Boston University The Frederick S. Pardee Center
for the Study of the Longer-Range Future

BOSTON UNIVERSITY

THE PARDEE PAPERS / No. 1 / August 2008

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The Pardee Papers series features working papers by Pardee Center Fellows and other invited authors. Papers in this series explore current and future challenges by anticipating the pathways to human progress, human development, and human well-being. This series includes papers on a wide range of topics, but with a special emphasis on interdisciplinary perspectives and a development orientation.

Series Editor: Professor Adil Najam

The Frederick S. Pardee Center for the Study of the Longer-Range Future at Boston University convenes and conducts interdisciplinary, policy-relevant, and future-oriented research that can contribute to long-term improvements in the human condition. Through its programs of research, publications and events, the Center seeks to identify, anticipate, and enhance the long-term potential for human progress, in all its various dimensions.

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Preface

It gives me great pleasure to introduce President A.P.J. Abdul Kalam's thought-provoking essay on the future of the space explorations and the associated possibilities for human development and well-being. One could not have asked for a more fitting 'opener' for this new series of publications by the Boston University Frederick S. Pardee Center for the Study of the Longer-Range Future. The eminence of the author, the uniqueness of the topic, the clarity of conviction, and the fine balance between a deep recognition of the challenges of today and a bold vision of the possibilities of tomorrow, are exactly the qualities that we seek to emulate in future installments of this series.

It is, of course, a distinct honor to have this new publication series launched with this essay by Dr. Kalam, India's former President and premier space scientist. This essay is based on the keynote address delivered by President Kalam (then the President of India) to the Pardee Center conference on "The Future of Space Exploration" in April 2007, which was organized by Professor Supriya Chakrabarti, the Director of the Center for Space Physics at Boston University. The conference brought together the leading thinkers on space policy to ponder how space exploration in the future might help solve the earthly problems of today and tomorrow. (Details of the conference and videos of all its proceedings, including the Keynote Address from Dr. Adbul Kalam, are available on the Pardee Center website, www.bu.edu/pardee/). I am thankful to Professor Chakrabarti not only for his intellectual leadership in organizing the conference, but also for making the publication of this essay possible.

This essay brings into sharp relief the combination of Dr. Abdul Kalam's expertise as a space scientist with his passion for human development not just for Indians but for all humanity. It is uncommon to see individuals in political power speak with such scientific insight, or to see eminent scientists speak of uplifting the human condition with such passion. In reading this essay one is struck not only by how fresh and unique this combination is, but even more so by how important it is to bring these passions together. The Frederick S. Pardee Center for the Study of the Longer-Range Future stands committed, in all its work, to bring together scholarship and policy in meaningful ways that can enrich the worlds of knowledge as well as those of action.

We hope that this essay will set the tone for this series of publications, which is designed to encourage thoughtful and thought-provoking explorations into the potentialities of the future. This series will showcase scholarly enquiry that is grounded in the realities of today but seeks to respond to current and future challenges by anticipating the pathways to human progress, human development, and human well-being. The series will explore a wide range of topics related to the Pardee Center's mission, but with a special emphasis on interdisciplinary perspectives and a development orientation.

Professor Adil Najam
The Frederick S. Pardee Professor of Global Public Policy
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The Future of Space Exploration and Human Development

Dr. A.P.J. Abdul Kalam
Former President of India

Editor's note: This paper is adapted from the keynote address by Dr. A.P.J. Abdul Kalam, then President of India, presented by video transmission from New Dehli to a symposium titled "The Future of Space Exploration: Solutions to Earthly Problems" on April 12, 2007 at Boston University.

As a scientist who has been part of the growth process of space science and technology in India, I find this field of human endeavour has, in the last 50 years, made an unprecedented impact on the life of the human race. It has been easy to see the aspirations and pain of the people of India and the great expectations they have for further improving their quality of life using technology including space. It is critical to continue researching how space technology can enhance further the quality of life of world citizens, while examining many innovative ideas for space exploration, including exciting aspects like space colonies, search for extra terrestrial intelligence and planetary exploration. We have to understand our planet more completely, and evolve and adapt our life to its environment and ecology.

INDIAN SPACE VISIONARY AND THE INDIAN SPACE PROGRAMME

Fifty years ago, space initiatives started with only two major space-faring nations. Now, there are many. India is among the countries with space science and technology accelerating the social and economic advancement of the nation. Reflecting on the space accomplishments of the last 50 years and the vision for the future, one must acknowledge the role of Dr. Vikram Sarabhai, who pioneered India's space programme, which in the last four decades has been touching the lives of many among the billion people of India in several ways.

Professor Vikram Sarabhai unfurled the socio-economic application-oriented space mission for India in 1970. Today, India has 14,000 scientific, technological, and support staff in multiple space research centers, supported by about 500 industries and academic institutions, and has the capability to build any type of satellite launch vehicle to place remote sensing, communication, and meteorology satellites in different orbits and space applications. These facts have become part of daily life. India has today a constellation of six remote sensing and ten communication satellites serving applications like natural resource survey, communication, disaster management support, meteorology, tele-education (10,000 classrooms) and telemedicine (200 hospitals). India is in the process of establishing 100,000 Common Service Centres (CSC's) across the country through a public-private partnership model for providing knowledge input to rural citizens.

Recently, India has launched into orbit and recovered a space capsule after performing micro gravity experiments. This is a major technological milestone and is an important step towards reusable launch vehicle and manned space missions. India is now working on its second space vision. It is quite possible that India will make an important contribution for the future of exploration with space missions to the Moon and Mars founded on space industrialization.

