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## Space Power System – Motivation, Review and Vision

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### 1. Introduction

The world's population growth is exhausting the world's limited supply of non-renewable energy sources, and along with it, introducing significant anthropogenic environment and climate change. Although the economic and business inertia trend to cling to the lure of non-renewable energy resources, it is imperative that in the foreseeable future extensive renewable or green energy sources should be progressively utilized to replace the non-renewable ones and to sustain reasonable living standard for the entire world's population.

The world's dream of world's socio-economic and technological equity and networking is still far from being a reality, and many of the pioneering technology breakthrough for the benefits of humanities, to some extent, contribute to their widening gap. Then it will be timely and appropriate that a new vision for world's "green" energy be shared by and contributable to a fair distribution of world's population, presently still grouped into countries with unbalanced capacity distribution. In particular, judging from the large population distribution and growth in developing countries compared to the developed ones, the need and growth for energy resources will also be more or less similar.

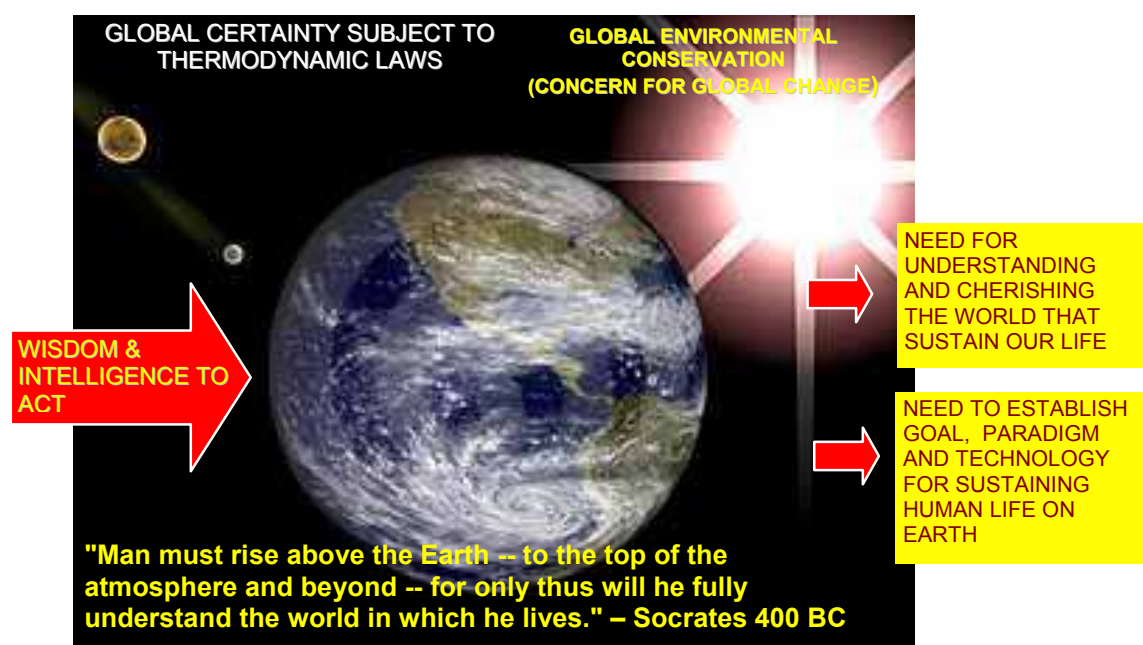
Mankind success in space exploration has opened up their vision of the uniqueness of the world we live in and the need for conserving our environment (Djojodihardjo, 2009; Djojodihardjo & Varatharajoo, 2009), as illustrated in Figure 1. Such vision which has inspired mankind to develop technological capabilities in atmospheric and space flight as well as exploring new frontiers beyond the earth's atmosphere has been profoundly articulated as far back as in 400 BC by Socrates in the well known verse: "Man must rise above the Earth -- to the top of the atmosphere and beyond -- for only thus will he fully understand the world in which he lives."

Mankind has acquired further wisdom and intelligence to observe, identify and respond to the challenges posed by the observed global climate change from advances in space science, technology and exploration, and its close relationship to sustainable life on earth and mankind dramatically rising demand of energy. Such state of affairs is summarized in Figure 1. With the appreciable climate change that has been observed and of great concern

not only by scientists but world population at large, the need for global energy and its production demands new approaches and paradigm.

Through advances in space science, technology and exploration, mankind also acquired awareness of the presence of our sun as an inexhaustible source of energy, which may then offer a host of additional solutions to meet the need of world expanding population and increasing demand for energy.

The globalization process that have been taking place at impressive pace due to progress and wide accessibility of information technology, products and network has made each individual is figuratively speaking a world citizen, with more or less common objectives, interest and role in the world problems. Therefore, for a synergetic effort in Space Solar Power imperatives, open participation should be encouraged, and barriers should be identified and resolved.



These words due to Socrates in 400 BC has inspired mankind to explore new frontiers beyond the earth's atmosphere which eventually convince mankind for the preciousness of our unique world and the the need to for sustainable llife on earth and the significance of space exploration to that end.

Fig. 1. Mankind Vision for Sustainable World

Hence, as implicitly stipulated in Figure 1, in this article attention will be focused on three issues: 1. the need and efforts to meet basic and mandatory mankind quality of life, which at present will be directed to achieving high or acceptable Human Development Index (such as described in the United Nations Framework Convention on Climate Change), with a perspective on mankind dramatic increase in energy demand<sup>1</sup>; 2. understanding the global climate change process in order to identify practical conceptual approaches and policies in meeting mankind energy demand; 3. status, progress, projection and development of global energy utilization and technologies.

<sup>1</sup> The efforts to meet the basic and mandatory mankind demand for quality of life will be discussed after the discussions on environment and energy, since these may shape up the former, although in general these issues are interconnected.

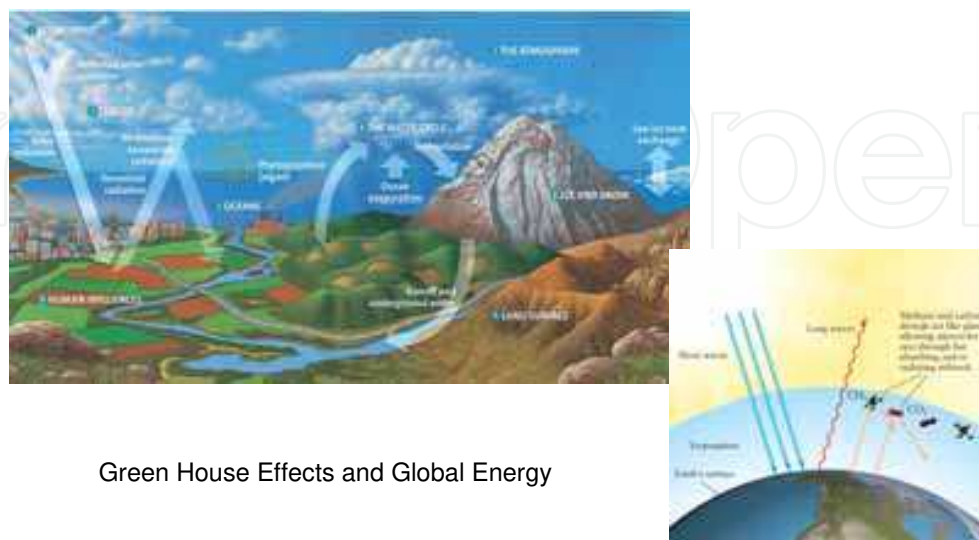
Through a meticulous review of these issues to direct our wisdom and intelligence to establish vision for future solutions of man kind needs and problems, the present article will explore the prospects of space power system as one of the feasible, viable, and equitable solutions for world population as a whole and entity.

It is with such overview that the following aspects associated with Space Solar Power or Solar Power Satellite is discussed:

1. Review of Global Environment Imperatives which necessitates proactive initiatives for Sustainable Power System leading to Space Power System; Environment and Climate Change Imperatives
2. Energy Demand and Space Power System addressing the whole world, with particular reference to the developing world
3. Significance of Space Power System to the developing world, including the developing countries
4. Space power system: review of selected architecture and technologies
5. Space Power System as a Unifying Agent for Global Networking
6. Stimulating Positive Attitude in Developing Countries: The Microsatellite Tool
7. Universal SPS Program Initiatives – arms reaching but novel paradigm – establish productive and resourceful partners-in-arms by expanding opportunities at creative circles
8. Technological options considerations in view of overall strength and weakness, gains and losses

## 2. Environment and climate change imperatives

The Global Climate Change and the Green-House Effect are terminologies that have been widely discussed and of global concern and global efforts in the last decades, and brought to the attention of world top policy-and-decision-makers through a series of World Summits (also known as the Earth Summits), which have been organized under the auspices of the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO).



Green House Effects and Global Energy

Fig. 2. Global Warming due to Unsustainable Use of Fossil Fuels is of Mankind Concern

To this end, UNEP and WMO established the Intergovernmental Panel on Climate Change (IPCC) to provide policy makers with authoritative scientific information in 1988. Related to this, the United Nations Framework Convention on Climate Change (UNFCCC or FCCC), which is an international environmental treaty, was produced at the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro from 3 to 14 June 1992.

The objective of the treaty is to stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (United Nations Framework Convention on Climate Change). Actually the greenhouse effect is important, since without it, the Earth would not be warm enough for humans to live. But if the greenhouse effect becomes stronger, it could make the Earth warmer than usual that may impose serious problems for humans, plants, and animals, and thus, the environment and what is now recognized as Global Warming.

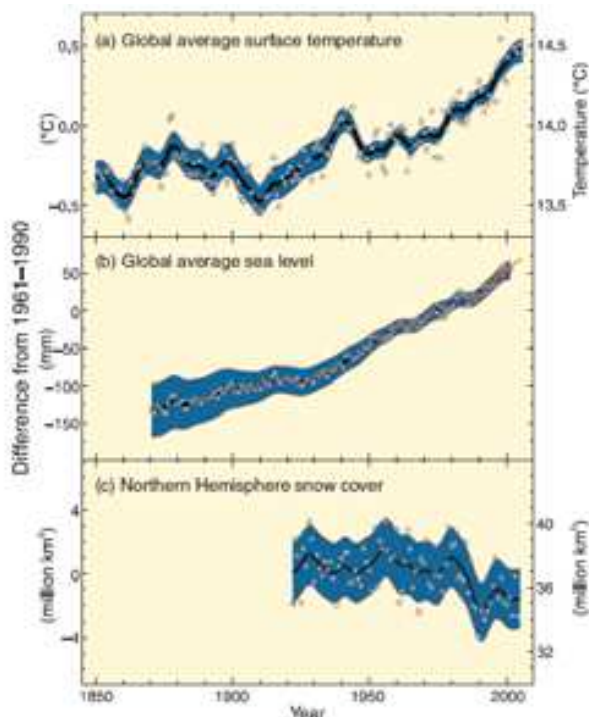


Fig. 3. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961- 1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c) (Bernstein et al, 2007).

As illustrated in Figure2, energy from the sun enters the Earth’s and filtered by the atmosphere in the form of electromagnetic radiation in the visible spectrum, with small amounts of Infra-Red and Ultra-Violet radiation. The incoming solar energy has a very short wavelength and passes through the atmospheric gases unaffected to reach the Earth’s surface. The Earth’s surface absorbs the solar energy and releases it back to the atmosphere as infrared (IR) radiation, some of which goes back into space. Some of the IR radiation emitted by the Earth is absorbed by the gases in the atmosphere that re-emit the energy as heat back towards the Earths surface. The Counter Radiation and Greenhouse Effects consist of



- Long-wave radiation from the earth's surface is absorbed by atmospheric gases: CO<sub>2</sub>, H<sub>2</sub>O, CH<sub>4</sub>, other gases
- The increase in atmospheric gases increases the heat absorption by the lower atmospheric layers
- Cloud layers (water droplets) also absorb radiation.

The unbalanced production of these greenhouse gases and their absorption by the Earth's surface has been identified as the major contributor to what is now identified as Global Warming, which will be further elaborated and discussed subsequently.

Bernstein et al's report (2007), which is based on the assessment carried out by the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC) provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report (AR4). Some of their findings are reproduced or adapted below.

### **Observed changes in climate and their effects**

Warming of the climate system is undeniable, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level, and illustrated in Figure 3. The report stipulates that eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the Third Assessment Report (TAR) of IPCC. The temperature increase is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the oceans.

Rising sea level is consistent with warming, as indicated in Figure 3(b). Global average sea level has risen since 1961 at an average rate of 1.8 [1.3 to 2.3] mm/yr and since 1993 at 3.1 [2.4 to 3.8] mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets.

### **Causes of change**

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004, as indicated in Figure 4. Global atmospheric concentrations of CO<sub>2</sub>, methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.

Figure 5 shows that decadal averages of observations for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica), as indicated by Figure 5.

Long term CO<sub>2</sub> concentration estimates within 150,000 years are also given by Walker et al (2010) as exhibited in Figure 6. The striking peak during last few decades may indicate the anthropogenic causes of the change in CO<sub>2</sub> concentration.

