Efficiency of Thermal Power Stations	▲1%
	(4) Adoption of Kyoto Mechanism	▲1% (Equivalent to reduction of 3.8 M ton-CO_2/year)

4. The Role and Problems of Nuclear Power

Table 2 shows the number of currently operating nuclear power plants in the ten countries with the largest nuclear power outputs, and the total number of operational plants (429) (33). The US has the highest number with 103 plants providing 20% of total power generation,

Table 2. Present worldwide status of nuclear power stations

(As of 2006 / In order of total output / (Survey by JAIF))

(Unit)

	(Country)	Under operation	Under construction	Under planning
1	USA	103		
2	France	59		1
3	Japan	55	3	11
4	Russia	27	4	5
5	Germany	17		
6	South Korea	20	4	4
7	Canada	18		
8	Ukraine	15	2	
9	UK	19		
10	Sweden	10		

⇩

Overall number of nuclear power plants now under operation	429 units

Nihon Keizai Shimbun, April 3, 2007

France with its national policy to encourage nuclear power has 59 plants providing 78%, and Japan has 55 plants providing 30% to 40%. In addition, China and India are surging rapidly into the field with plans for several tens of new plants each, and the number of planned new plants worldwide exceeds 200 (35). Thus it is impossible to consider the current world energy situation without taking account of nuclear power generation (41).

From the standpoint of CO_2 emissions, nuclear power is regarded as a clean energy source (see **Fig. 10**) and hence a trump card for the environment-conscious 21st century, and the world is said to be seeing a renaissance of nuclear power (41). However, from the standpoint of reserve/production ratio (see **Fig. 6**), uranium must be classed as a transient resource (21) for which international competition is fierce (35), and so the question of whether or not nuclear power can be the ultimate answer for energy supplies in this and future centuries must be answered in the negative.

Table 3 presents preliminary calculations of the potential for using nuclear power to attain the per capita energy supply level of 1 kW (the steppingstone to developed nation status attained by Japan in the 1970s, charted in **Fig. 4**), in China and in the world. In view of the uranium reserve/production ratio of roughly 60 years for the existing 400-odd plants, projections of some 400 nuclear plants in China alone and some 6,000 for the world as a whole cannot be regarded as feasible no matter how the numbers are juggled. In other words, we must inevitably realize that nuclear power is a very short-term, transient resource. Furthermore, even without bringing up the case of the Chernobyl disaster, various concerns about safety guarantees will have to be addressed. Then there is the back-end policy for managing radioactive waste, typically involving vitrification for 50 to 100-year surveillance followed, if all goes well, by transfer to deep underground storage for as long as ten thousand years, which forces serious consideration of the imbalance between the service life for the user generations and the need for long-term management by future generations (42).

Another area that must be pointed out is the issues of service life, maintenance and renovation of nuclear reactors. The design life of nuclear reactor, even in the case of the 103 reactors in the US and the 55 in Japan, two of the leading nuclear-power countries, has been set at 30 to 40 years from the technical standpoint. Consequently most of the nuclear plants in the US, which entered the field first, have already reached the end of their design life, and most of the plants in Japan will reach theirs between 2020 and 2030. At this time, neither the US nor Japan has any plan whatsoever in place for reactor renovation, other than measures to extend service life. The US addressed the issue for the first time in 2000 with a decision to extend the life of existing plants by 20 years (43), and has since taken some steps toward that end. Naturally any policies for extension of service life should include serious and prudent investigations of the appropriate engineering standards and procedures for surveying and testing equipment that was designed with 30 to 40-year-old technology, for assessing the potentials for repair and life extension and renovation, and for the planning of subsequent technical monitoring (see **Fig. 11**). An opinion survey conducted in Japan by the Japanese Cabinet Office and the Ministry of Economy, Trade and Industry in December 2005 found that the majority of Japanese believe there should be "cautious encouragement of nuclear power while addressing safety concerns" (44).

The Chuetsu offshore earthquake in Niigata Prefecture, Japan occurred on July 16, 2007, caused

Table 3. Expected worldwide electric energy status in near future: Electricity demand in China and atomic power generation

⟨Electricity industry ≒1/3 of total CO_2 emissions; Stepping stone to developed nation status = 1kW/capita⟩

⟨Population (in 2007) = 6.6 billion ; Japan's electricity generation capacity = 250 million kW ; Power generation capacity of standard atomic power plant = 1M kW = 1GW⟩

Global energy use when all nations are fully developed. (How many times that of Japan?)	(6.6 billion × 1kW/capita) ÷ 250 million kW = 26.5
Global energy use when all nations are fully developed. (How many times that of USA?)	(6.6 billion × 1kW/capita) ÷ 900 million kW = 7.3
Number of nuclear plants required for meeting all of electricity demand when all nations are fully developed.	(6.6 billion × 1kW/capita) ÷ 1GW = 6,600GW/1GW = 6,600 plants
Number of nuclear plants required for supplying 35% of electricity demand when all nations are fully developed.	6,600 units × 0.35 = 2,310 plants (Presently≒400 plants)
Per capita electricity consumption in present China.	622 million kW/1.3 billion = 0.48kW/capita (Japan: 2kW per capita) (USA: 3kW per capita)
Number of nuclear plants required for meeting all of electricity demand in fully developed China.	1.3 billion × 1kW/capita = 1,300GW ➔1,300 plants
Number of nuclear plants required for supplying 35% of electricity demand in fully developed China.	1,300 × 0.35 = 455 plants (Presently 10 plants in China) ↔ Present worldwide atomic power generation = 385GW (USA: 103 plants (≒1/4))

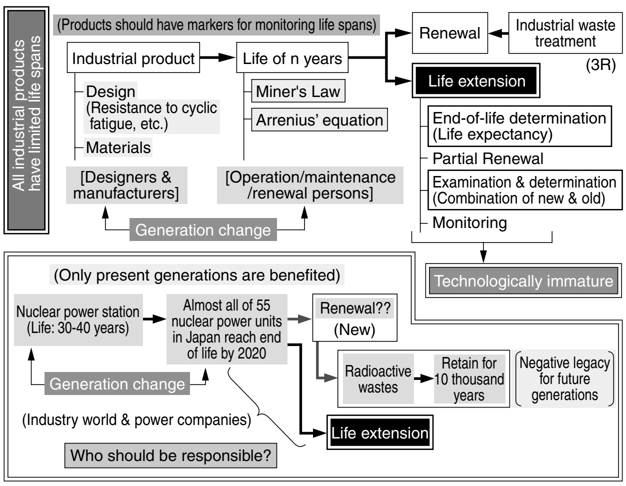
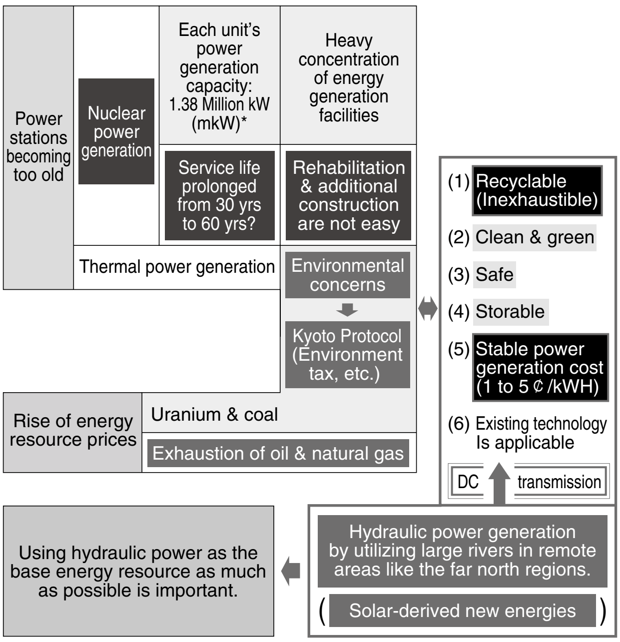


