Harnessing the Sun
A Permanent Solution to Global Crisis

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About 200 years has passed since the start of the industrial revolution, and humanity has now arrived at a major crisis related to its energy supply. In recent years there has been extensive debate and media coverage about clean energy, sustainable development, and global climate change, but what has largely been missing in the mainstream media is genuine knowledge about the point of view of scientists and engineers concerning viable and permanent solutions to many of these challenges. This chapter will elaborate on the prospects of mankind's technological capability focusing specifically on taming the energy of our Sun, especially on the great potential of harvesting solar energy directly from space before it enters our atmosphere (or SBSP, space based solar power), and explore the imperative to invest in the development of this critical human endeavor not only to resolve our crisis in energy supply, but also to address major crises including anthropogenic (human-caused) climate change, war, terrorism and sustainable and peaceful human development on this planet and beyond.

As you read this chapter, please keep in mind that I approach these questions from my professional viewpoint as an expert in risk management. Assessing risks and devising methods to address them has been my professional focus for more than two decades.

I. Why Fossil Based World Civilization must be Replaced with a Solar Civilization

The debate about clean energy, fossil fuel energy, and the combustion economy inevitably raises the issue of greenhouse gas (GHG) emissions and their adverse impact on the Earth's climate. Most scientists hope that the climate debate is over, as they believe that the scientific evidence of anthropogenic global warming is overwhelming.

The potential negative consequences of anthropogenic climate changing are simply too significant to ignore – after all, what could be more significant (to us) than the extinction of our species? There is simply no reason for us to carry on with 'business as usual' and to continue marching down the path of a combustion-based world economy when it is no longer necessary for us to do so.

The historical and political view leads us to the same conclusion. Humanity's track record in regards to competition for local fossil fuel-based resources has not been very encouraging, inasmuch as geopolitical conflict arising from the ownership and operation of oil fields has had a profoundly destabilizing impact on world politics for more than a century. As we enter the era of so-called 'peak oil,' during which demand for energy will continue to increase while the supply of oil will progressively decrease, the search for alternatives will accelerate even while disputes over the remaining supplies of oil will also likely increase in severity. A reliable and abundant alternative to oil is highly desirable in this scenario as well.

An additional benefit that we may anticipate from going into space to harvest energy is the great potential to fundamentally change our way of thinking about Earth. Professor Frank White calls this the *Overview Effect*, and notes in his writings that it occurs when astronauts see the blue Earth from the depths of space. They report that the sight of Earth floating in the blackness of space fundamentally alters their perspective on humanity. If, through the pursuit and development of space based solar power, we can bring many more people to this profound realization of the oneness of all humans, then the positive consequences could be as profound as the political and economic ones.

II. Solar Power from a Historic Perspective of Human Evolution

Solar Energy, including both terrestrial-based and space-based solar power, is starting to be viewed by many scientists and visionaries as one of the most promising and feasible ways to completely overcome human dependence on fossil fuels.

At the 2007 Foundation For the Future International Energy Conference in Seattle, my presentation took a look back at energy use throughout human history, and here I would also like to offer a brief summary of the stages humanity has passed through in our quest for energy. In order to understand and fully appreciate the profound idea of harnessing solar energy, there are no better lessons to help us foresee what may be ahead than those we can learn by looking back at the path of our ancestors.

There have been three fundamental eras of energy supply and consumption in human prehistory and history. After the first fire was lit by mankind, humanity's energy economy was based on plants. We burned firewood, tree branches and the remains of crops from agricultural harvests. Around year 1600 we found coal, and entered into the 2nd era of energy uses with the first fossil-based energy supplies. The Romans used flaming oil containers to destroy the Saracen fleet in 670, and, in the same century, the Japanese were digging wells with picks and shovels in search of oil, to a depth approaching 900 feet. By 1100, the Chinese had reached depths of more than 3000 feet searching for energy, all many centuries before the West sunk its first commercial oil well in 1859 in Titusville, Pennsylvania. Demand for kerosene led to the commercial use of oil and gas, and the development of the internal combustion engine became the basis of the entire modern industrial economy. Oil and gas energy sources; being fossil-based, still belong to the 2nd era. Near the middle of the 20th century, propelled by atomic energy, came the dawn of the Techno-era of energy use and production.