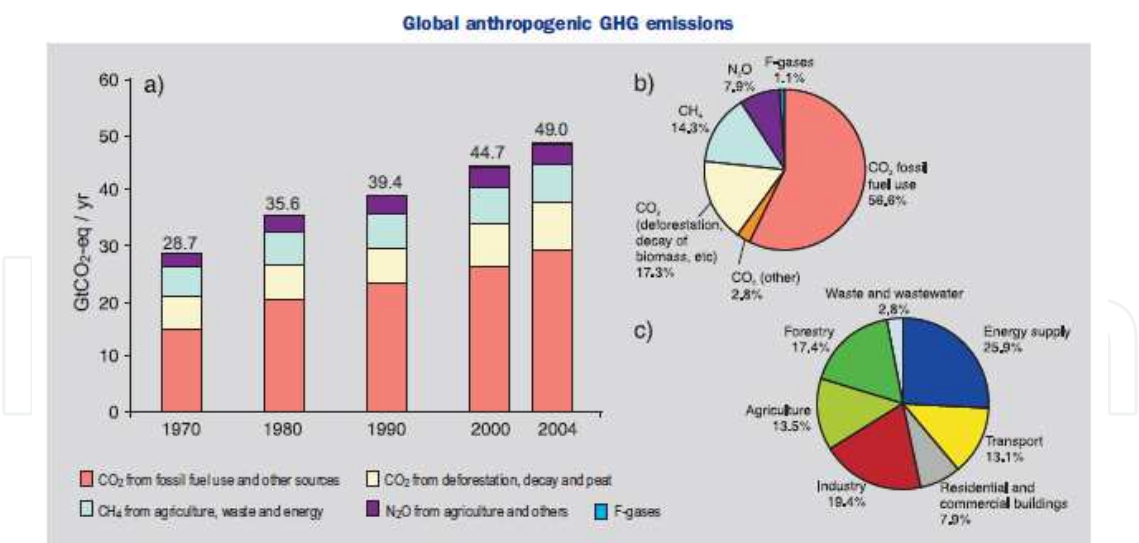


Fig. 4. Global annual emissions of anthropogenic Green House Gases (GHGs) from 1970 to 2004 (Bernstein et al, 2007).

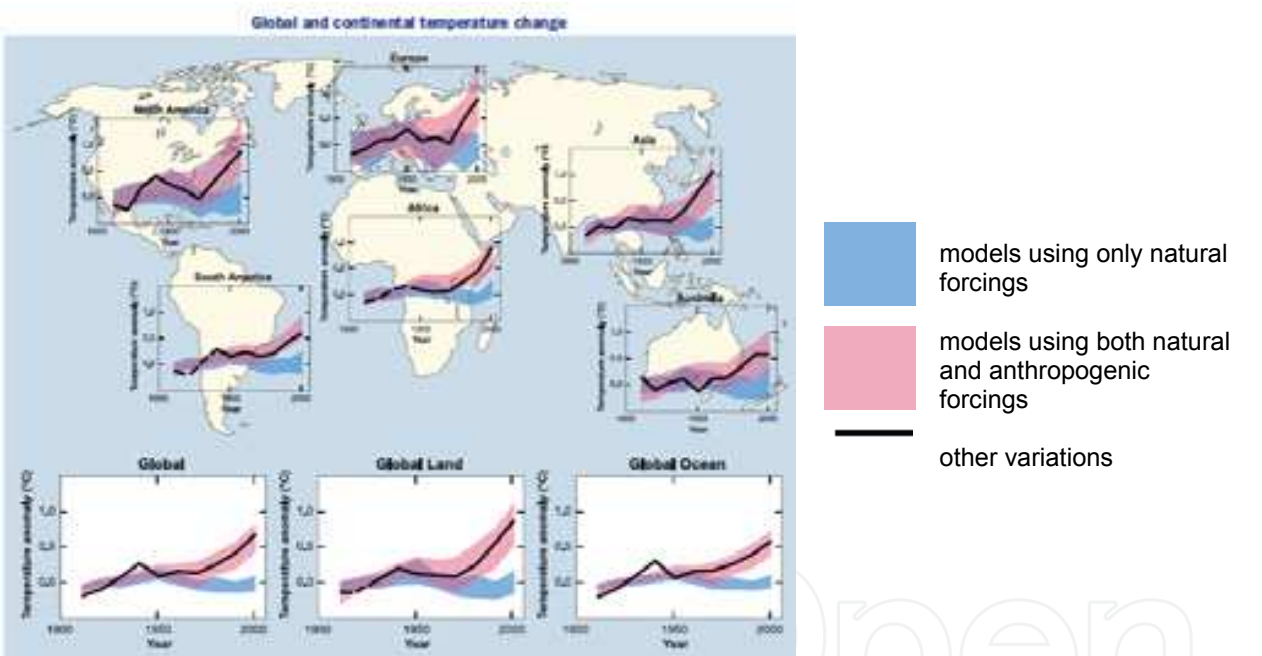


Fig. 5. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings (Bernstein et al, 2007).

Projected climate change and its impacts

There is high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. The IPCC Special Report on Emissions Scenarios (SRES, 2000) projects an increase of global GHG emissions by 25 to 90% (CO<sub>2</sub>-eq) between 2000 and 2030 (Figure 7), with fossil fuels maintaining their dominant position in the global energy mix to 2030 and beyond. More recent scenarios without additional emissions mitigation are comparable in range. Continued GHG emissions at or above current rates would cause

further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.

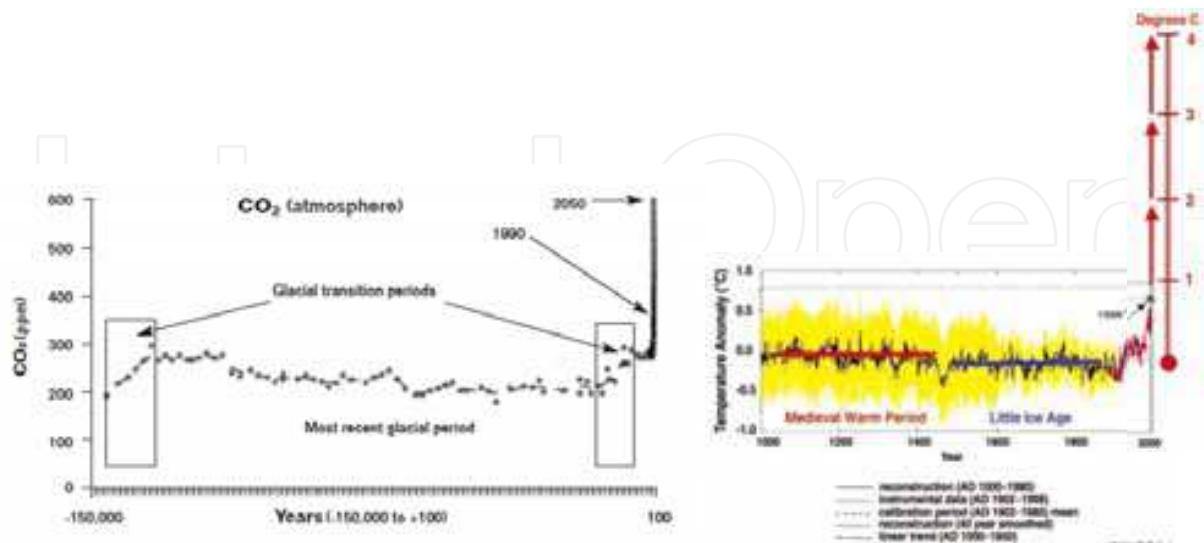


Fig. 6. Estimates of CO<sub>2</sub> concentrations for the last 150,000 years with a projection to A.D. 2050 based on present-day rates of emission. The corresponding temperature anomaly is shown on the right hand side (From Walker, Keim and Arndt, 2010).

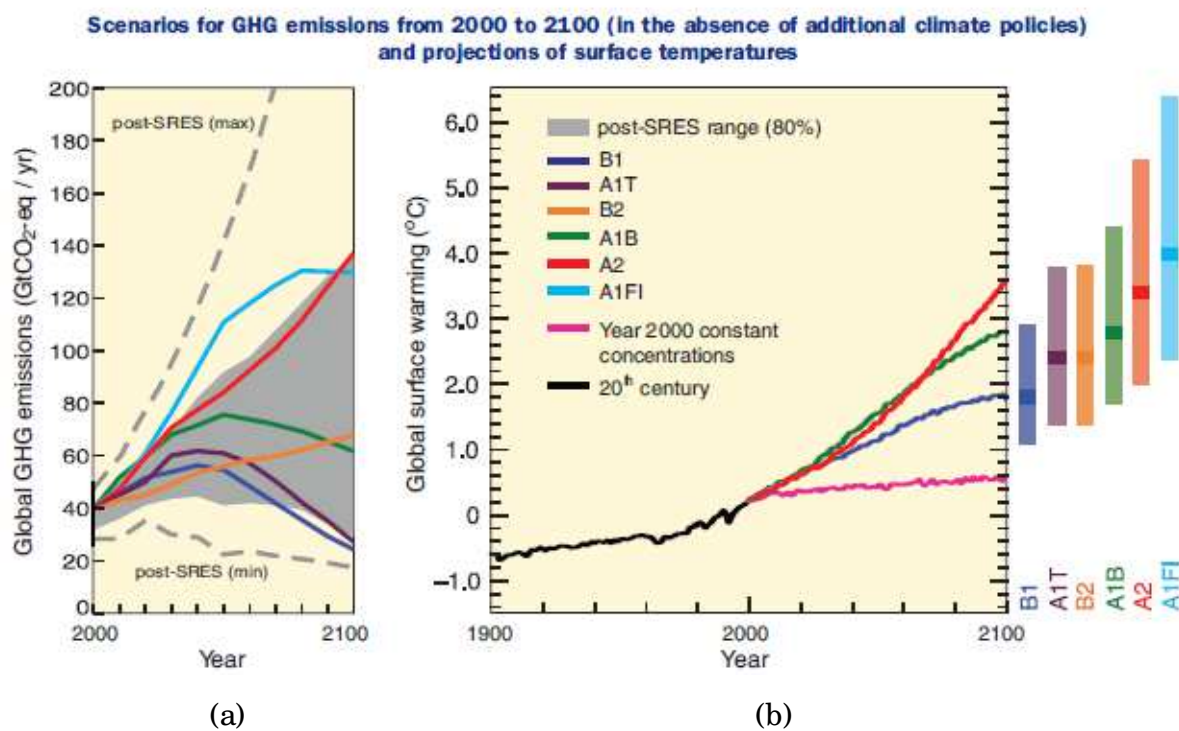


Fig. 7. (a) Global GHG emissions (in GtCO<sub>2</sub>-eq) in the absence of climate policies: six illustrative SRES marker scenarios (colored lines) and the 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area) (Bernstein et al, 2007).



In Figure 7, the dashed lines show the full range of post-SRES scenarios. The emissions include CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and F-gases. (b) Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999 (Bernstein et al, 2007).

Thus these scientific studies and facts have led to the conclusion that human influences have:

1. *very likely* contributed to sea level rise during the latter half of the 20th century
2. *likely* contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns
3. *likely* increased temperatures of extreme hot nights, cold nights and cold days
4. *more likely than not* increased risk of heat waves, area affected by drought since the 1970s and frequency of heavy precipitation events.

Such situation certainly need fully fledged and visionary mitigation efforts to change the situation drastically, subject to the effectiveness of such measure due to natural causes and elapsed time required for such actions take effects. A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood. Both bottom-up and top-down studies indicate that there is high agreement and much evidence of substantial economic potential for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels indicated in Figure 6 and Figure 7. While top-down and bottom-up studies are in line at the global level there are considerable differences at the sectoral level.

### **Natural Forcings to Counteract Assessed Green House Gases effects**

Sensitivity experiments indicate that a level of solar variability as reconstructed over the past 1000 years is insufficient to mask the predicted 21st century anthropogenic global warming. Volcanic forcing could counteract the anthropogenic greenhouse warming, but this requires (i) a permanent level of very high volcanic activity, (ii) a volcanic forcing increasing with time, (iii) a huge stratospheric aerosol burden (unlike anything we have seen in the recent past).

Bernstein et al (2007) carried out study of various mitigation scenarios, which results in a range of future emission scenarios is exhibited in Figure 8.

Another projection of policy impact on global climate is exhibited in Figure 10. These scenarios indicate that:

- i. There is an urgent need for global mitigation policy and action to mitigate the GSG global warming effect to allow sustainable development for mankind to take favorable effect.
- ii. Even with appropriate immediate mitigation action, their favorable effect to the global environment will take more than hundred years to return the situation to previous situation, as Figure 10 illustrates.