Fig. 11. Life extension measures of nuclear power plants: Importance of technology for determining life span of industrial products

about 50 aspects of damage [48] (up to 2900 aspects according to another report [58]) to the Kashiwazaki-Kariwa Nuclear Power Plant, the world's largest nuclear generating station by net electrical power rating, including a leak of water containing traces of radioactive materials from the No. 6 reactor. The overall performance of the plant during the earthquake, including routine automatic shutdown of the four units in operation, was regarded in some quarters as a demonstration that nuclear plants in Japan actually have basically sound seismic resistance [49]. Yet the quake also raised the fundamental question of whether the Japanese archipelago, most of which is riven by active faults that cause numerous earthquakes, should have as many as 55 nuclear plants [50], [51], and heightened the controversy over the proposed national project to set a new world standard for nuclear plants through joint public-private development of a next-generation ultra-large light-water reactor with a power rating of 1.7 to 1.8 GW [52].

Figure 15 concludes this section. As energy and resource demands rise sharply amid rapid population growth that cannot arbitrarily be stopped, the people of the 21st century are being forced to urgently undertake the development and steady application of new technologies to cope with unprecedented levels of energy consumption, including technologies necessary to manage the negative legacies bequeathed by the 20th-century world and to maintain and renew existing infrastructure. Now is the time to recognize that those efforts must have the perspective of sustainability, from the standpoint of future centuries. The core concepts should be the application of the solar-derived technologies of photovoltaic and wind-turbine power generation, and hydraulic power generation [47] especially from major rivers [21], [45] (see **Figs. 12 and 14**).



*Note:
Shiga NPS: 1.35 mkW, Hamaoka NPS Unit-5: 1.38 mkW, Higashidori NPS Unit-1: 1.385 mkW, Ohma NPS: 1.383 mkW

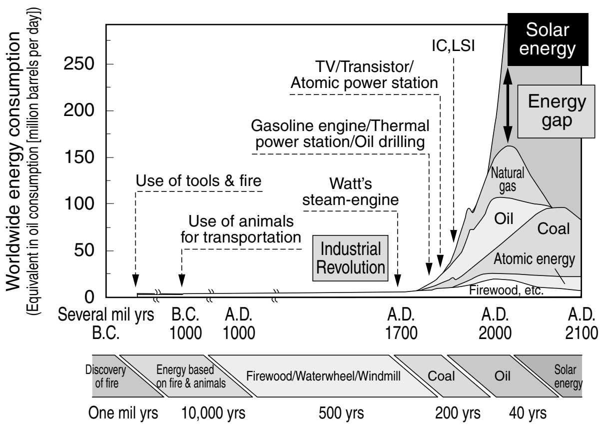
Fig. 12. Diagram of why long-distance transmission of electricity generated by hydraulic power or new energies is necessary

5. What Could Be the Ultimate Energy Resource?

Section 2 pointed out the transient nature of fossil fuels and uranium, in view of the reserves of those resources. Section 3 described how unlimited growth of energy consumption has strong potential for triggering an unexpected natural catastrophe affecting humanity and all living organisms. Section 4 described how nuclear power, although it may be advantageous from the standpoint of global warming, cannot provide the ultimate answer due to limited resource reserves, the problem of managing radioactive wastes from a potentially massive number of new plants, and the technical issues of reactor lifespan, and so in the end must be classed as a transient technology even though its importance at the present time cannot be denied.

As an ultimate solution that could provide relief from the crises of energy, resources and the environment, academic researchers have suggested nuclear fusion technology. They envision a manmade miniature sun on the earth as the ultimate salvation for human civilization. At this time, however, even a sympathetic assessment of the prospects suggests it would take centuries to achieve, which means that in reality, nuclear fusion technology cannot be humanity's salvation. What then might present-day engineers be able to suggest as an "ultimate salvation for human civilization" that is actually feasible?

What is the real significance of the data in **Figs. 1, 2, 5, 8 and 13**? Drawing the lessons of history, they mean that prior to the Industrial Revolution, humanity lived (modestly) as merely one species in the context of all life on the planet, surviving within the range of energy provided from the sun (more precisely, solar-derived energy forms that are both generated and consumed over very short time spans, from less than a year up to several years [21]). To use contemporary terminology,



Source: World Population Prospects 1990. Energy Statistics Yearbook

Fig. 13. History & forecast of energy consumption by mankind

humanity survived over millions of years by relying exclusively on energy and other resources that were recyclable, sustainable, clean, and green [45]. Rather than proceeding to survey nuclear fusion technology, **Fig. 14** provides a simple outline of mechanisms that rely essentially on recyclable, sustainable, solar-derived "new energy resources." The sole doubt about these new energy technologies is whether the necessary resources will be available in sufficient quantity, and **Table 4** in the next section shows that in theory those resources are nearly inexhaustible [5].

Figure 13 shows human energy consumption through the past and into the future, from several million years ago up to 2100. We know now that the currently exploited energy resources are being used up, as stated above, which indicates that on the whole we will inevitably be forced to utilize new types of solar-derived energy. We are also being forced to use new energy resources in order to avoid triggering an environmental catastrophe. It took an unimaginably long period (at least two billion years) for the dynamics of solar energy to form the earth's atmosphere through stabilization and accumulation of CO_2 and continuous generation of