As the world demand for energy continues to soar, we are running into profound energy and environmental crises, and there is great uncertainty about the world's future energy supply. If you plot the energy demand through the history of human civilization on a terawatt scale, you will see a huge increase beginning barely a hundred years ago. With oil supplies dwindling and coal highly polluting, it's evident to nearly everyone that we must now embark the next era of energy supply, and it's also clear that we can do this by rediscovering the mighty energy resource of our Sun. The era of taming solar energy through technology breakthroughs may well trigger the next giant leap of our civilization, elevating our species by transforming our combustion world economy into a forever sustainable Solar-electric world economy.

III. Solar Energy: The Ultimate Answer to Anthropogenic Climate Change

The evidence of global warming is increasing and increasingly alarming. As a scientist at NASA's Goddard Space Flight Center, for many years, I received first-hand scientific information relating to global warming issues, especially on the latest of ice cap melting dynamics or changes on both poles of our planet. Whether this is due to human interference or cosmic cycling of our solar system dynamics, two basic facts are crystal clear:

1. There is overwhelming scientific evidence showing direct correlation between the level of CO2 concentration in the Earth's atmosphere and historical fluctuation of global climate and temperature.

2. The overwhelming majority of the world's scientific community have reached consensus that catastrophic global climate change is highly likely if humans continue to ignore this problem, and continue dumping huge quantities of greenhouse gases into the atmosphere.

In my view as a risk assessment expert, from a probabilistic perspective it is orders of magnitude *more* risky for humans to do nothing to curb our fossil-based energy needs, and significantly less risky to shift our primary sources of energy supply. This underlying reason is simply that the risks of a catastrophic anthropogenic climate change could lead to the extinction of the human species.

From this perspective it is absurd to hear the argument made by some of our politicians, that humans should not worry about 'global warming' because if we restrict the burning of fossil energies there will be economic consequences. Those who make such arguments are clearly ignorant of the concepts of risk, uncertainty, and risk mitigation.

What we are really talking about is choosing between risks. Every human activity involves risk taking, and in matters of this scope we cannot avoid risk entirely. We must therefore choose between them, making science-based policy trade-offs, and hopefully selecting wisely.

Therefore, there must be a risk-based, probabilistic analysis underlying national and international policies that address all global warming and energy issues. As the measure of Risk is a product of event Likelihood and Consequence, I believe the choice is clear. When the consequence or risk of a potential human extinction due to catastrophic climate change is compared with the potential consequence or risk of loss of jobs or slowing down the economy due to restriction of fossil-based energy consumption, we must choose for the survival of humanity and accept the much smaller risk of negative economic consequences, which, in any case, are most likely short term and limited in scope. Furthermore, by making a paradigm shift of the world's energy supply through extensive

R&D and technology innovation on renewable energy production we may well create countless new jobs, and end up triggering enormous economic development and a new industrial revolution beyond what we have ever seen.

IV. Solar Power: the Best Renewable Energy Source for the Future

It took about 3.5 billion years of rare geologic events to sequester hydrocarbons and build up fossil deposits beneath Earth's surface. Humanity is now at an energy crossroads, and we have two distinctive and fundamental directions to choose between:

1. Either we look for energy based on cosmic-based, open, and unlimited original resources, which means everything that comes from the stars, including our Sun, or,

2. We follow the direction of using Earth-based, local, and confined secondary energy resources.

Using direct solar energy could be, in theory, about 1,200,000,000,000 times more efficient than using the secondary solar energy captured in oil, gas and coal, and going forward we can anticipate that humans will learn to bypass the solar-to-fossil inefficiency.

Some will argue that nuclear power offers an effective alternative, but of course there are significant risks with this as well.

In any case, there can be little doubt that the best place for a nuclear fusion reactor (which is what our Sun is) is about 149 million km away from Earth, where it operates on our behalf safely and free of charge. The Sun's energy takes only 8 minutes to arrive here, leaves no radioactive waste, and is terrorist proof. It puts out about 3.8E11 terawatts of energy per hour, and Earth receives about 174,000 terawatt each second. In fact, in every hour the Earth's surface receives more solar power than all humans use in a year.

V. Solar Energy Compared With Other Sources

Projected world energy use by fuel type in the next 30 years suggests that we are going to have an explosive increase in demand. According to recent U.S. DOE data, renewable energies including biomass, hydropower, geothermal, wind, solar, and others totaled about 6 percent of total energy production in the U.S., while nonrenewable fossil energies made up the rest.

To identify the best energy options for the future, we have to first understand our energy requirements and decide how to evaluate and compare the alternatives. Let us postulate that energy should be affordable for all human beings, inexhaustible in terms of the livable planetary lifetime, cause no harm to the environment of humans, and be easily available and evenly accessible to everyone around the globe. It has to be distributed in usable, flexible, decentralized, scalable forms, and there must be low risk of potential misuse for mass destruction. Energy has to help retain and improve human values and global collaborations, must help expand human presence and survival within our solar system, and has to be consistent in elevating human culture, quality of life, and civilization.