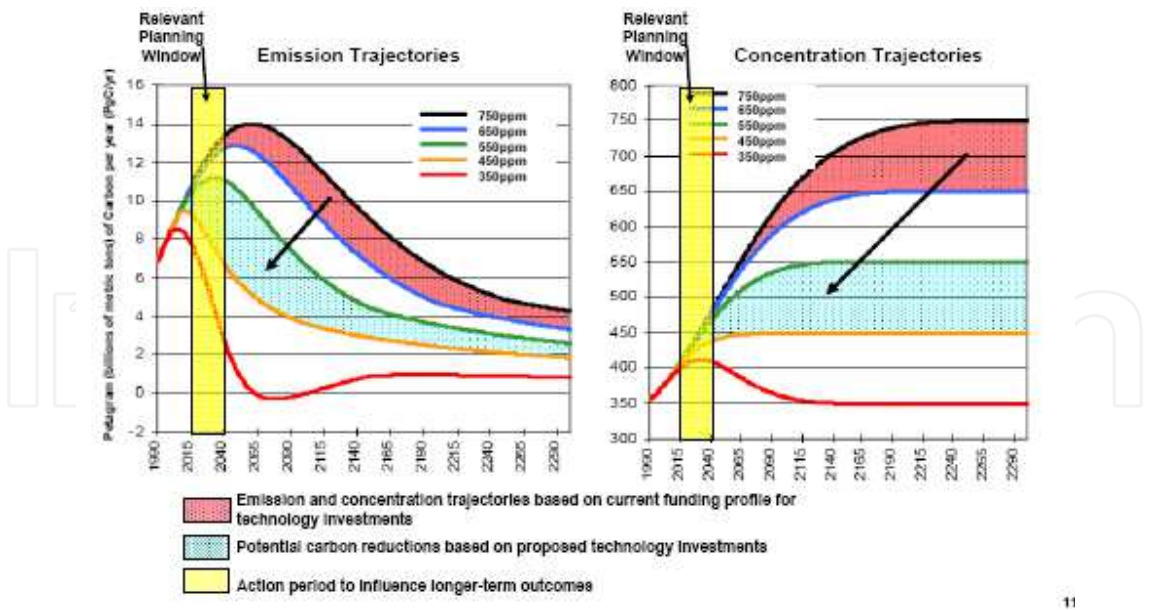


Fig. 8. Policy Impact on Global Climate (adapted from Ghoniem, (2008)

3. Energy demand and space power system adressing the whole world, with particular reference to the developing world

World Energy Demand is very much related to Economic Development, and without the global concern of global environmental sustainability, will probably be ever increasing. Such trend will probably change in a decade or so, as projected by various studies, as illustrated in Figure 9. In the US Energy Information Administration IEO2009 projections (2010), total world consumption of marketed energy is projected to increase by 44 percent from 2006 to 2030. The largest projected increase in energy demand is for the non-OECD economies, as illustrated in Figure 10(a). Grillot (2008) made a forecast, based on UNDP and DOE data that the World energy consumption will increases about 60% from 2004 to 2030~2030. Associated with this, the Carbon emission is projected in Figure 10(b).

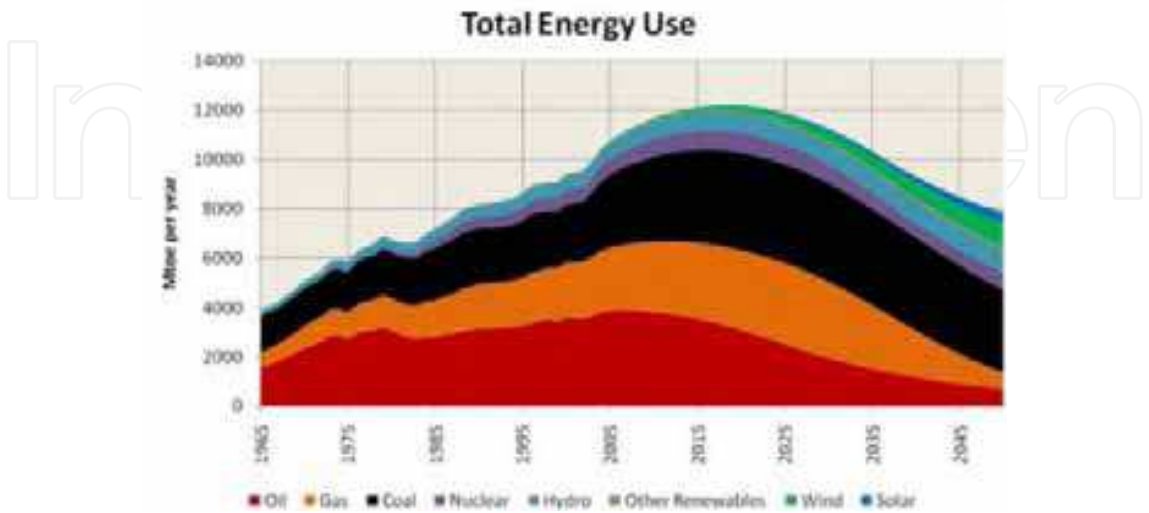


Fig. 9. World total energy utilization projection, as projected from 1965 to 2045. (Source: Chefurka, 2010).

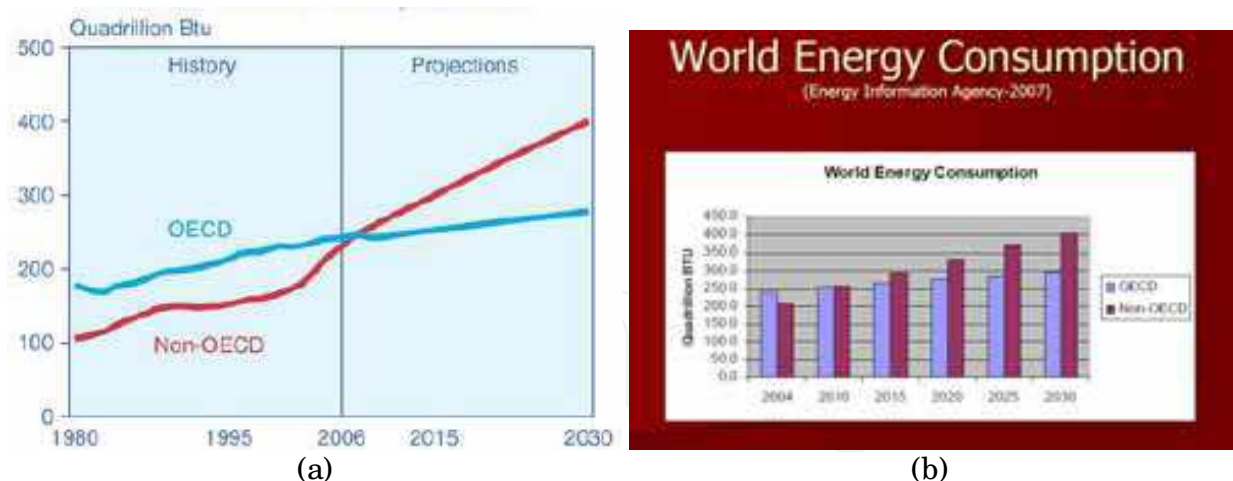


Fig. 10. (a) World marketed energy consumption, in Quadrillion Btu., in OECD and Non-OECD countries, 1980-2030, indicating higher rate of increase in developing countries (Source: US Energy Information Administration, 2010) (b) World Energy Consumption from 2004 to 2030 (Grillot, 2008). Both (a) and (b) indicate higher rate of increase in developing countries.

Much of the growth in world economic activity between 2006 and 2030 is expected to occur among the nations of non-OECD Asia, where regional GDP growth is projected to average 5.7 percent per year. China, non-OECD Asia's largest economy, is expected to continue playing a major role in both the supply and demand sides of the global economy. *IEO2009* projects an average annual growth rate of approximately 6.4 percent for China's economy from 2006 to 2030—the highest among all the world's economies. Although the difference in world oil prices between the high and low oil price cases is considerable, at \$150 per barrel in 2030, the projections for total world energy consumption in 2030 do not vary substantially among the cases. There is, however, a larger impact on the mix of energy fuels consumed. The projections for total world energy use in 2030 in the high and low oil price cases are separated by 48 quadrillion Btu, as compared with the difference of 106 quadrillion Btu between the low and high economic growth cases.

The potential effects of higher and lower oil prices on world GDP can also be seen in the low and high price cases. In the long run, on a worldwide basis, the projections for economic growth are not affected substantially by the price assumptions. There are, however, some relatively large regional impacts. The most significant variations are GDP decreases of around 2.0 percent in the high price case relative to the reference case in 2015 for some regions outside the Middle East and, in the oil-exporting Middle East region, a 5.5-percent increase in GDP in 2015.

The regional differences persist into the long term, with GDP in the Middle East about 6.2 percent higher in 2030 in the high oil price case than in the reference case and GDP in some oil-importing regions (such as OECD Europe and Japan) between 2.0 percent and 3.0 percent lower in the high price case than in the reference case.

Economic viability will play a critical role in determination of the optimal energy option. The current worldwide energy market is dominated by fossil fuels, making any alternative difficult to implement due to lack of existing infrastructure, as well as commercial and practical interest driven, although may not be visionary. Not only will the technical feasibility and cost of both green and space based power sources be well understood and appreciated, but also the necessary technological learning curve and economic pressure.



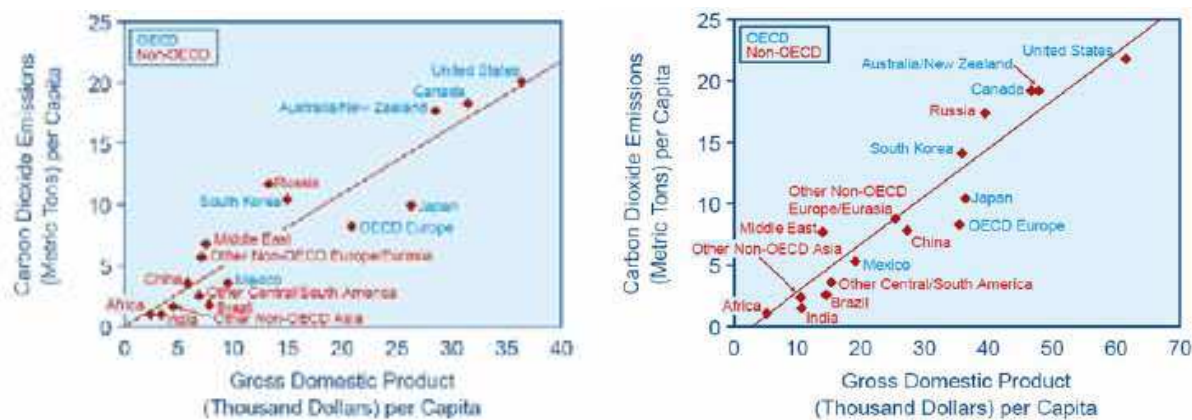


Fig. 11. (a) Carbon Dioxide Emissions and Gross Domestic Product per Capita by Region, 2004 ; (b) Carbon Dioxide Emissions and Gross Domestic Product per Capita by Region, 2030, (Grillot, 2008).

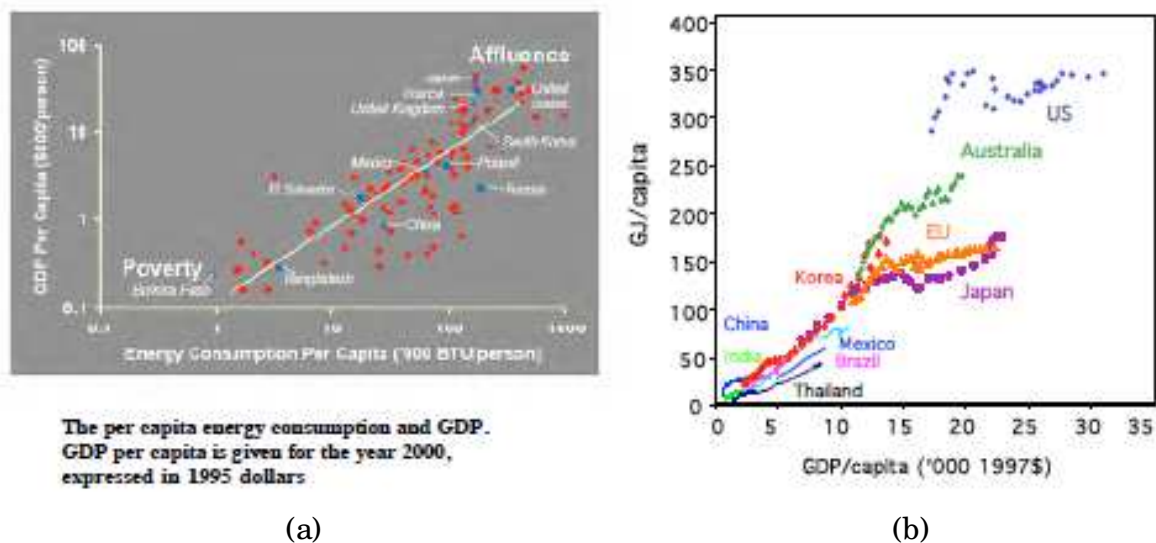


Fig. 12. The trends in energy utilization is driven by developing economies (Ghoniem (2008), using data from UNDP Human Development report (2003))

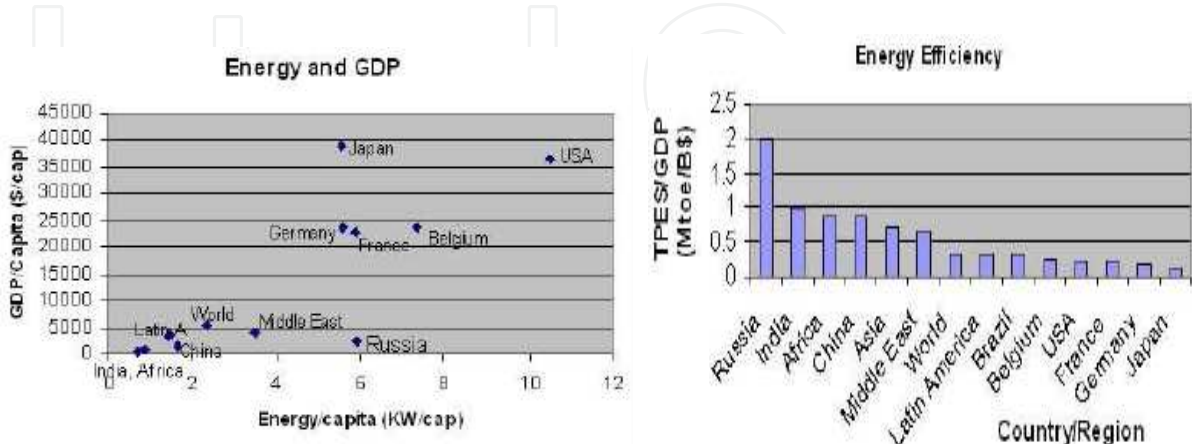


Fig. 13. (a) GDP versus energy consumed per capita in selected countries and the world, which indicates that it is driven by developing economies. (b) Energy efficiency of selected countries and regions (Schmitt, 2007).