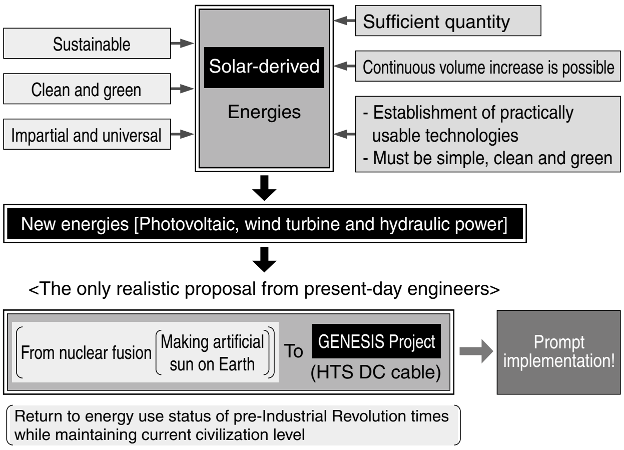


Fig. 14. Ultimate energies for future generations and Earth's environment

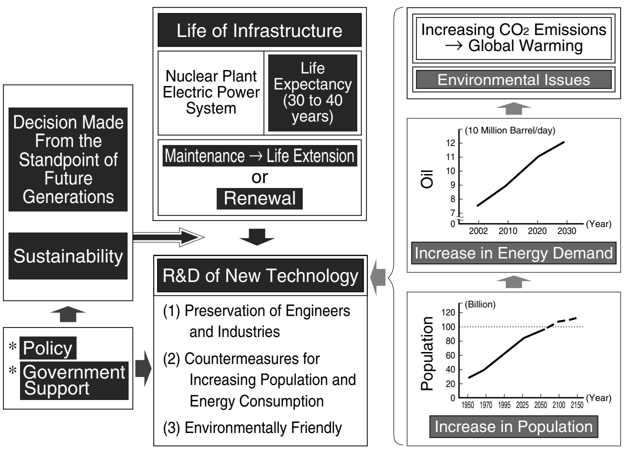


Fig. 15. Necessity of passing on technologies to future generations and developing new technologies

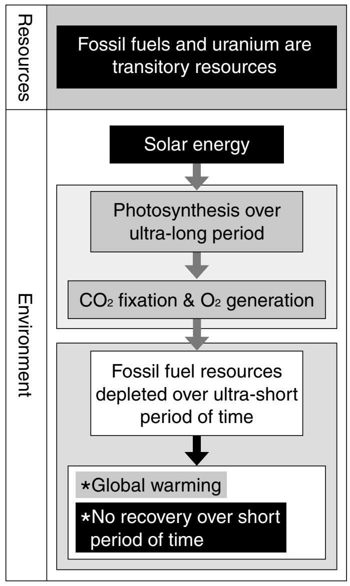


Fig. 16. Fixation of CO_2 and generation of O_2

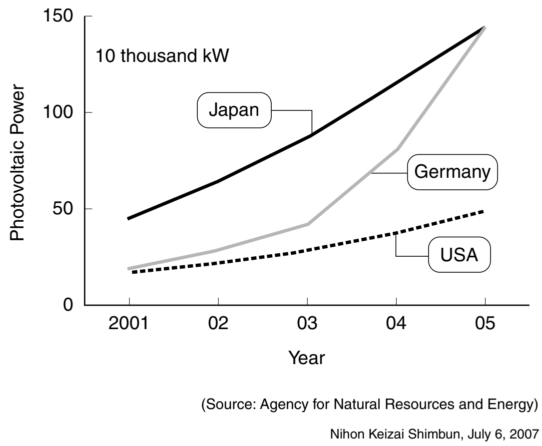


Fig. 17. Total installed capacity of photovoltaic power generation

O_2 (see **Fig. 16**). Now that the equilibrium has been destabilized in a relatively very short period by anthropogenic discharges of fossil fuel byproducts, it may take an extremely long time to recover, or it may even be irreversibly altered. In other words, we cannot avoid considering the possibility that humanity is rushing full tilt toward a catastrophe (which could occur before current resources are exhausted) [21], [45]. [See the Author's Note II after Section 7 "Conclusion."]

Photovoltaic power generation, one of the leading new energy resources, is growing by 150 percent (or 1.5 times) each year, with a total installed capacity of 3.7 GW at the end of 2005 (see **Fig. 17**), and the reason it has not been generally adopted is that the generating cost remains too high, at 46 yen per kW hour [46]. This is a problem to be resolved by future eco-innovation (new technology to meet environmental challenges), as well as by public policy decisions based on a future perspective (see Section 6 and **Figs. 15 and 32**).

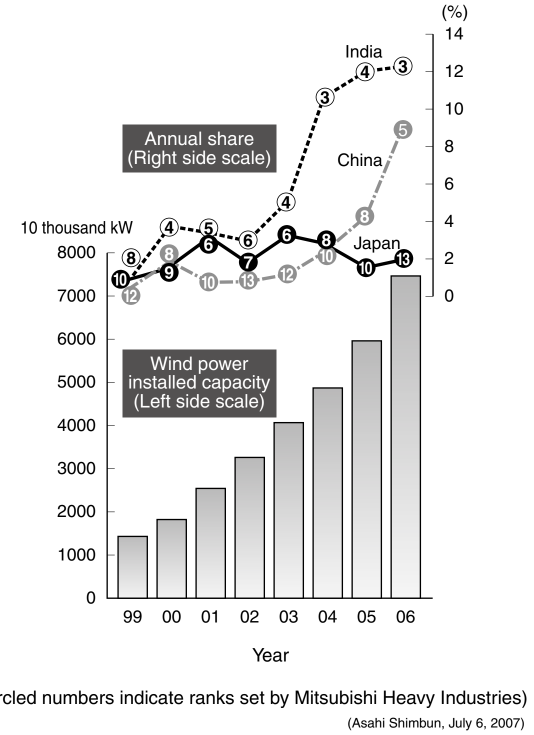


Fig. 18. Total installed capacity of wind turbine power generation

Wind turbine power generation has been growing at the rate of 70% per year, with a total installed capacity of 74 GW at the end of 2006 [(19)] (see **Fig. 18**). The greater success is due to a generating cost of 7 to 8 yen per kilowatt hour, comparable to thermal power generation. The size and strength of wind turbine generators need to be enhanced in order to support full-scale utilization in the future. Yet it must be kept in mind that wind turbines lack the universality like photovoltaic facilities, as they are limited to certain suitable sites.

Hydraulic power generation is another type of new energy resource [(47)]. While technical improvements are still needed to make these new energy resources more effective and economical in the future, they should all be recognized as currently available, developed technologies. Yet these new solar-derived energy resources cannot become a meaningful proposal for the ultimate salvation of humanity until the generating technology can be supplemented with large-scale, very-long-distance transmission technology (see the next section). In fact present-day engineers have finally succeeded, through the development of high-temperature superconducting (HTS) DC power cable, in bringing such a far-reaching proposal into the realm of feasibility. The GENESIS Project, combining "new energy" with HTS DC cable, has reached the stage where it can be announced to the world at large that present-day engineers have the opportunity to move step by step toward realizing the unfinished dream of salvaging modern civilization under the watch word of "From nuclear fusion technology to the GENESIS Project."

[See the Author's Note I after Section 7 "Conclusion."]

6. The GENESIS Project and HTS DC Cable

GENESIS stands for "Global Energy Network Equipped with Solar cells and International Superconductor grids," and of course the name echoes the Old Testament term for the creation of the world. The project is diagrammed in **Fig. 19**.