So what are our options? All fossil fuels are harmful to Earth's biosphere, while nuclear power poses major concerns concerning waste deposit and the risks of proliferation and misuse. Hydro power is limited and unstable, and liquid biomass competes for land with food production. (You may have heard that in Mexico tortilla prices have gone up about 60 percent in the last two years.) Hydrogen (fuel cell) carries high storage and transportation risks, and it is not a source of energy but rather a form of energy storage. Wind, geothermal, and tidal sources are intermittent, unstable, and presently costly. Nuclear fusion has been studied using government funds for more than half a century, and seems unlikely to be achieved any time soon; in any case it has high potential for misuse.

When you carefully compare and evaluate each available option of nonrenewable and renewable energy sources against these requirements and criteria, it is evident that solar power is the most viable source of renewable energy for sustainable human development into the future.

VI. The Prospect of Solar Energy Development from Space

It would be reasonable to ask, Why solar energy from space instead of on Earth? Is it a technologically feasible or commercially viable human endeavor? My answer is positively and absolutely: 'Yes.'

One of the major challenges of terrestrial solar power is the high cost of photovoltaic (PV) cells, and the inefficiency of converting the Sun light energy into electricity. Depending on the location on Earth, there is roughly 7 to 20 times less energy per square meter on Earth than in space. Based on existing solar technology and PV materials, it would require a field of solar panels the size of the state of Vermont to provide U.S. electricity needs. Unless there are significant breakthroughs in the conversion efficiency of PV cells, to satisfy world demand would require about one percent of the land that is currently used for agriculture worldwide.

Space Based Solar Power has been systematically studied since the middle 1970s, and long before that, Nikola Tesla, the pioneer of modern electromagnetism and inventor of wireless communication dreamed of finding the means to broadcast electrical power without wires. Early in the 20th century Tesla addressed the American Institute of Electrical Engineers to explain his attempts to demonstrate long-distance wireless power transmission over the surface of the Earth. He said, *"Throughout space there is energy. If static, then our hopes are in vain; if kinetic – and this we know it is for certain – then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature."*

The SBSP concept in its present form was originated in 1968 when Dr. Peter Glaser first developed the idea of SBSP as a source for continuous power generation for the Earth's future energy needs. Glaser's basic idea was that satellites in geosynchronous orbit would collect energy from the Sun, the energy would be converted to radio waves and beamed to receiving sites on the ground, and the ground antenna would then reconvert the radio waves to electricity.

In our current, more refined version of the SBSP system, solar energy is collected in space by satellites in a geostationary orbit. It is then converted to direct current by solar cells, which power microwave generators in the gigahertz frequency range. The generators feed a highly directive satellite-borne antenna, which beams the energy to the Earth. On the ground, a rectifying antenna (rectenna) converts the microwave energy to direct current, which, after suitable processing, is fed into the terrestrial power grid. A typical Solar Power Satellite unit, with a solar panel area of about 10 square km, a transmitting antenna of about 2 km in diameter, and a rectenna about 4 km in diameter is expected to yield about 1 GW of electric power, the equivalent of a large scale nuclear power station.

VII. The Technological and Commercial Viability of Space Solar Power

Is SSP a viable option? Among the key technologies involved in SBSP are microwave generation and transmission techniques, wave propagation, antennas, measurement, beam control and calibration techniques. Key issues include potential effects on humans and the potential interference with communications, remote sensing, and radio-astronomy observations.

Current analysis suggests that it can be a viable energy option for base-load electricity generation to power the needs of our future. Further, SBSP satisfies every major criterion of a viable energy option listed above, with the exception of the cost based on current space launch and propulsion technology: space transportation cost is one of the major hurtles for SBSP, as solar power satellites will only become economically feasible if there is low cost space transportation.

To overcome the high launch cost, the development of a Reusable Launch Vehicle (RLV) and autonomous robotic technology for in-orbit assembly of large solar structures is needed, along with systems to assure safety and reliability for these large and complex orbital structures. Nevertheless, there are no breakthrough technologies that need to be invented, nor any theoretical obstacles that need to be overcome for an SBSP project to be carried out.