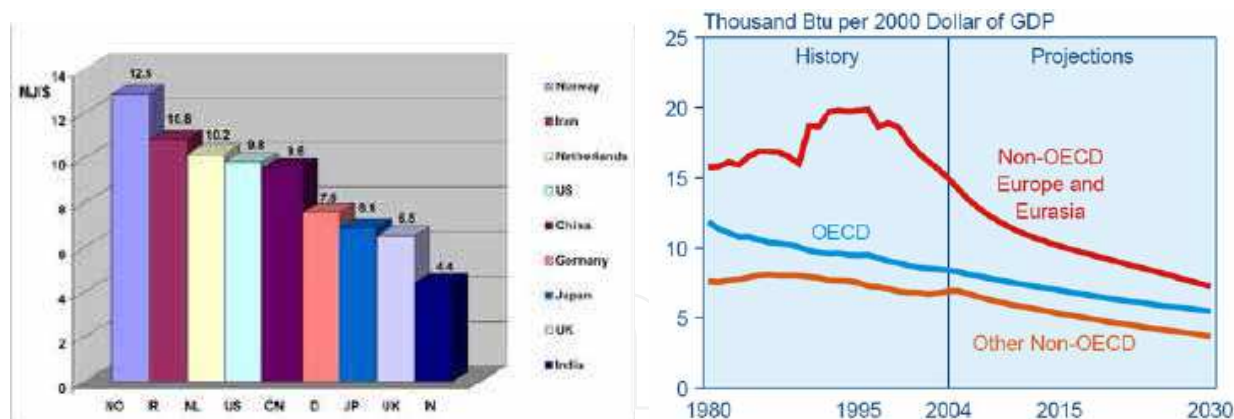


Fig. 14. (a) Energy Intensity of different economies<sup>2</sup> The graph shows the amount of energy it takes to produce a US \$ of GNP for selected countries. GNP is based on 2004 purchasing power parity and 2000 dollars adjusted for inflation (US Energy Information Administration 2010). (b) Energy Intensity by Region, 1980-2030 (Grillot, 2008)

The trends reflected from the results of these studies as illustrated in Figures 12 to 14 indicate that the world energy utilization is increasing commensurate with population increase and economic development as indicated by GDP's of individual countries. However, the encouraging information reflected here, as illustrated in Figure 14, is the energy intensity, which tends to decrease in 2030.

It will be imperative how these trends relate to the UN Millennium Goal and Human Development Index. Energy can be considered to be a key factor in promoting peace and alleviating poverty. Solar power from space can help keep the peace on Earth. In September 2000 the world's leaders adopted the UN Millennium Declaration, committing their nations to stronger global efforts to reduce poverty, improve health and promote peace, human rights and environmental sustainability.

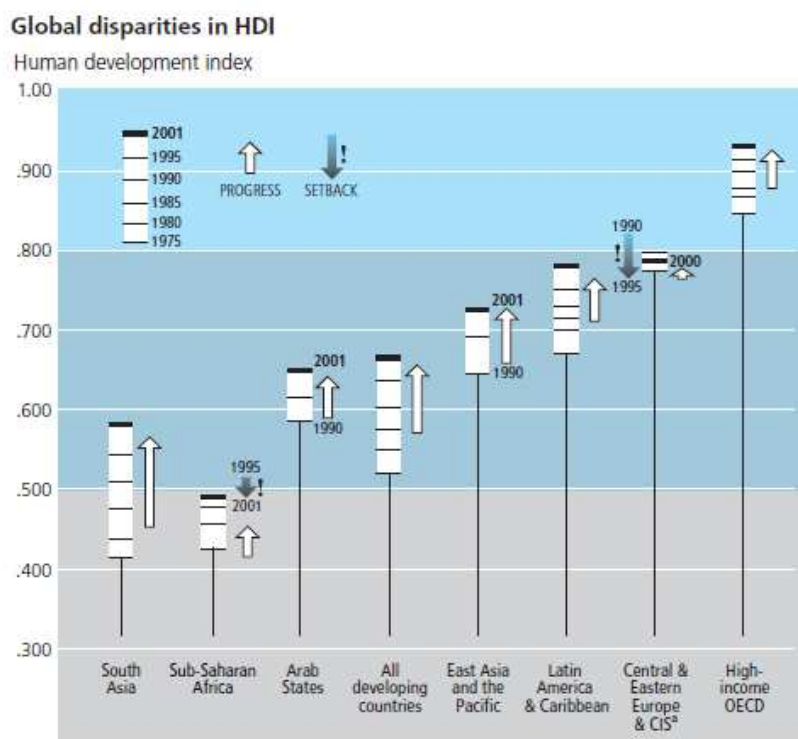
The Millennium Development Goals that emerged from the Declaration are specific, measurable targets, including the one for reducing—by 2015—the extreme poverty that still grips more than 1 billion of the world's people. These Goals, and the commitments of rich and poor countries to achieve them, were affirmed in the Monterrey Consensus that emerged from the March 2002 UN Financing for Development conference, the September 2002 World Summit on Sustainable Development and the launch of the Doha Round on international trade (UN Development Report, UNDP, 2008).

As reflected by Figures 9, 10 and 12, the world is facing an energy crisis on two fronts. There are not enough fossil fuels to allow the developing countries to catch up to the developed countries and global warming (Figures 3, 6 and 7) is threatening to cut short the production of the fossil fuels we can access today (UNDP, 2003 and 2008). These two factors necessitate the active role of relevant stake-holders in developing countries as represented by the triple-helix of government, research institutions and universities, and industries to establish integrated policies, action plans and budgetary measures to accelerate local participation and contribution to the global market that address sustainable development issues and green initiatives, with particular reference to energy issues. Active role of government in developing countries taking advantage of the research initiatives by local research and

<sup>2</sup> Energy intensity is energy consumption relative to total output (GDP or GNP)

academic institutions in utilizing locally available and/ or renewable technology will be necessary, as transitional stage towards more sustainable energy mix structure.

Economic viability will play a critical role in determination of the optimal energy option. The current worldwide energy market is dominated by fossil fuels, making any alternative difficult to implement due to lack of existing infrastructure. Not only will the technical feasibility and cost of both green and space based power sources be investigated, but also the necessary technological learning curve and economic pressure.



Source: Human Development Report Office calculations based on indicator table 2.

Fig. 15. Human Development Index Assessment on various geographical regions (UNDP, 2008)

In addition, international cooperation and industrial and developing countries economic interactions should also be directed towards these two factors: human resources development and industrial development transactions that is intricately related to environmental policy issues. Such initiatives should be based on long term and global vision rather than short term and local interest if an overall gain is desired, and should be seriously dedicated to overcome local and / or short term hurdles.

With respect to energy model and energy policy, the following which demand real solutions should be given due considerations (Ghoniem, 2008):

- i. Energy consumption rates are rising, fast.
- ii. Energy consumption rates are rising faster in the developing world.
- iii. The developing world can not afford expensive energy.
- iv. Oil is becoming more expensive, so is gas.
- v. Massive and cheap coal reserves and resources should not distract synergetic efforts for green energy
- vi. CO<sub>2</sub> will become a dominant factor (as illustrated in Figures 8 and 11).

4. Significance of space power system to the developing world

People all over the world are more or less aware about solar power satellites, although their comprehension, initiative and creativity in addressing related problems do depend to a large extent to the above mentioned differentiations. It is also an observed fact that since the inception of the idea of SPS, the world has experienced tremendous increase in energy utilization.

The Solar Power Satellite (SPS) system is a candidate solution to deliver power to space vehicles or to elements on planetary surfaces and to earth to meet increasing demand of electricity. It relies on RF or laser power transmitting systems, depending on the type of application and relevant constraints (Cougnet et al. 2004).

It has also been observed that the fruit of developments taking place in the developing countries is manifested in terms of higher rate of increase of energy utilization compared to the industrial world, as indicated in Figures 10 and 12.

Region	Consumption, (million toe)			Increase, 1985-95 (%)
	1985	1990	1995	
Asia excluding Japan	924.0	1219.6	1591.1	72.2
Total Europe	1656.2	1739.3	1725.2	4.2
Japan	362.7	428.3	490.2	35.2
USA	1739.0	1930.7	2069.4	19.0
ASEAN (5)	84.4	135.9	201.2	138.4
World	694.1	7855.2	8135.8	17.1

Table 1. The trends in energy utilization is driven by developing economies (adapted from UNDP Human Development report, 2003, and Ghoniem, 2008)

There are not enough fossil fuels to allow the developing countries to catch up to the developed countries and global warming is threatening to cut short the production of the fossil fuels we can access today.

Space solar power is potentially an enormous business. Current world electrical consumption represents a value at the consumer level of nearly a trillion dollars per year; clearly even if only a small fraction of this market can be tapped by space solar power systems, the amount of revenue that could be produced is staggering (Landis, 1990). To tap this potential market, it is necessary that a solar power satellite concept has the potential to be technically and economically practical.

Possibly the most interesting market is third-world "Mega-cities," where a "Mega-city" is defined as a city with population of over ten million, such as São Paolo, Mexico City, Shanghai, or Jakarta. By 2020 there are predicted to be 26 mega-cities in the world, primarily in the third world; the population shift in the third world from rural to urban has been adding one to two more cities to this category every year, with the trend accelerating.

Even though, in general, the third world is not able to pay high prices for energy, the current power cost in mega-cities is very high, since the power sources are inadequate, and the number of consumers is large. Since the required power for such cities is very high-- ten billion watts or higher-- they represent an attractive market for satellite power systems, which scale best at high power levels since the transmitter and receiver array sizes are fixed

by geometry. In the future, there will be markets for power systems at enormous scales to feed these mega-city markets. Therefore, it is very attractive to look at the mega-city market as a candidate market for satellite power systems (Landis, 1990).

Therefore, it is imperative that Space Power System should be viewed and analyzed as a challenging but realistic answer to the need to meet electrical energy needs for developing countries, just like satellite communication has proven itself since its visionary projection by Arthur Clark and its utilization in the past five decades.

To be economically viable in a particular location on Earth, ground based solar power must overcome three hurdles. First, it must be daytime. Second, the solar array must be able to see the sun. Finally, the sunlight must pass through the bulk of the atmosphere itself. The sky must be clear. Even on a seemingly clear day, high level clouds in the atmosphere may reduce the amount of sunlight that reaches the ground. Also various local obstacles such as mountains, buildings or trees may block incoming sunlight.

In addition, global concern and interest point toward the need for the world community to progressively but urgently change for environmentally friendly and green energy utilization. Hence one should examine existing power sources as well as near term options for green energy production including cellulosic ethanol and methanol, wind-power, and terrestrial and space solar power (Supple & Danielson, 2006; Andrews & Bloudek, 2006).

The prevailing economic gaps between developing (non-OECD) and industrialized (and space-fairing) countries also introduces significant gaps that place developing countries as by-standers in the global efforts for space technology utilization for appropriate development. It is therefore imperative to carefully examine:

- a. Options, resources and policies related to establishing developing countries vision on the inter-related relevance and promise of space, energy and environment
- b. Economic development considerations as viewed from developing country
- c. Human capital development considerations as viewed from developing country

These aspects can be discussed in view of two extreme factors: Policy impact on global climate, which is illustrated in Figure 8, and Human Development Index (HDI), Figure 15. HDI measures overall progress in a country in achieving human development,

The utilization of terrestrial solar energy has increased significantly in industrialized countries, and to a lesser extent in many developing countries, due to economic competitiveness and local industrial support. In this conjunction, analogous to the use of domestic communication satellite without waiting for well established terrestrial microwave communication network (which has proved to be very gratifying judged from a multitude of objectives, which was the case of Indonesia), the utilization of Solar Power Satellite services without waiting for well established terrestrial solar power may prove to be appropriate. Therefore, the idea suggested by Landis (1990) to utilize space solar as a "plug and play" replacement for ground solar arrays could be attractive for developing countries. Table 2 shows the advantages of using space solar as a "plug and play" replacement for ground solar arrays. From the point of view of a utility customer, a rectenna to receive space-solar power looks just like a ground solar array-- both of them take energy beamed from outer space (in the form of light for solar power, in the form of microwaves for the space solar power) and turn it into DC electricity.