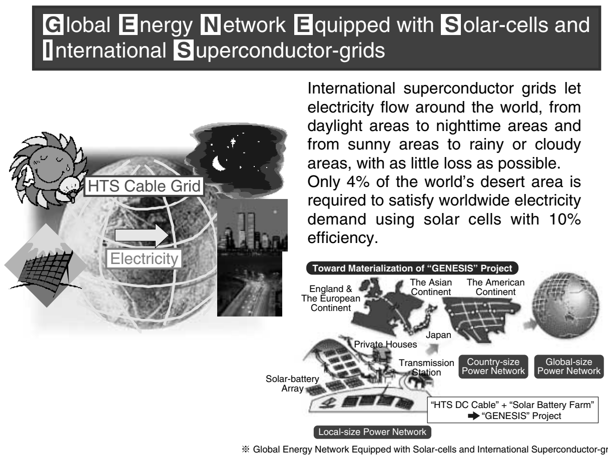


Fig. 19. GENESIS Project

Table 4 shows future global energy consumption and the land area that would be needed to supply it exclusively through photovoltaic power generation, based on calculations by Dr. Yukinori Kuwano, the former president of Sanyo Electric Co., Ltd. who first proposed the GENESIS Project [(5)]. When 10% efficiency solar cells are used in converting photovoltaic power to electrical energy, the electric energy obtained is enormous and a land area about 800 kilometers (or around 500 miles) square would be required to hold the generating facilities to supply all human energy needs [(5)]. That area would correspond to only about 4% of the world's desert terrain [(5)] (see **Fig. 20**).

The GENESIS Project envisions a series of new-energy power plants in various locations (mainly solar farms, supplemented by wind farms), linked into a global electric power network through very-long-distance HTS cables (see **Fig. 21** [(6)]). The long-distance transmission network would have to utilize direct-current (DC) cables that do not generate reactive power. **Figure 22** describes the GENESIS Project with the additional components required to complete an integrated system for power generation and transmission. The key components are solar and wind farms, HTS DC cable, cable cooling stations (using liquid nitrogen), and DC/AC conversion stations (with conversion devices, transformers, fault current limiters, circuit breakers, etc.).

To present a clearer picture of the scale of the GENESIS Project, **Fig. 23** compares it with currently operating power generation and transmission systems with capacity of from some 0.1 to 1 GW. In conventional electricity transmission systems using copper or aluminum cables, in order to minimize the transmission loss which corresponds to the square of the current

Table 4. Worldwide energy demand prediction and land area required for installing solar-battery array

Solar radiation conditions for calculation

- Solar radiation intensity
  Max. 860kcal/m²h (=1.00kW/m²)
  Mean 610kcal/m²h (=0.71kW/m²)
- Solar radiation time
  Yearly solar radiation days 329D (90% of 365 days)
  Effective solar radiation hours per day 8h/D (Equivalent in mean solar radiation intensity)
- Yearly amount of solar radiation
  1.606×10^6kcal/m²·y
  =610kcal/m²·h × 329D/y × 8h/D
  =1.606×10^6kcal/m²y

Year	Primary energy consumption (Crude oil equivalent) ($\times 10^{10}$kl/y)			Solar battery system efficiency	Power generation efficiency	Conversion coefficient from electricity to crude oil (kl/m²·y)		Land area required for installing solar-battery array ($\times 10^{10}$m²)			Land area required for system with 50% margin
	Overall consumption (A)	(Electricity) (A_1)	(Heat) (A_2)	(%) (η)	(%) (α)	Simple calculation (B_1)	Crude oil for power generation (B_2)	(For electricity) (A_1/B_2)	(For heat) (A_2/B_1)	Total area (km²)	($\times 10^{10}$m²) (km²)
2000	1.100	0.275 (25%)	0.825	10	35	0.01736	0.04960	5.54	47.54	53.07 (729)	106.14 (1030)
2010	1.387	0.416 (30%)	0.971	10	35	0.01736	0.04960	8.38	55.93	64.32 (802)	128.6 (1134)
2050	3.496	1.224 (35%)	2.272	15	40	0.02604	0.06510	18.79	87.27	106.06 (1030)	212.12 (1456)
2100	11.116	4.446 (40%)	6.670	15	50	0.02604	0.05208	85.38	256.13	341.50 (1848)	683.0 (2613)

Primary energy consumption: Cited from OECD/IEA "International Energy Outlook 1996 Edition"
Predictions for years 2050 and 2100 are based on an assumption that annual rate of increase is 2.4%.

Source: Yukinori Kuwano, "Full Utilization of Solar Arrays, New Edition" Kodansha Blue Backers, 1999

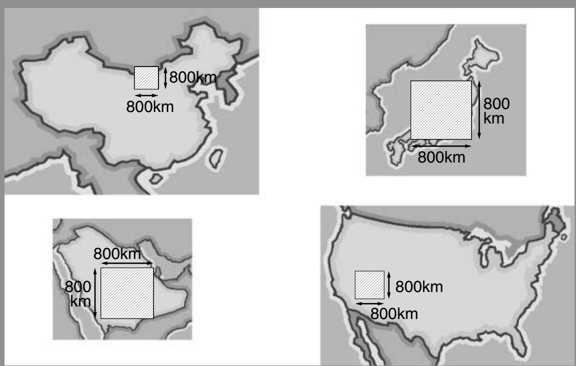


Fig. 20. Land area required for solar battery farm: 4% of world's desert area (800 km × 800 km)