The U.S. government provided about $20M to study SSP in the late 1970s, but then abandoned this project with almost nothing additional spent up to the present day. The excellent book *Sun Power: The Global Solution for the Coming Energy Crisis* by my friend, Ralph Nansen, offers a detailed history on the subject. Ralph was the Boeing manager of the DOE-NASA funded SBSP proof of concept study, and published *Sun Power* in 1995, accurately predicting our current situation. Dr. Peter Glaser's book *Solar Power Satellites: A Space Energy System for Earth* also offers superb reading on this topic.

We can solve the cost issue to make SBSP a commercially viable energy option through human creativity and innovation on both technological and economic fronts. Besides the continuing quest for a low-cost reusable launch vehicle (RLV), there are other possibilities for ingenious commercial or business models that could overcome the SBSP cost issues.

One model now being pursued by the Space Island Group, an American private aerospace entrepreneurial company based in California, is to use modified Space Shuttles by turning the huge volumes of the external tanks into commercial assets for space-based research and orbital tourism. A huge demand in space tourism would bring about a higher launch rate, and that will in turn drive down the space transportation cost, thereby helping to make SBSP more viable. If we compare this possibility with the commercial aviation industry, who would have thought that ordinary people could afford air travel just several decades after the Wright Brothers had succeeded in their first aircraft test?

In addition, we do not need to restrict our vision to choosing between terrestrial solar and SBSP. In fact, the dream of SBSP can be realized much sooner through the use of terrestrial solar energy and engaging in the pertinent R&D on a grand global scale. The advancement of major terrestrial solar technologies including the nano-particle based ultra high efficiency and low weight, low cost PV cells, along with super capacity and low cost energy storage systems will also support affordable terrestrial and SBSP development, and many companies are now engaged in this work. With rapid advances in nanotech-based PV solar cell material, now reaching over 50% efficiency, and which can be cheaply produced (along with revolutionary battery technologies), it is possible that one day we won't have to launch huge PV structures into Earth orbit to satisfy the base-load electricity consumption requirements of the entire planet.

Hence, it is thrilling to see the rapid advances in the PV cells research and annual growth in solar energy production of more than 30%, even without government policy support from major countries such as the U.S. and Russia. Indeed, if every house in the future were built with cheap and highly efficient solar cell materials on the roofs and sidings, and every shaded parking lot in shopping malls and office buildings was built and equipped with solar powered charging plugs for electric cars, then how different our energy picture would be.

VIII. Achieving Energy from Space: A Roadmap Ahead

The realistic hope of a commercially viable SBSP system lies in a collaborative effort between the emerging private, entrepreneurial space businesses, government, and venture capital. I am not optimistic about government involvement in this great human engineering and technological endeavor, especially concerning the much needed support of the U.S. government. But I am happy to see that great private sector visionaries see the significance of future energy systems as part of their vision for space commerce.

One such visionary is the recently retired president of India, Dr. Kalam Abdul. Dr. Abdul had the great courage to speak publicly on SBSP while addressing the Symposium on *"The Future of Space Exploration"* organized by Boston University in January 2007. Dr. Abdul noted that space research is truly inter-disciplinary, and has enabled innovations at the intersection of multiple areas of science and engineering.

He also noted that, *"Civilization will run out of fossil fuels in this century. However, solar energy is clean and inexhaustible. And while solar flux on Earth is available for just 6-8 hours every day, incident radiation on a space solar power station would be 24 hours every day. What better vision can there be for the future of space exploration, than participating in a global mission for perennial supply of renewable energy from space?"*

Government support for policies and financial resources for R&D and the related technology demonstrations are crucial to the success of such giant effort, and to date nations other than the US have taken a leading role. The Japanese government became interested in the concept in the late 1970s, and updated the reference system design developed in the System Definition Studies, conducted some limited testing, and proposed a low orbit 10 megawatt demonstration satellite. Their effort has been curtailed by their economic problems and by their lack of manned space capability. SBSP interest by other nations has persisted, but only at low levels.

Therefore, for SBSP to be successful we need an organized consortium consisting of private businesses, venture capitalists from major international partners, along with government support of major industrial nations to bring down associated project and technology risks concerning safety, reliability, and technology maturity. A consortium-based Comsat model (as was used for successful launch and commercialization of communications by the satellite industry) should be a viable approach. A major Apollo-like effort with participation from the broad international community may the best way to successfully create, implement and operate a commercial-scale SBSP system.