Such exercise may be beneficial in establishing energy policy which has multiple goals, which addresses economic, national security, as well as environmental issues, as illustrated below, as adapted from Supple & Danielson (2006).



Economic

- limit consumer costs of energy
- limit costs & economic vulnerabilities from imported oil
- help provide energy basis for economic growth elsewhere
- reliably meet fuel & electricity needs of a growing economy

Homeland And National Security

- minimize dangers of conflict over oil & gas resources
- avoid energy blunders that perpetuate or create deprivation

Environmental

- improve urban and regional air quality
- limit greenhouse-gas contribution to climate-change risks
- limit impacts of energy development on fragile ecosystems

A wide variation of different energy production technologies was examined and Monte Carlo analyses were generated to take into account the data variability in the rapidly changing energy field (Mankins, 2008). Initial model results indicate that the shortage of fossil fuels can be overcome within a reasonable time period.

<p>A Natural Synergy: Ground-based solar as the precursor to space solar power</p> <p><i>Ground solar precedes space solar</i></p> <div><div>1. Ground solar economically feasible in good locations as soon as solar array price reaches SSP targets</div><div>2. Does not need to wait for development of the beaming technology or low-cost space transportation</div></div> <p><i>Upgrade ground-solar facilities to space solar</i></p> <div><div>1. SPS receiver looks and operates just like a solar array</div><div>A. Both receive power from space and converts it to electricity</div><div>B. Utilities see "plug and play" replacement that operates at night</div><div>2. SPS rectennas can be put at the same location as solar facility</div><div><div>• rectenna sites bought and paid for by ground solar</div><div>• energy distribution infrastructure already in place</div><div>• rectennas can be made transparent to sunlight</div><div>• or advanced solar array can be designed with integral rectenna built in</div></div></div> <p><i>Approach:</i></p> <div><div>• Design a SPS to capitalize on the synergy between ground solar and space solar [4,14].</div><div>• Such a satellite concept must use ground-based solar when it is economical to do so, but fill in for ground-based solar when ground based solar is inadequate.</div></div>
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Table 2. A Natural Synergy: Ground-based solar as the precursor to space solar power (Landis, 1990)

The SPS system is characterized by the frequency of the power beam, its overall efficiency and mass. It is driven by user needs and SPS location relative to the user. Several wavelengths can be considered for laser transmission systems. The visible and near infrared spectrum, allowing the use of photovoltaic cells as receiver surface, has been retained. Different frequencies can be used for the RF transmission system. The 35 GHz frequency has been considered as a good compromise between transmission efficiency and component performances.

## 5. Space power system: review of several architecture and technologies

Through advances in space science, technology and exploration, mankind has also been acquiring awareness of the presence of our sun as an inexhaustible source of energy, as depicted in Figure 16, which may then offer a host of additional solutions to meet the need of world expanding population and increasing demand for energy.

Since its introduction by Dr. Peter Glaser (Glaser, 1968a; Glaser, 1968b; Ledbetter, 2008) for which it was granted US patent in 1973 (Glaser, 1973), Solar Power Satellite as a means to supply inexhaustible power from the Sun for use on the Earth and/ or other space objects of human interest has gained much attention and endeavor, in particular with the global concern on environmental issues and sustainable development. Energy from the Sun is inexhaustible, as clearly underscored in Figure 16.

Solar Power Satellite then reflects mankind vision and scientific and technological progress on the problem solving end but also global concern for energy and environmental sustainability on the problem end. Even it has been strategically recognized that Solar power from space can help keep the peace on Earth (Mankins, 2008), which should be intimately related to mankind observed certainty on human population “Exponential growth”, and which has led to a multitude of practical consequences.

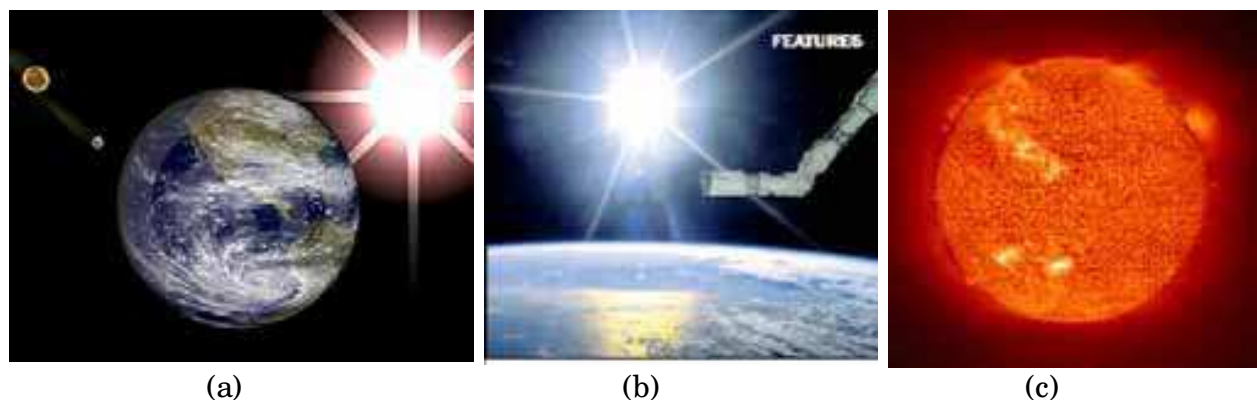


Fig. 16. Impressive views of the Sun: (a) The Sun, the Earth and the Moon, (b) The Sun as seen from Space Shuttle Endeavour (c) and the Sun observed surface, all of which emphasize its tremendous potential as an inexhaustible source of energy ([http:// www.google. com. my/ imglanding](http://www.google.com.my/imglanding)).

Therefore, Solar Power Satellite has become a universal human interest regardless of human earth-based and anthropogenically defined differentiations: geographical origin, color, creed, wealth, intelligence and the like. A space solar power generation system can be designed to work in synergy with ground solar power. In fact, progress in space-based photovoltaic technology has been the driver for their earth-based utilization, as well as making them more economical. Hence in a broader sense, terrestrial-based and extra-terrestrial based Solar Power should provide a feasible answer for meeting mankind energy needs. The principle and operation of Solar Power Satellites is illustrated and summarized in Figure 17 (Harkins et al, 2008).

Electricity has been produced and used in space from sunlight by hundreds of satellites in operation today. One may say that technological progress in land-based Photo-voltaic Electricity Generator to an affordable techno-economic state is due to a large extent by progress in space-based Photo-Voltaic Cells. As introduced by Dr. Peter Glaser in 1968, the

concept of a solar power satellite system with square miles of solar collectors in high geosynchronous orbit is to collect and convert the sun's energy into a microwave beam to transmit energy to large receiving antennas (rectennas) on earth.

In 1999 NASA formed SERT, the Space Solar Power Exploratory Research and Technology program to perform design studies and evaluate feasibility of Solar Power Satellites (SPS). The concept has now evolved into a broader one: Space-Based Solar Power (SSP), which incorporates the concept and design of Sun Tower, as illustrated in Figure 18.

The general benefits of Space-Based Solar Power is that there is no pollution after construction, no GHG during power generation, the source of energy is free and it has a large amount of energy potential.

The advantage of placing the Solar Power Generator in space rather than on the surface of the Earth are, among others: less atmosphere for sunlight to penetrate for more power per unit area, any location on the Earth can receive power, the Satellite can provide power up to 96% of the time, the solar panels do not take up land on Earth while there are figuratively speaking infinite space is available in space and the initiative will promote growth of space, solar, and power transmission technology. On the other hand, there are significant problems to overcome with SSP. These are, among others, very expensive initial cost, power transmission by microwave and/ or lasers still has to be developed to counter their possible harmful effects, cosmic rays can deteriorate panels, very large receiving antennas on earth may be required, maintenance problems and to avoid solar winds displace it off course would need a complex propulsion system.

Technological options considerations in view of overall strength and weakness / gains and losses. Several studies have been carried out for various Solar Power Satellites, including those located in Low Earth Orbits. These are the LEO and MEO SPS, Geostationary SPS and Supersynchronous SPS.

Some visionary concepts have been introduced, such as the Solar Power Satellite / Space-Based Solar Power to be located at an orbit around the Lagrange point L2, illustrated in Figure 19. Recent study on Innovative Power Architectures has been carried out by Landis

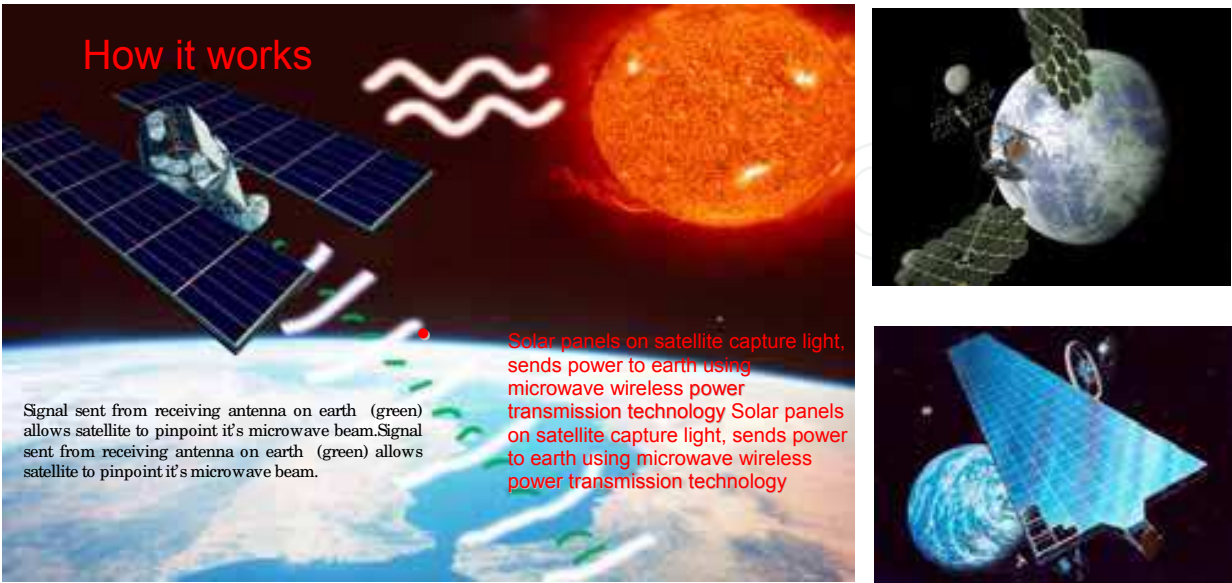


Fig. 17. The principle and operation of Solar Power Satellites (Harkins et al, 2008)



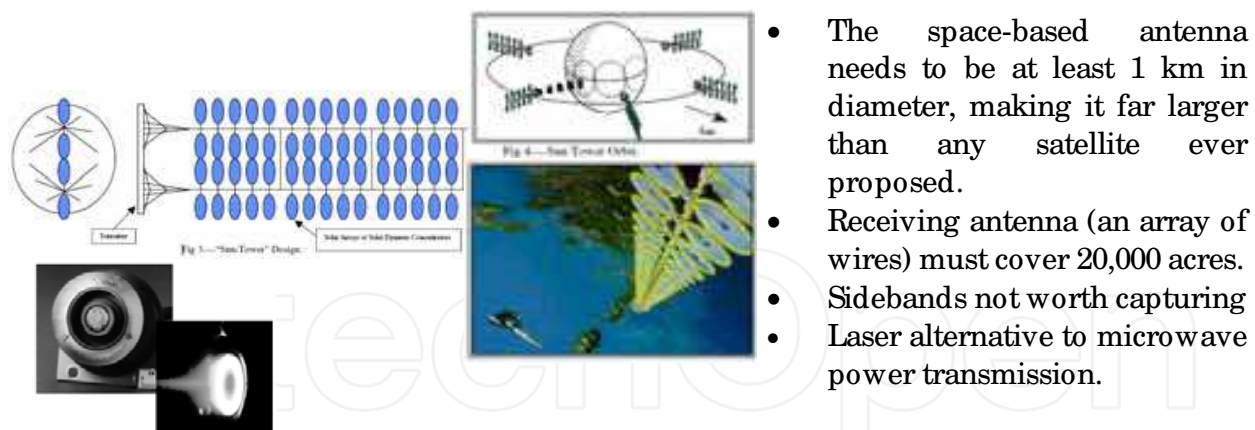


Fig. 18. Design Ideas of Sun Tower (Harkins et al, 2008)

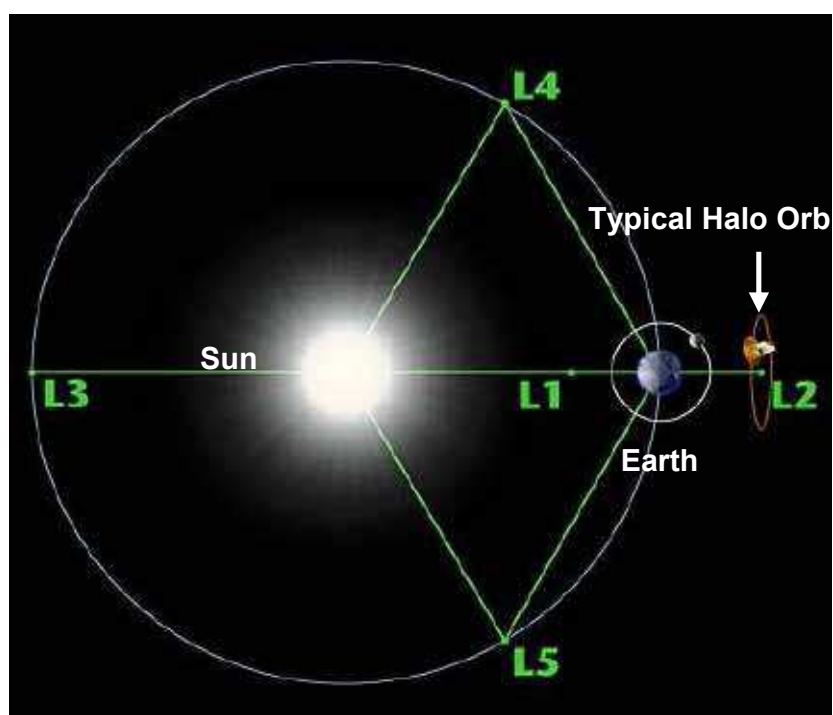


Fig. 19. Lagrange Points of the Earth-Sun system (not to scale). The Earth-sun L2 point distance is 1.5M km from Earth. Also shown an example of a typical halo orbit around L2 (2004), with some concepts of Earth-Sun L2 Design details are exhibited in Table 3. Three new concepts for solar power satellites were invented and analyzed:

- a solar power satellite in the Earth-Sun L2 point,
- a geosynchronous no-moving parts solar power satellite, and
- a non-tracking geosynchronous solar power satellite with integral phased array.