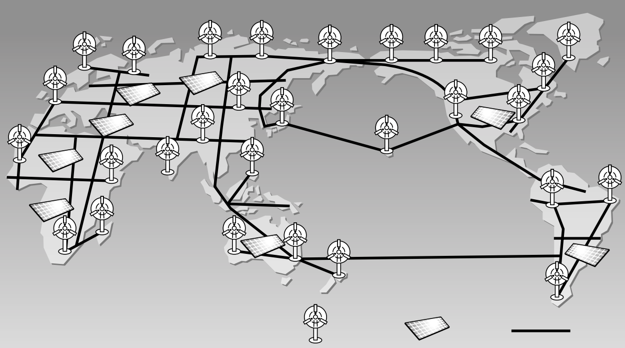


Fig. 21. Global electric power network linked by HTS cables

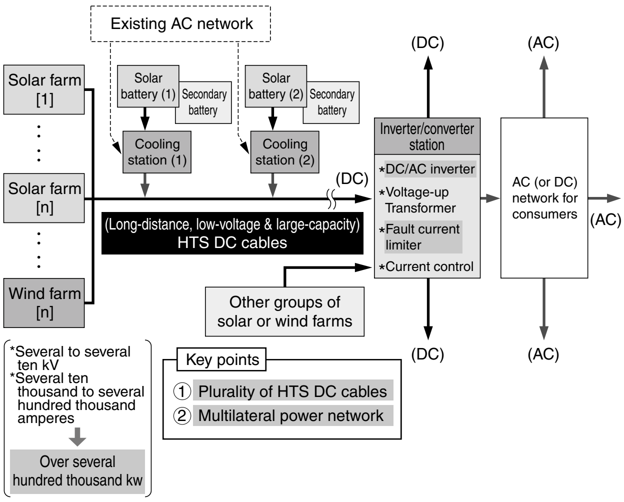


Fig. 22. GENESIS Project and HTS DC cables

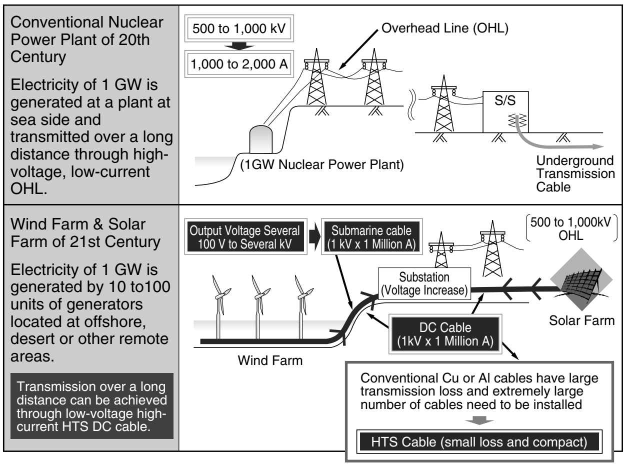


Fig. 23. 1-GW low-voltage, high-current transmission system using HTS DC cables for linking wind/solar farms

transmit and distribute the power. This key component, which would be required in huge quantities, is needed to achieve the construction of the global power supply network as shown in **Fig. 21**. Therefore, the development of HTS DC cable made using ceramic materials can open the way to realization of the GENESIS Project (and also avoid the difficulty of obtaining large supplies of copper, which is a vanishing resource). [See the Author's Note II after Section 7 "Conclusion."]

Since the discovery of the high-temperature superconducting phenomenon in 1986, Sumitomo Electric has undertaken continuous research and development of HTS wire. The results have included the development of the controlled-over-pressure (CT-OP) method of sintering, and commercialization of a first generation of high-performance bismuth-based HTS wire (marketed as DI-BSCCO) [(53)]. **Figure 24** shows the construction of 3-core HTS AC cable that Sumitomo Electric developed using these DI-BSCCO wires [(54)]. That cable was installed as an actual commercial line in Albany, the capital city of the State of New York, and has been supplying power to about 70,000 households since July 2006 in the

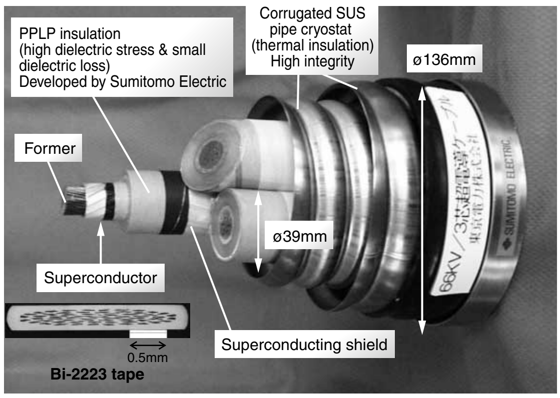


Fig. 24. Three-cores-in-one-cryostat HTS cable (Cold dielectric, 100 m, 114 MVA, 1000 A)

world's first practical demonstration of HTS cable [(27), (54)] (see **Fig. 25**). The insulation design of HTS DC cable is simpler to achieve than that of HTS AC cable [(55)]. The success of the Albany HTS AC cable demonstration project proves for the first time that the GENESIS Project is technically feasible, giving us full confidence that it can be realized. (The DC cable with DI-BSCCO conductors manufactured by Sumitomo Electric was used in the world's first DC current application test performed in 2006 at Chubu University. The test used a Peltier lead to control the heat invasion from a room-temperature copper conductor to an ultra-low-temperature HTS conductor, and proved the HTS DC cable's effectiveness [(59)-(61)].)

The advantages of HTS are brought out most fully in its DC application. The main reasons are that, even with superconductivity, AC transmission inherently involves AC transmission loss, and also inductance differences between the individual HTS wires, due to the way the wire is wound, which cause differences in the currents distributed to multiple HTS wires. **Figure 26**

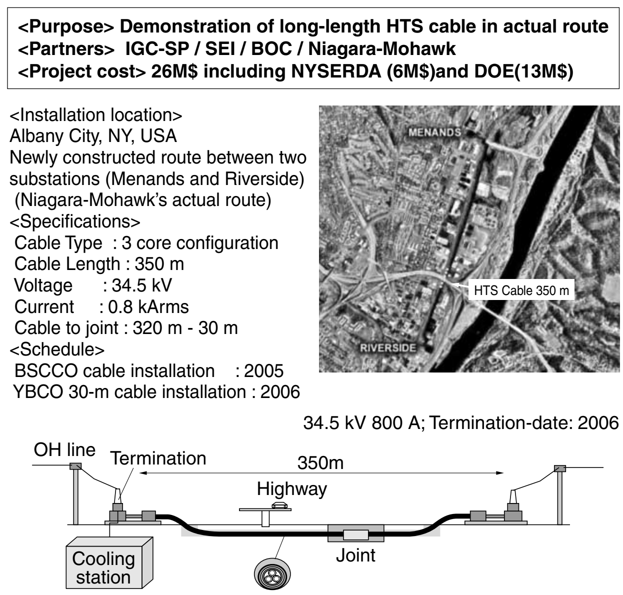


Fig. 25. Outline of Albany HTS cable project

shows that while the transmitted current is limited by the heat generated during current-flow through HTS AC cable, with HTS DC cable that limitation is not at all present, so as much current as necessary can be carried simply by increasing the number of HTS wire. For example, using DI-BSCCO wire that is 4 mm wide and about 0.23 mm thick (˜ 1 mm^2) with a critical current (Ic) of 200 A, it is possible to double the Ic to 400 A by means of subcooling with liquid nitrogen (LiN_2) (see **Table 5**). If liquid hydrogen (LiH_2) could be used as the coolant, the Ic could be increased 5.7 fold to more than 1,000 A, enabling lossless transmission of 400 to 600 times the current that copper wires can carry, over any distance. (Expanding on this concept, there is a team working on plans to place HTS DC cable inside liquid hydrogen transport pipes, to enable simultaneous delivery of two important energy resources, liquid hydrogen and electric power, to distant places in the 21st Century that is characterized as the "Century of Hydrogen" [(63)].)