IX. An Apollo-like Project of Space Solar Power

An inherent feature of solar power satellites is their location outside the borders of any individual nation. Energy is delivered to the Earth by way of wireless power transmission (WPT), but the use of WPT must be compatible with other uses of the radio frequency spectrum in the affected orbital space. Therefore, it is vital for international governmental involvement in coordinating global treaties and agreements covering frequency assignments, satellite locations, space traffic control and many other aspects of space operations.

A multi-governmental organization or entity should be put in place for a major SBSP project, as it would be extremely difficult, if not inconceivable, for any other single nation to do this alone at any useful or significant power scale. Space solar power is going to be a huge technology and engineering endeavor, similar to going to the Moon and splitting the atom.

Private enterprises will also play key roles in this process. The company I work for, the Space Energy Group (SE), is pioneering a fundamental SBSP energy solution, and our goal is to transform the US from an energy dependent nation to a net energy exporter by launching huge satellites into space to harvest energy from the sun and send it wirelessly to Earth. If large consortia including the Space Energy Group and competing firms such as Solaren are successful then humanity will have a vast source of extremely clean power for the next few … billion years.

The Space Energy Group recently signed a preliminary agreement with a provincial government in China to provide 10 gigawatts of electrical power in incremental delivery over 10 years, starting around the middle of this decade. Overall, energy exports to China could grow to be worth more than $100B, thus reversing the balance of trade with America’s biggest creditor.

As noted, to make SBSP a reality, companies such as SE and Solaren will require a great many launches to get the necessary hardware into space to meet their energy sale contracts. Hence, the number one problem that SE and others face is the high cost of launch.

X. Looking Forward to an Ever Bright Future

It is time for humanity to look to the Sun for answers to our ever-increasing energy needs, and to solve our environmental and economic fossil fuel crises.

I suggest that ‘harnessing the Sun’ will be the 3rd giant leap in the process of human evolution. The first, when human beings came down from the trees and started to use fire, led to tool-making, agriculture, and ancient civilizations. Then humans invented machinery and discovered electricity, which enabled the 2nd giant leap forward to modern industrialization. Now humans are running into profound energy and environmental crises, and we must embark on the next giant leap. By harnessing the Sun to transform combustion civilization, we can evolve into a solar-electric civilization fueled by the inexhaustible and direct energy source from the stars.

Can humanity achieve the third giant leap into the solar-electric civilization? My answer is positively YES. Humans are capable of profound achievements, and we can certainly succeed in taming the mighty power of our star.

Indeed, it is a policy issue more than a technology or economic issue. As Dr. Robert Goddard liked to say, *“It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow.”* As I noted in my talk at the Seattle energy conference, *“As intelligent creatures rooted in the cosmic origin of the universe, humanity was meant to survive and spread its presence all over the universe by milking the energy of the stars!”*

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Dr. Feng Hsu is a world expert on risk and risk assessment. He is Senior Vice President, Systems Engineering & Risk Management with The Space Energy Group. He was formerly a research fellow of Brookhaven National Laboratory in the fields of risk assessment, risk-based decision making, safety & reliability and mission assurances for nuclear power, space launch, energy infrastructure and other high integrity social and engineering systems.

He also headed the NASA Goddard Space Flight Center risk management function, and was the GSFC lead on the NASA-MIT joint project for risk-informed decision-making support on key NASA programs, such as the GPM (Global Precipitation Measurement), LSS (Lunar Surface Systems) and the CxP (Constellation) etc. He was a leading engineer/scientist in the Shuttle and Exploration Analysis Department at Johnson Space Center, SLEP and Shuttle upgrade trade studies.

Dr. Hsu served on many agency and center expert panels supporting challenging SMA issues, and was co-chair of several international technical committees. He played key roles in the: (1) STS-107 (Space Shuttle Columbia) investigation team, (2) the RTF (Return to Flight) team, and (3) the ECO (Engine Cut-Off) expert team for the Discovery mission. Dr. Hsu has over 90 publications and is co-author of two books. He is frequently invited to be the keynote speaker in many international forums. His recent interests span from challenges to human space exploration to solar energy; and include global collective intelligence and risk based policy-making on emerging environmental and energy security issues.

Dr. Hsu holds a Bachelors degree in Applied Math, a Masters degree in Operations Research and Statistics and a Doctoral degree in Engineering Science. As a senior advisory member of the Aerospace Technology Working Group (ATWG) and a co-founder of Space Development Steering Committee, Dr. Hsu has been a strong advocate for Space Based Solar Power (SBSP) for years, and was instrumental in instigating the 2007 NSSO study on SBSP. Dr. Hsu has contributed whole-heartedly to the great human endeavor of harnessing solar energy for sustainable human development.