The space power system designed to be located at Earth-Sun L2 will be radically different from conventional GEO Space power concept. As illustration, individual concentrator/ PV/ solid-state-transmitter/ parabolic reflector element is exhibited in Figure 20. and An integral-array satellite has been proposed and invented and has several advantages, including an initial investment cost approximately eight times lower than the conventional design.



1	❖ Since the sun and Earth are nearly the same direction, it can feature:	
		• Integrated solar concentrator dish/ microwave transmission dish
		• Integrated solar cell/ solid state transmitters
		• <b>No rotating parts or slip-rings</b>
2	❖ Frequency: 30 GHz:	
	❖ efficiency is lower than 2.45 GHz, but much tighter beam	
		• transmitter diameter: 3 km
		• receiver diameter: 6 km
3	❖ 33,000 16.5 meter integrated PV concentrator/ transmitter elements	
		• Concentrator PV efficiency 35%
4	❖ Larger distance from the sun means less solar radiation intensity compared to geosynchronous orbits, MEO and LEO	

Table 3. Earth-Sun L2 Design details (Landis, 2004)

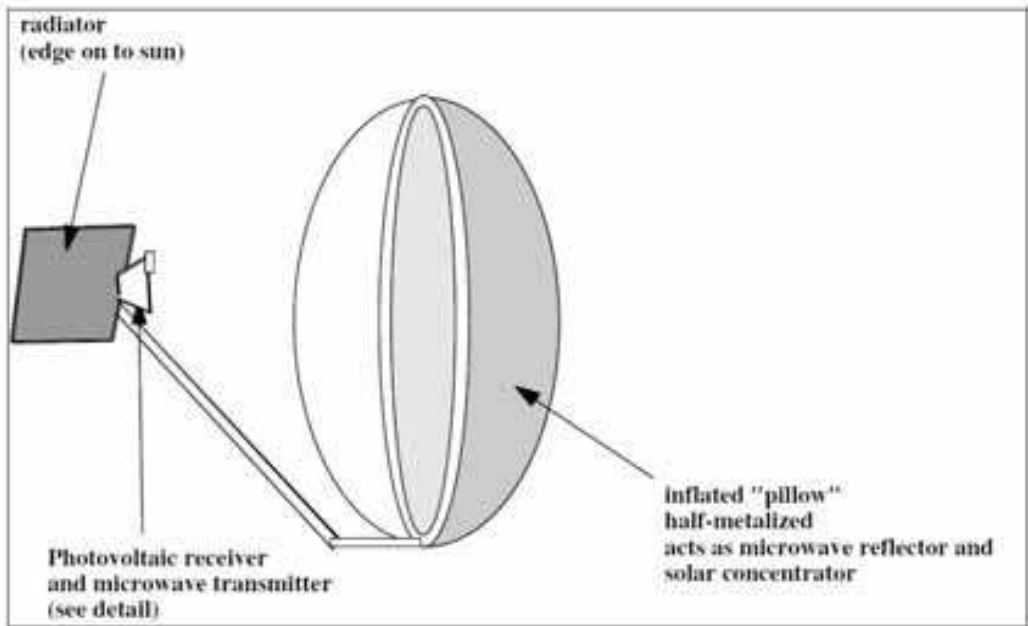


Fig. 20. Individual concentrator/ PV/ solid-state-transmitter/ parabolic reflector element (Landis, 2004)

The following criteria, among others, will have to be used for a credible analysis of solar power satellite economic benefits and rate of return: Satellite power generation should fit electrical demand profile, Satellite power generation should generate power at the maximum selling price, and actual data on electrical demand and price should be used in its concept, design, implementation and operation

A novel scheme to implement Space Solar Power (SSP) to generate abundant, clean, and steady electric power “twenty-four hours a day every in a year” (or “24/ 365”) in Space

from solar energy, and conveyed down to Earth has been proposed by Komerath [26]. To overcome the massive cost to build large collector-converter satellites in Geosynchronous Earth Orbit (GEO) or beyond, the Space Power Grid (SPG) approach has been proposed by Komerath [27-28] breaks through this problem by showing an evolutionary, scalable approach to bringing about full SSP within 25 to 30 years from a project start today, with a viable path for private enterprise, and minimal need for taxpayer investment. This paper deals with the interplay of technology, economics, global relations and national public policy involved in making this concept come to fruition.

Given their high retail costs and unsteady nature, terrestrial solar-electric and wind power sources still remain secondary and subsidized. The key feature of Komerath's concept is to use the potential of the space-based infrastructure to boost terrestrial "green" energy production and thus benefit from the concerns about global warming and energy shortage.

In this first paper on the concept, the scope of the project, possible benefits and the obstacles to success are considered. It is seen that the inefficiency of conversion to and from microwave poses the largest obstacle, and prevents favorable comparison with terrestrial high-voltage transmission lines. However, competitive revenue generation can come from the nonlinearity of cost with demand at various places on earth. Point delivery to small portable, mobile receivers during times of emergencies is necessary. The benefits to 'green' energy generation make the concept attractive for public support as a strategic asset. This also sets a market context for concepts to convert solar power directly to beamed energy – a prospect with many applications. The following description is taken from Komerath (2007), with stages illustrated in Figures 21 and 22.

Briefly, the SPG approach is a 3-phase process to bring about full SSP. In Phase 1, no power is generated in Space. Instead, Space is used as the avenue to exchange power generated by renewable-energy plants located around the world. This is a breakthrough because renewable power plants today are unable to compete with local alternatives such as nuclear and fossil thermal power, due to their inherently unsteady, fluctuating nature. The sun only shines during the day, and not very well in cloudy weather, on Earth's surface. Wind power fluctuates wildly. The ideal locations for wind, solar and tidal/ wave power plants are typically far from their customers, hence demanding the installation of new high voltage

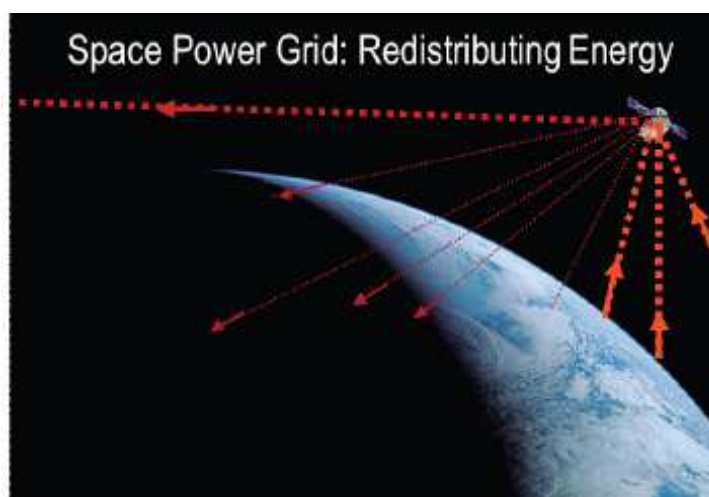


Fig. 21. Space Power Grid satellite receiving and redistributing beamed power (Komerath, 2007).

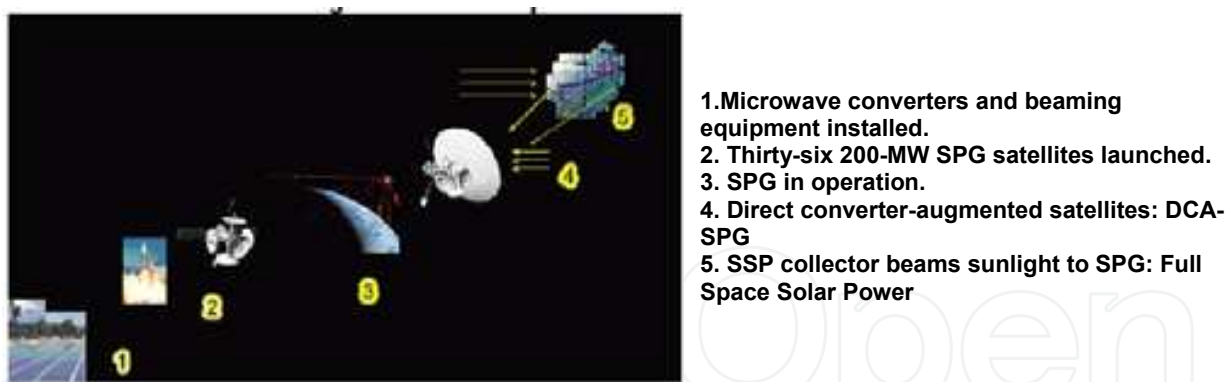


Fig. 22. Evolutionary path to full Space Solar Power (Komerath, 2007).

power grids in an age when land rights and environmental impact policies impose high costs on such infrastructure. In addition, to qualify for “base load” status, renewable power plants must install auxiliary power generators amounting to essentially 100% of their standard capacity, in order to be able to guarantee a steady level of output, and the ability to respond to demand surges. Such auxiliary generators are usually fossil burners, and relatively inefficient.

Once the Phase 1 SPG is in place and essentially self-sustaining by synergy with the renewable power industry, the satellites are gradually replaced, as each reaches about 17 years of age, with new, larger Phase 2 satellites that incorporate collector-converters for solar power, using the technological advances of the 23 years since project start. These put a small amount of space-generated power into the already-functioning grid, at a much lower generation cost.

Phase 3 consists of launching several very large, but ultra-light collector/ reflector satellites to high orbits. These will contain no converters (thereby reducing their mass by 2 orders of magnitude) but simply collect and focus sunlight on to the Phase 2 collector-converters in L/ MEO. Phase 3 then allows for expansion until the constellation in L/ MEO reaches saturation. To double terrestrial primary energy availability, some 300 square kilometers of ultra-light reflectors will be needed, in high orbits.

Such a system involving global power exchange obviously requires international collaboration on a global scale. Komerath et al (2007) proposes a global public-private Consortium, partially based on the model for the European Space Agency, where member nations and private corporations collaborate to reduce risk, make low-interest funding available, and organize the construction of major Space infrastructure. This set up is also shown to be open a path towards resolving some of the most vexing obstacles in space resource utilization, arising from current Space Law. On a national level, moving towards the Space Power Grid approach requires some fundamental realignments that synergize the Space and Energy enterprises with the environmental/ Climate Change control movement.

The scheme proposed by Komerath is a bridging between the present economic and technological capabilities with acquired technologies and global economic capabilities to be acquired in the future, taking into account synergistic and cooperative efforts among countries.

## 6. Space power system as a unifying agent for global networking

The vision of Space Power System is a world of synergy: synergy of development efforts, bridging the Technological and Economic Gaps, Economic and Business Partnership and

unify world communities for common concern and interest. Space Power System may serve to unify global efforts in its conception, design, implementation which may include manufacturing, assembly, commissioning and operation, and so forth. These objectives are quite in line with the objectives stipulated in many UN/ UNDP studies: to promote public policies to improve people's health and education, to ensure environmental and energy sustainability, and to promote truly global partnership, in which the rich countries should not follow the paradigm of charity, but what rich countries can do to cooperate with the less developed ones to serve as partners in reaching the common goals as articulated in the UN Millennium Goals.