Since HTS cable functions only at temperatures below 77 K (-196°C), no matter how strong the thermal insulation properties of the cable could be furnished, heat from the open air will gradually penetrate it and increase the temperature of the liquid nitrogen coolant. Consequently it will be necessary both to recool the liquid nitrogen and to reboost the coolant pressure at cooling stations at given intervals that will have to be built. **Figure 27** shows the distance between typical cooling stations that would be able to service both AC and DC cable, with HTS AC cable projected to require a station every 5 km, and HTS DC cable every 15 km [(55)]. The electricity needs of the cooling stations would be tiny in comparison to the transmission capacity (0.001% of transmission capacity per kilometer [(14)]), and each station should be able to provide its own power preferably with a combination of photovoltaic cells and secondary batteries (see **Fig. 22**).

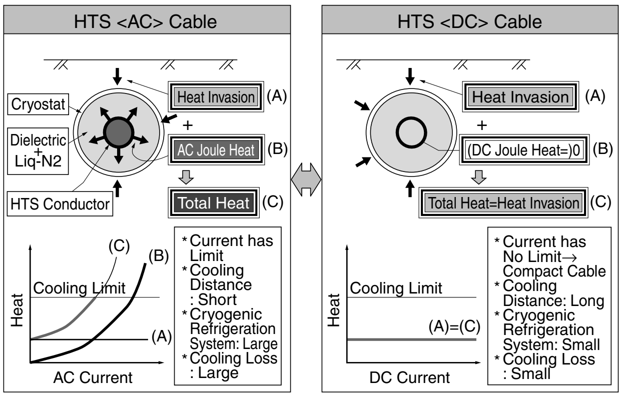
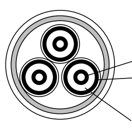


Fig. 26. Advantages of HTS DC cable over HTS AC cable

Table 5. Increase of critical current (Ic) of DI-BSCCO with different coolants

Coolant	Temp. (K)	Ic of DI-BSCCO (A)
Liquid nitrogen (LN_2)	77	200 (α=1.0)
Liquid nitrogen (Subcooled) (LN_2)	65	400 (α=2.0)
Liquid hydrogen (LH_2)	20	1,140 (α=5.7)
Liquid helium (LHe)	4	1,400 (α=7.0)

	HTS AC Cable		HTS DC Cable
Structure			·3-cores-in-one-cryostat type ·HTS wires: (Conductor) About 50 wires/core (Shield) About 50 wires/core ·Ic of HTS wire: 200 A ·Insulation thickness: 6 mm
Current capacity (Margin: 10%)	3 kArms		27 kA / 3 cores (200A×50 wires/core×3 cores×0.9)
Transmission voltage	66 - 77 kVrms (Conventional level)		130 kV (O-P) (Design value derived from polarity reversal properties)
Transmission capacity	About 350 MVA	⇐ 10 times ⇒	About 3,500 MVA

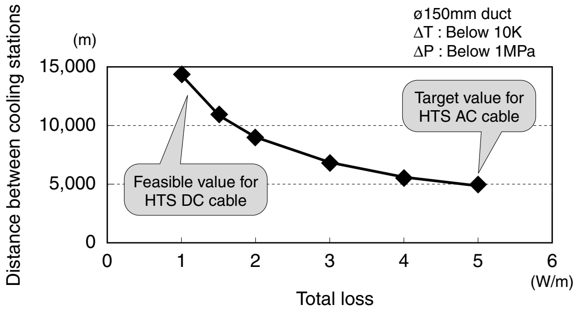


Fig. 27. Transmission capacity of HTS cable

Table 6. Economical evaluation of HTS cable

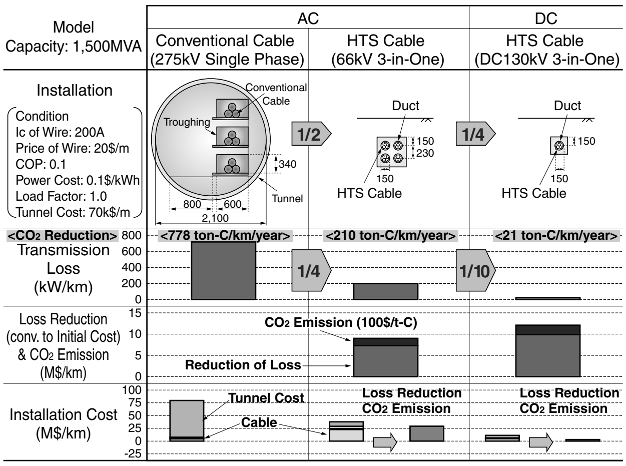


Table 6 is a comparison of conventional copper conductor cable, HTS AC cable and HTS DC cable in terms of compactness (transmission capacity differential), transmission loss, present value of the reduction in transmission loss (including CO_2 emission right utilization), and total transmission line construction cost. HTS cable is likely to be the cable of the future, and it is quite clear that it is HTS DC cable that will provide superior performance. **Figure 28** shows an example of a GENESIS Project system for installing six 1.5 kV/12 kA HTS DC cables for a transmission capacity of 100 MW.

One key component for the project (shown in **Fig. 22**), the electric conversion devices (inverters and con-

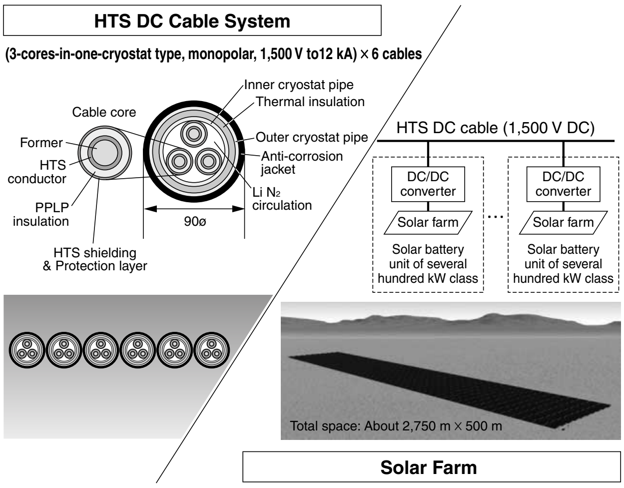
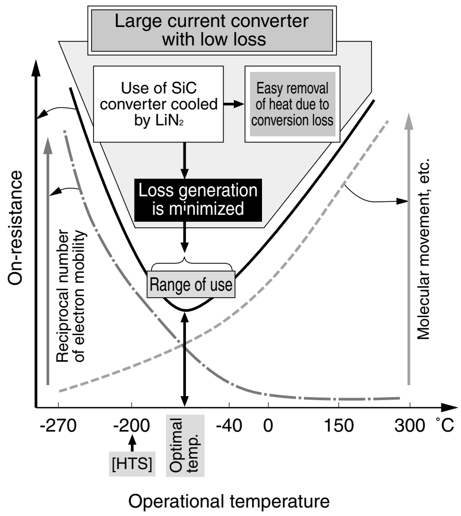


Fig. 28. 100-MW-class GENESIS System with HTS DC cable

verters), would have to be made more loss-resistant in order to transmit very large currents. The practical conversion devices at this time are silicon-based semiconductors. However, intensive development work is now under way on wide-band-gap semiconductors, and if a silicon-carbide (SiC) power semiconductor device becomes available, its on-resistance at normal temperatures would shrink at least by one hundredth compared with silicon-based semiconductors [21] (see **Fig. 29**). In addition, as shown in the graph in **Fig. 29**, the use of silicon carbide device for HTS cables can be expected to sharply reduce on-resistance at negative temperatures obtained preferably by liquid nitrogen (LiN_2) coolant,



Application Effect				Attained Status * for SBD; Others for pn	
Transistor (SiC/Si)		Inverter/Converter Equipment (B-to-B, SVC)			
High Temp. Operation	3 times	From Water Cooling to Air Cooling		3 times	(350˚C)
High Electrical Strength	10 times	Reduction of Series Devices		2.5 times	(19.5 kV)
Low Loss	1/100	Compact & High Efficiency		1/420	(23 mΩcm²)*
High Speed Switching	10 times	Compact & High Speed		10 times	(29-130 ns)

Fig. 29. Use of SiC converter at very-low temperature

Step I	Step II	Step III	Step IV
*Individual houses *Small-scale communities *Battery & converter *Autonomous consumption	*Small solar/wind farms *Connection to existing grid *Small to medium-sized battery & conversion system *Cu cable & Si-based converter *Sale of generated power	*Small to large solar/wind farms *Connection to existing AC network & network between farms *Middle to large-scale battery(*1) & converter *Cu cable + HTS DC cable As many SiC converters as possible can be applied *Sale of power is dominant (*1) Battery can be omitted when network has sufficient power storage capability.	*Small to large solar/wind farms *HTS DC cable network (Ultra-long-distance, large-power transmission with low loss) →Establishment of "global power grid" *SiC low-loss converter *International interconnection of electric power *PPLP Solid DC submarine cable (Ultra-long international interconnection) [*No battery is needed in principle]
(Local)	(Local: Domestic)	Within individual power company's service territory: Domestic	Multinational: International interconnection
In practice	Partially in pracitce (until 2020)	(From 2010 to 2050 and onwards)	(From 2020 to 2050 and onwards)

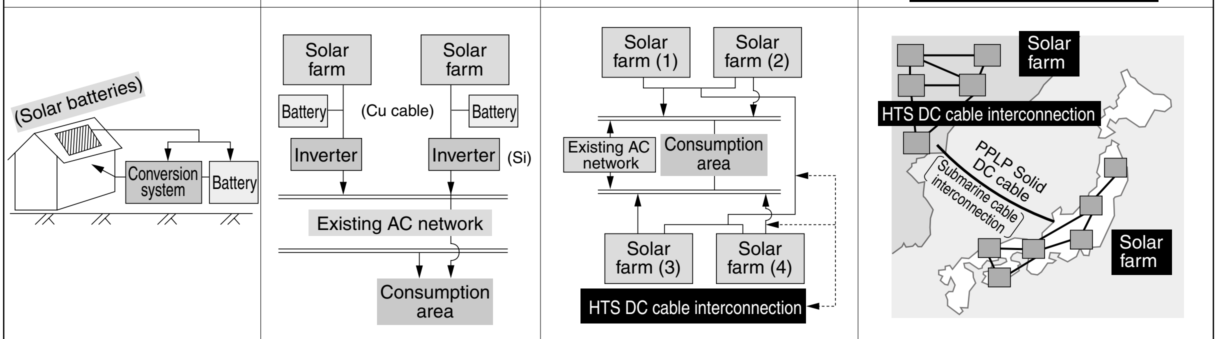


Fig. 30. Step-by-step development of "GENESIS Project"

and to simplify the elimination of generated conversion loss. The concept of combining the use of silicon carbide-based conversion devices at very low temperature with liquid nitrogen cooled HTS DC cable offers a potential foundation for significantly advancing the efficient implementation of the GENESIS Project.

Ideas for the specific development of the GENESIS Project are explored in references 4, 5, 6 and 14. Here, in **Fig. 30**, a phased development scheme consisting of four steps is presented. Step I and Step II are already the subjects of development programs in various parts of the world. Step III is quite easy to envision, as the power generated by each solar or wind farm can immediately be connected to the existing regional grid, with suitable arrangements for prioritizing local consumption and passing surplus power along to neighboring areas. In Step IV–the final phase of realizing the global superconducting power network portrayed in **Fig. 21**–full international linkage would be established by means of submarine cables, and rather than HTS cable, the undersea portions would probably utilize PPLP Solid DC cable with copper conductor [(45), (56)]. The Bakun Project for transmitting 2 GW of electricity across the South China Sea for 680 km from Sarawak on the island of Borneo to the Malay Peninsula (both in Malaysia) is now under way (see **Fig. 31**) [(45), (56)], and in future this submarine DC cable technology in that project is likely to become associated with the GENESIS Project.

In terms of other promising technologies for GENESIS Project, there would be special HTS DC cable which partially includes the second-generation YBCO (or HoBCO) wires at both ends of the cable line where fault currents can be eliminated by HTS cable itself, in other words, HTS cable with the function of fault current limiter (FCL) [(57)]. Also under investigation are innovative approaches to utilize the extensive length of the HTS DC cable to increase its inductance (L), which is proportionate to a cable length or a line distance, and, through the application of ultra large currents (I), to add an electricity storage function ($W = \frac{1}{2} LI^2$) to the cable [(60), (61)], either of which would be an eagerly awaited dream technology for making the HTS DC cable-based GENESIS Project more practicable.

7. Conclusions

The 21st century will be "the century of energy, resources and environment". Amid rapid increases of population and energy consumption, we will have to make the fullest efforts to preserve our energy, resources and environment while clearing up the negative legacies of the 20th century, and work to spread strong consideration for the welfare of all life including future human generations. Given that population growth is inevitable, we must make comprehensive plans for development of new technologies, inspired by new ideas, for the preservation of energy, resources and environment, and act forcefully to implement them. Moreover, in view of the exponential advance of energy consumption and environmental degradation, we have no more important duty than to introduce new systems based on those new technologies into human society sufficiently before it reaches the point of no return, and bring those systems to maturity. If we survey the future with the wisdom oriented by the lessons of history, it is clear that rather than nuclear fusion, the "GENESIS Project plus extra something", combining HTS DC cable as well as PPLP Solid DC cable with new solar-derived energy resources (photovoltaic, wind and hydraulic power), is indeed the only feasible solution (see **Fig. 32**). Viewed from the standpoint of the present (looking outward from our current situation or "In-Out"), the GENESIS Project may appear to be just an idea which faces very high hurdles. However, viewed from the standpoint of the future (looking back at our current situation or "Out-In"), it can be seen clearly as an inevitable reality.