In particular, Energy utilized by world population manifests itself in the following forms:

*a. Primary forms:*

sunlight, biomass, hydropower, wind, ocean currents, waves, tidal energy, fossil fuels: coal, crude oil, gas, oil shale, tar sands, methane, clathrates, geothermal energy, ocean heat, fission fuels (U, Th), and fusion fuels (H<sub>2</sub>, Li, He<sup>3</sup>)

*a. Secondary forms*

gasoline (from oil), diesel and heating oil (from oil, biomass), jet fuel (from oil), electricity (from anything), hydrogen (from anything), alcohol (from any biomass), charcoal (from wood), "town gas" (from coal), and synfuels (from coal, oil shale, biomass)

The state of affairs of primary energy availability and utilization is reflected in Table 3 and Figure 9.

Associated with energy policy and vision, the following key questions could be posed (adapted from Supple et al (2006):

- Could the ever-increasing need for energy be a unifying driver for world community in synergistic and unified effort for inexhaustible source of energy but sustainable for the global environment?
- What is the current and future composition of energy utilization in industrial and developing country and will it tend towards acceptable range of energy utilization per capita? Or by source? by sector? by region?
- What scenarios have been forecast for the future? Do they or should they lead to unified and synergistic efforts rather than competitive ones?
- Could Space Power System (and Renewable Energy Initiatives) be a driving force for concerted and unified efforts by and for the world community as a whole? Could this be incorporated and envisioned by individual and mutual energy policy?

These questions need to be resolved by stakeholders in the near future. Indications for such desire and emerging paradigm could well be in the offing, as reflected as a motto in the UNDP 2003 summary report (2003, 2008): **Climate change—together we can win the battle**

In this conjunction, the following factors could be identified as pushing and pulling factors:

**Pushers:**

- Sustainability
- Investment – and economic transactions
- Government policy and triple helix mutual interaction
- The role of international and United Nations bodies, in particular the UN-COPUOS
- Lessons learned from hard facts derived from other countries' experience

**Pullers:**

- Common universal goal



- Extending hands - together we can win the battle
- New paradigm
- Cooperative efforts, synergy and networking

Analysis along such frame of thought has been carried out by Sathaye (2006). Table 4 displays indicator analysis carried out which could be used in analyzing how countries of differing economic category develop their energy policy to respond to world’s sustainability requirements.

	Buildings	Industry	Transportation
Activities	<div><div>•Population</div><div>•No.of households</div><div>•(eletrification, urban/ rural)</div><div>•M2 residential</div><div>•M2 commercial</div></div>	<div><div>•GDP</div><div>•Production:</div><div>–Economic</div><div>–Physical</div></div>	<div><div>•Personal</div><div>–Pax-km</div><div>•Freight</div><div>–Tonne-km</div></div>
Structure	<div><div>By sub-sector</div><div>Residential</div><div>commercial</div><div>By end-use</div><div>Heating/cooling</div><div>Refrigeration</div><div>Appliances</div><div>Euipment</div><div>Lighting</div><div>Cooking</div><div>Water-heating</div></div>	<div><div>By sub-sector</div><div>Iron &amp; steel</div><div>Non-ferrous</div><div>Cement</div><div>Pulp &amp; paper</div><div>Chemicals</div><div>etc</div><div>Product mix</div></div>	<div><div>•By mode</div><div>–Road</div><div>–Rail</div><div>–Air</div><div>–Watere</div><div>•By Vehicle Type</div><div>–Passenger car</div><div>–Truck</div><div>–etc</div></div>
Energy Intensity	<div><div>Technology</div><div>•Energy intensities</div><div>–Efficiency</div><div>–Usage</div><div>–Site features</div><div>–Energy carrier</div></div>	<div><div>Technology</div><div>•Energy intensities</div><div>–Efficiency</div><div>–Usage</div><div>–Energy carrier</div></div>	<div><div>Technology</div><div>•Energy intensities</div><div>–Efficiency</div><div>–Usage</div><div>–Energy carrier</div></div>

Table 4. Indicators Analysis: Drivers, Indicators Sector and Technology Structure (Sathaye, 2006)

Considerations of all these issues will lead to the need for narrowing the Technological and Economic Gaps, and in turn unify world communities for common concern and interest and the prospects and potential of Space Power System.

7. Stimulating positive attitude in developing countries:  
The microsatellite tool

It is well known that the United Nations, in particular through its Committee on Peaceful Uses of Outer Space and its Office of Outer Space Affairs, is dedicated to bring the benefits of Space Science and Technology, in particular, to the outreach of the developing nations. In his keynote address at the First Asian Conference, Abiodun (2004) recognizes that the space enterprise has become one of the fundamental foundations of industrialization, and will be much more so in the foreseeable future. Accordingly, translating the national and global policies into successful national operational programs that can take advantage of progress in space science and technology to address global and national strategic and relevant issues demands a strong political will by the government(s) concerned, as well as public

understanding and proactive attitudes. Such a political will demands commitment to human resources development at all required levels, institutional building, and far-sighted funding plan(s) - all needed to ensure the successful implementation of the national space policy. Its success would be further enhanced if the government is able to ensure the full support of all stakeholders, the decision makers at various levels and the society at large, in the different aspects of its space activities resulting in demonstrable tangible and positive impact in the lives of the people, in particular to meet those demands implicitly implied by the objective of defining the Human Development Index.

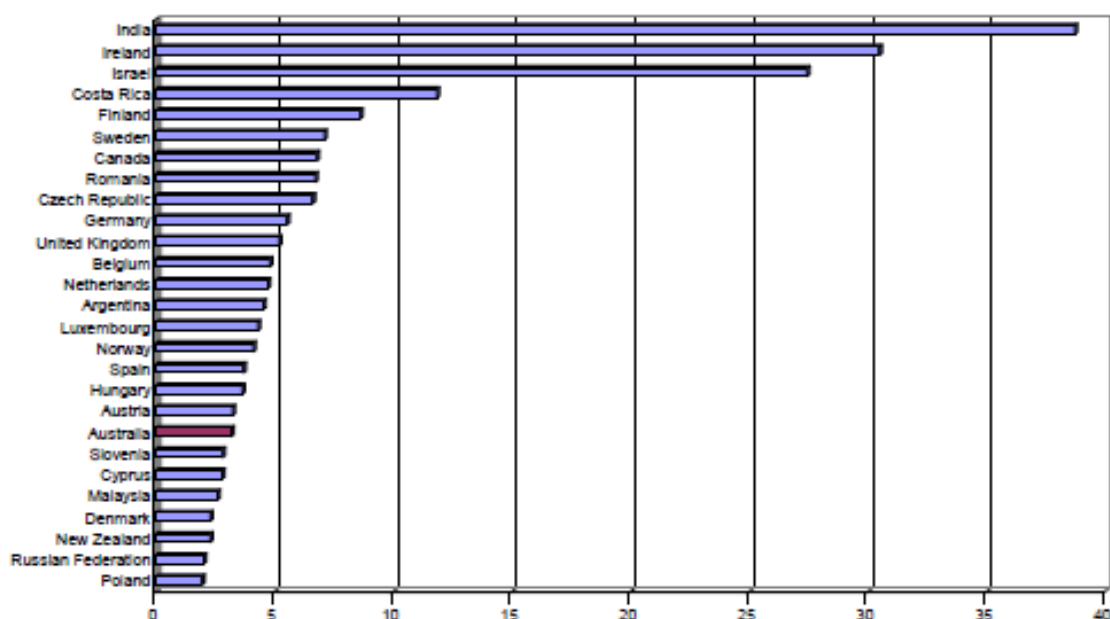


Fig. 23. Share of IT services in total services exports, 2006 (per cent)(Houghton, 2009)

The systematic implementation of the program associated with such space policies within the global spirit and environment for cooperation, has placed each country in the world a specific space-capability categorized as Space-fairing nations, Space-capable nations, Space-aspiring nations and Space-aiming nations (Abiodun, 2004).

Many developing countries have taken steps to take advantage of the advances in space science and technology for their national interest, in pace and promoting their national development goal, and even accelerating their status, using the categorization above, from space aiming to space fairing nations.

In addition to looking into the interest, technological and industrial capabilities in space science and technology for addressing national and global issues, it is an observed fact and necessity that each country to a large extent utilize and develop Information and Communication technologies (ICT) in almost every aspect of life, in particular related to those activities related to productivity and creativity. ICT is very intimately related to Space Technology in a large host of social and economic activities.

Both developed and developing countries face many environmental challenges, including climate change, improving energy efficiency and waste management, addressing air pollution, water quality and scarcity, and loss of natural habitats and biodiversity. Houghton (2009) has looked and explored how the Internet and the ICT and related research communities can help tackle environmental challenges in developing countries

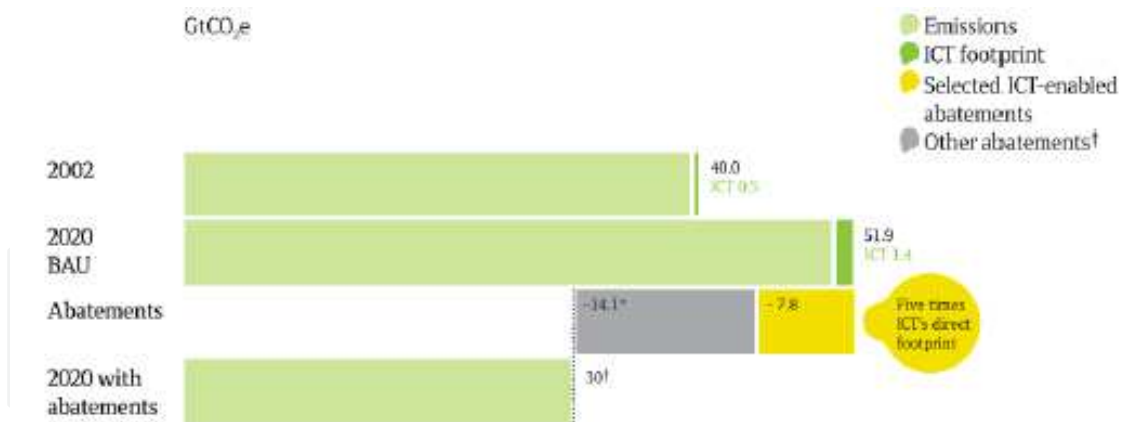


Fig. 24. ICT Impact: The global footprint and the enabling effect (Houghton, 2009).

through more environmentally sustainable models of economic development, and examines the status of current and emerging environmentally friendly technologies, equipment and applications in supporting programs aimed at addressing climate change and improving energy efficiency. Such concern could be extended to addressing energy and space technology, the present focus interest, in particular in addressing and developing positive attitude and enabling technological capabilities for establishing a synergistic global society for space endeavor of mutual concern in mega-scale. Figure 23 exhibits the share of IT services in total services exports for the year 2006 (in per cent), while Figure 24 exhibits ICT Impact and the global footprint and the enabling effect. Such information which may lead to further study relating manpower and technological capabilities for particular nation in carrying out more full-fledged space related activities addressing a broad spectrum of applications, including environmental challenges, improving energy efficiency and exploring novel energy initiatives.

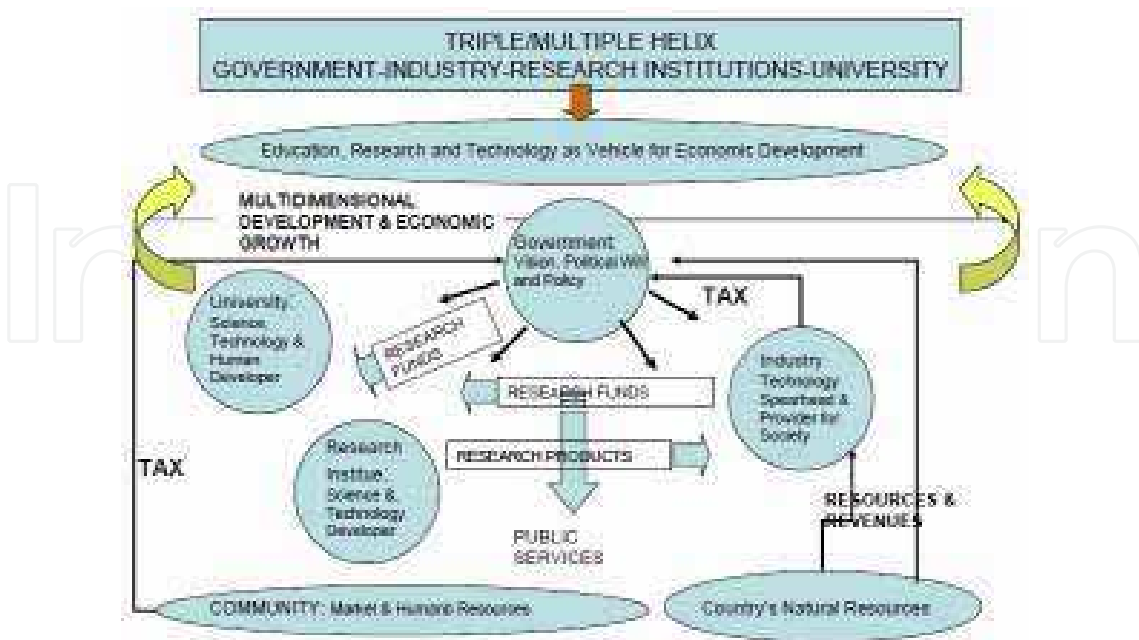


Fig. 25. Strategic (Triple-Helix) Partnership for Capacity building (Djojodihardjo, 2003; Djojodihardjo et al, 2007).