Finally, the essence of this entire paper is encapsulated in **Fig. 33**. Now is the time for each of us to reflect on the true meaning of sustainability, in addition, for us to

Items		Descriptions
Customer		SPC (Sime Darby, etc.)
Hydraulic power		2,400 MW
Transmission cable	OHL	Between B·H·P·P and TG. DATU; 660 km 2 bipoles (4 cables)
	Submarine cable	Between TG. DATU and TG. SEDILI; 680km; 2 PPLP Solid Cables ±500kV 1×2,000mm² 1,000MW/cable Total transmission power: 2GW
Construction period		2010 to 2013 & 2015
Estimated construction cost		3.5 to 4B$

Fig. 31. ASEAN Power Grid and Bakun Project

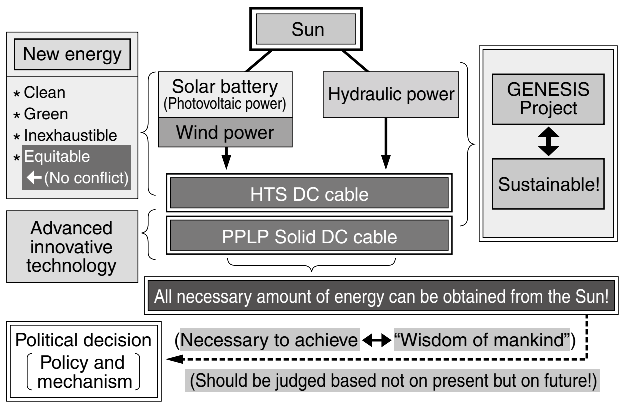


Fig. 32. Challenge for sustainable energy system

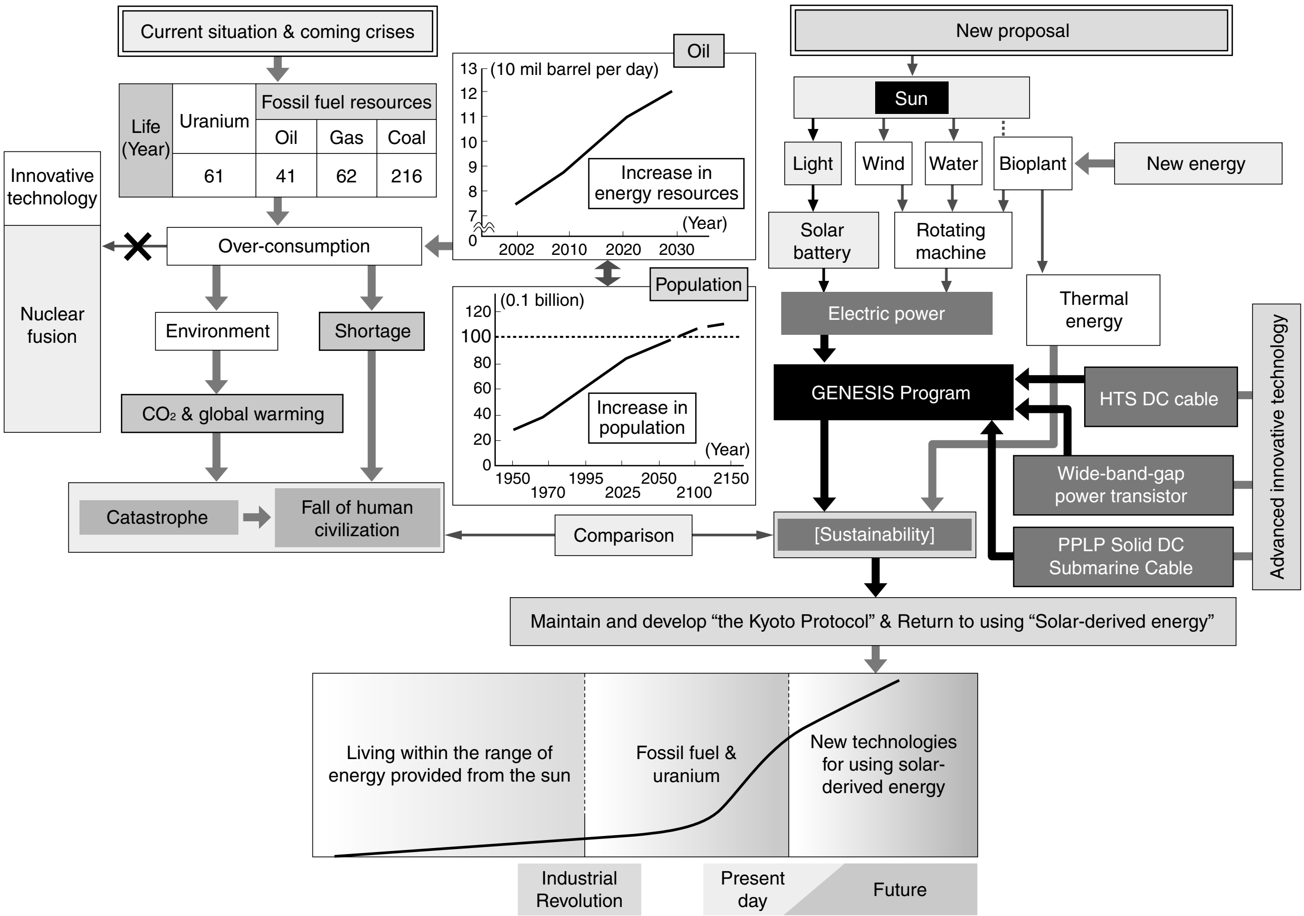


Fig. 33. Energy, resources and environment for 21st Century

ask to all people what inevitable scenario we should envision, and to endeavor to do our best to work steadily along that scenario, under the firm conviction that can be led by our wisdom, vision, sense of mission, and courage, as we begin to act to open up our path to the future.

[**Note I**] Dr. Kenshi Matsuura, professor emeritus at Osaka University, prudently pointed out that using solar-derived new energies is the same thing as safely and constantly utilizing the energy generated from the nuclear fusion reactions taking place in the sun.

[**Note II**] All fossil fuels that human beings are now using are composed of carbon-related materials that have been accumulated for such a super-long time as 4.6 billion years since the birth of this Planet Earth, essentially through solar-driven photosynthesis, in other words, carbon is fixed while oxygen is released. In a short time, such solar-derived energy are scattered all over the glove widely and impartially and not so densely, so it is meaningless unless energy had accumulated and condensed over a long period of time. Enormous energy can be released today when the accumulated and condensed fossil fuels are oxidized both in a large scale and in a short time, while carbon-dioxide is emitted at the same time.

To the contrary, in order to produce meaningfully sufficient energy from solar-derived new energy that is widely-scattered and sparse today, it is necessary that we collect and condense this energy by concentrating it into a small volume (or limited small spaces). This means that to obtain useful amount of energy, the integral of time should be replaced by the integral of space. Therefore, the key technology today to make the best use of new energy should be "electric power collection, transmission and distribution" followed by "electric power condensation."

Now it is in question whether or not the present generation living after the Industrial Revolution and enjoying the highly civilized life by means of consuming large amounts of energy can accomplish the "switch from time to space" in terms of energy resources by achieving the development of innovative and advanced technologies within a very limited period of time.

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