Another vehicle to in-country capacity building and establishing space-related human capital, technology and industry is by following a micro-satellite development oriented towards the needs of the country, which can be initiated at university and research institution level. Recent advances in Commercial Off-The-Shelf (COTS) sensor- and storage technology is enabling a completely new class of micro-satellites. Ground Sampling Distances (GSD) smaller than 5 m that was only possible on larger satellites, are now possible on satellites with a mass of less than 60kg due to smaller pixel sizes, refractive optics and accurate ADCS pointing and viewing control (Mostert, 2007). New paradigms for the application of remote sensing are expected to develop as a result of the possibility of having a personal remote sensing resource to complement more conventional Earth resource large satellites.

Such development are expected to lead to significant repercussions in the national decision circles which could lead to vision sharing and commitments of the four entities representing the responsible players and strategic stakeholders in “space ventures”: the government, the academic and research institutions, the private industry and the local and international organizations, which may lead to the following new socio-political paradigm (Salatun et al, 1975; Djojodihardjo et al, 2007): a. Space endeavor is essential for sustainable national development, b. Space endeavor contribute to national capacity building and establishment of infrastructure essential for industrial and knowledge-based economy.

Examples of successful national microsatellite program in non-space-fairing countries using triple-helix partnership (Figure 25) are exhibited in Figure 26.



Fig. 26. Examples of national microsatellite product: (a) LAPAN-TUBSAT as one of the TUBSAT based microsatellite development (shown here: DLR-, MAROC- and LAPAN-TUBSAT); b. TiungSAT-1 as one of the UoSAT based microsatellite development (with UoSat-1, TMSAT and TiungSAT-1 as examples); c. SUNSAT 1 from Stellenbosch University, South Africa (Mostert et al, 1998) which leads to follow on impressive microsatellites development.



SUNSAT micro satellite development demonstrated the potential of local triple-helix synergistic efforts for capacity development, which indicates also the space technology research and industrial capabilities progress in the conducive global cooperation in space-related venture. Most of these locally conceived microsatellite development served at least three purposes: establishing elements of integrated space technology capabilities locally, application of nationally oriented space application mission and establishing conducive national atmosphere with reference to strategic decision-making process and public acceptance for further space technology developments.

Space endeavor contributes to the betterment of human quality of life, economic and employment opportunities. At the conspicuous tip of the iceberg, microsatellite has projected itself as a new tool and paradigm for affordable space venture oriented towards basic human needs and quest for rapid progress. Mostert (2008) also demonstrated how satellite engineering is indeed a catalyst for development. Satellite and Space Engineering has posed a Complex Value Proposition, and successful initiatives in this direction could lead to geo-political Influence, National Pride and Strategic Capability, motivated Science and Technology Community in the country, provides added value to Government Services, stimulates Industrial Development, and provide commercially useful data/ information.

As was proved to be the case in the Indonesian Aircraft Technology program in 1976-1998, there is an intricate relationships between capacity development and development of space technology, which could be well reflected in Table 4 (adapted from Mostert, 2008).

Areas of Concern	Contribution of space technology
Shortage of Locally Available Technical Skills since many top local scientists & engineers are not locally employed and are engaged in space activities in the developed world	<ul style="list-style-type: none"><li>• High technology attracts &amp; retains high quality engineers &amp; scientists</li><li>• Attracts young people to science and maths disciplines – fulfilling careers</li><li>• Stimulates R&amp;D</li><li>• Independent space capability; contributes to world knowledge</li></ul>

Table 5. Intricate relationships between capacity development and development of space technology.

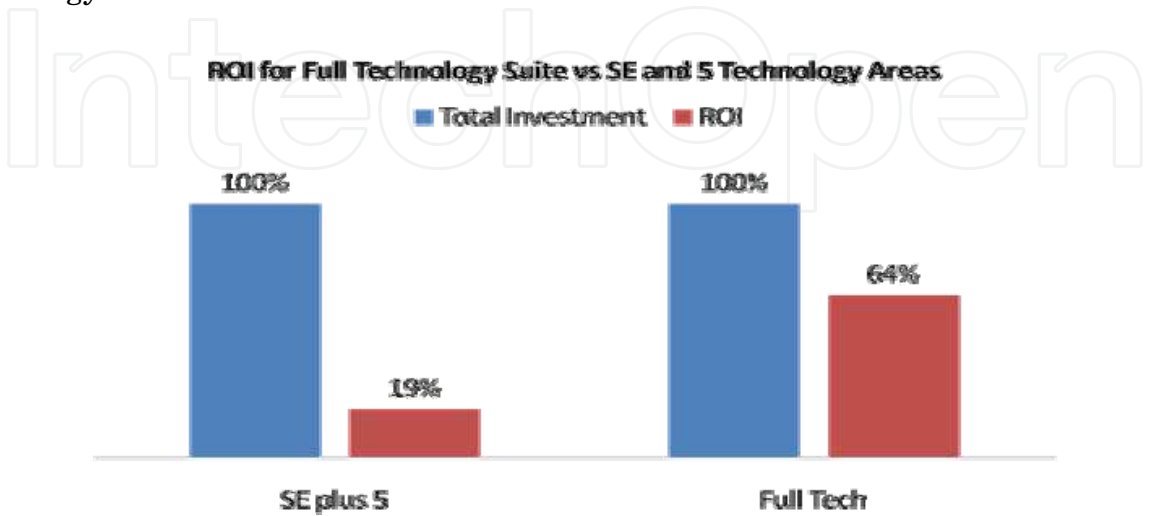


Fig. 27. Return on Investment (ROI) on Satellite Engineering Investment (from Mostert, 2008).

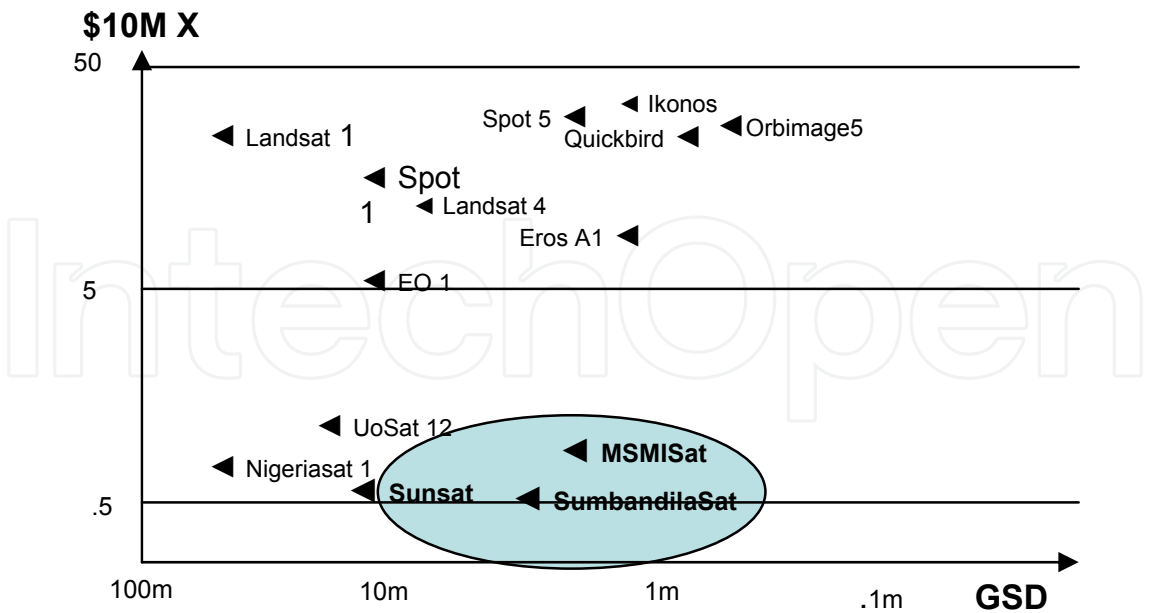


Fig. 28. Trends in Cost of Ground Sampling Distance (Mostert, 2008)

Desired triple-helix partnership (Etzkowitz, 2000) as schematically depicted in Figure 24 should be established in such space venture for effective efforts and capacity building with utmost national benefits. Micro-satellite programs established in Indonesia and Malaysia (Djojodihardjo et al, 2007; Triharjanto et al, 2007, Hardhienata et al, 2007, Md.Said et al, 2008) are a small example of such partnership for space technology development, implementing a combination of paradigms, and taking advantage of the technological progress and global cooperation atmosphere.

With such structure, synergy between private venture and government leadership could still be strengthened. It is heartening that since 2000, effort to develop microsatellite has gained new momentum by the support of key government officials. Such vision and atmosphere is required since budget for realizing developing country program space activities are allocated through an intricate mix of triple helix setting in developing country Cooperation between space communities, involving government space agency and strategic domestic industry with other regional countries as well as space fairing countries has developed favorably in the past decades. Of interest is the Return of Investment of national space venture. An encouraging example is elaborated by Mostert (2008), which is summarized in Figure 26. The viability of such efforts is also illustrated in Figure 27.

**8. Universal SPS program initiatives – arms reaching but novel paradigm – establish productive and resourceful partners-in-arms by expanding opportunities at creative circles**

Space Solar Power initiatives which give promise to the world energy and environment solution in not too distant futures could best be addressed by global cooperation and global networking, thus establishing less technologically (and thus industrially) endowed nations as partners in synergistic space ventures. The challenge for space program initiatives for non-space fairing developing countries, can be addressed in more positive partnerships

capitalizing on international cooperation paradigms now only promoted by the UN system. Decision makers and all stake holders in developing countries are also encouraged to develop National Development and Capacity Building Vision and National Program and sustainable development solutions capitalizing on enhancing the quality and capacity of their human capital through Coordinated Efforts and Broad Based Strategic Partnerships, thus aiming for more equitable distribution of Human Development Indices around the world and within each country.

The development of microsatellite in some developing countries, exemplified by Malaysia and Indonesia reflects the following situation.

1. Microsatellite development has to bear direct relevance to the national development objectives, and can draw strategic synergistic efforts and partnerships among stakeholders in the country, which may involve university community
2. Technology providers are sought from outside the country which appeals both form affordability and promise for in-country technology and human resources development.
3. New paradigm for space technology development that offer time-cost-effective, affordable and strategic participation and role for local human resources and local technology development / local space technology infrastructure are available and progressing.
4. Microsatellite development scheme undertaken should be able to convince national decision makers of its orientation towards basic human needs and overall effectiveness and success in the quest for rapid progress.

It is encouraging that the relevance of space related initiatives to down-to-earth basic human needs to a larger extend has been shared by stakeholders, by significant breakthrough in overcoming social, cultural and technological handicaps. The emergence and growing development of strategic technologies, cooperative spirit, globalization of information and vision for global techno-economic networking is considered to be responsible to the favorable paradigm shift that has enabled and conducive to the translation of Space Imperative for National Development and Capacity Building through Vision, Coordinated Efforts and Strategic Partnerships in relevant, mission-oriented and affordable space initiatives of these countries.

Universities can play significant role in the national and regional efforts to master new sciences and technologies which require high expertise in the relevant basic sciences and along with national research institutions in the region can form indigenous broad-based scientific and technological infrastructure conducive for effective development of advanced technologies.

Progressive regional initiatives that within conceivable future will contribute to the development of regional cooperative space program, close networking and coordination of research institutions, joint governmental funding, etc, as has been carried out in many joint bilateral as well as ASEAN programs, should be enhanced. To this end, efforts should be carried out by relevant stakeholders to establish political will and vision for such initiatives. Effective regional or geographical cooperation as carried out and developed by the European Space Agency that has now carried out significant, strategic and far-sighted space initiatives could serve as an encouraging example. Regional or Asian cooperative initiative which capitalize on Remote Sensing Space System dedicated for tropical equatorial

countries as stipulated in [19] and have been followed by national initiatives in the region should be a logical and feasible step. The Asian region, in particular the ASEAN region, is poised to evolve added regional approach in the not too distant future in the ever expanding space frontier, which also implies ever expanding opportunities, including progressive participation in a global program for Space Solar Power.

## 9. Conclusion

The SPS system appears as a promising solution for meeting future energy (electrical) needs of mankind on earth, notwithstanding other needs associated with mankind venture on space objects. A comprehensive review and analysis have been carried out on global participation on solar power satellite initiatives. The following conclusions can be made:

1. Space Power System initiatives could be extended to the developing world in progressive fashion, to address global urgent need for sustainable energy and equitable development.
2. Space Power System Global initiative has the potential to reduce the Technological and Economic Gaps, and in turn unify world communities for common concern and interest.
3. Space programs already carried out in many developing countries, including microsatellite development, will serve as a vehicle and policy stimulus for global partnership in space projects of interest to global community.
4. A universal SPS Program Initiatives could be envisioned with the assistance of international organization, in particular the UN COPUOS and its Office of the Outer Space Affairs.
5. Comparative analysis of several architecture and technologies could be carried out to look into feasible means of progressive participation of developing countries. Simulation by microsatellite-concept could be of interest.
6. A wide range of technological options for SPS configurations are available and could be given due considerations in view of overall strength and weakness.

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