SPACE RESEARCH AS A TECHNOLOGY GENERATOR

Space research is truly inter-disciplinary and has enabled true innovations at the intersection of multiple areas of science and engineering. It has been consistently aiming at the "impossible" and the "incredible," every time moving the frontiers of our knowledge forward. Space research has had as its major focus on making things work and bringing the dreams of mankind to fruition through technologies that mankind can be proud of. It is almost a "Green Technology." Its greatest asset is that in many cases what is perfected as a space technology becomes a technology that enhances the quality

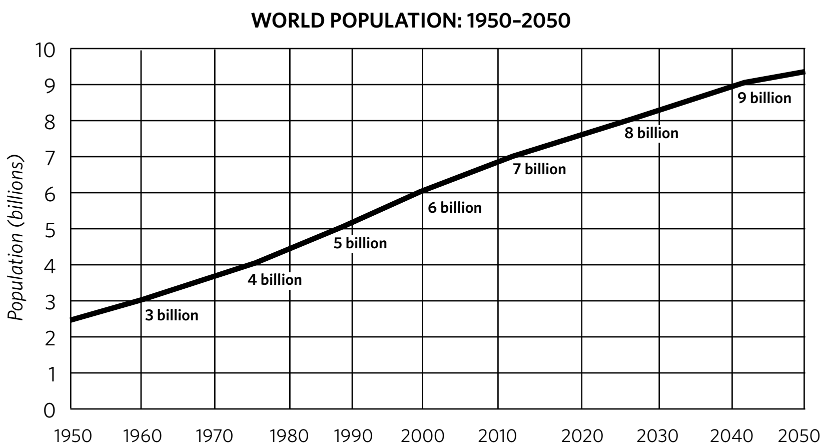
> What better vision can there be for the future of space exploration than participating in a global mission for perennial supply of renewable energy from space?

of human life on the Earth. Some examples are the revolution in communication, tele-presence, infotainment, and an integrated picture of earth and its resources. Besides direct contributions, the fruits of space research have also resulted in designing innovative products such as cardiac stent and heart pacemaker for healthcare.

WORLD POPULATION IN THE 21ST CENTURY & ITS RELATION TO FUTURE OF SPACE EXPLORATION AND SPACE TECHNOLOGY

The world population today is 6.6 billion and is projected to be more than 9 billion by 2050. (Figure 1) The critical issues arising from this population growth are a shortage of energy, a shortage of water, and increasing damage to the natural environment and ecology.

FIGURE 1: **Recent and Expected Population Growth**

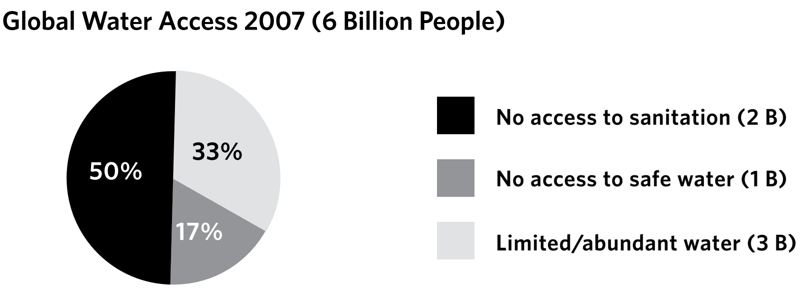


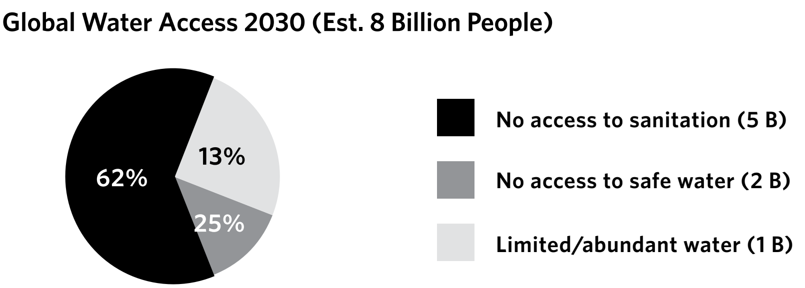
Source: U.S. Census Bureau, International Data Base, 2008 First Update.

Planetary Energy Supply and Demand Civilization on earth will run out of fossil fuels in this century. Oil reserves are on the verge of depletion, followed by gas and finally coal. However, solar energy is clean and inexhaustible. For example, even if 1% of India's land area were harvested of solar energy, the yield would be nearly 1000 gigawatts, or 10 times more than the current consumption. However solar flux on earth is available for just 6–8 hours every day whereas incident radiation on 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?

Water for Future Generations More than 70% of the Earth's surface is water, but only 1% is available as fresh water for drinking purposes. By 2050 when the world population will exceed 9 billion people, over 6 billion may be living under conditions of moderate, high, and extreme water scarcity. (Figure 2) There is a four-fold method towards providing safe and fresh drinking water for large population. The first is to re-distribute the water supply; the second is to save and reduce demand for water; the third is to recycle used water supplies; and the fourth is to find new sources of fresh water.

FIGURE 2: **Water for Future Generations**





Source: www.abdulkalam.nic.in/abdulkalam/sllatest1.jsp?id=1019

In India, earth observation satellites with unique resolution are being deployed for the survey of water bodies, their continuous activation so that water storage during rainy season is maximized. Establishing new water supply sources using advanced reverse osmosis technologies for sea water desalination on large scales is a cost-effective method of providing a new source of safe and fresh drinking water. However, desalination is an energy-intensive process. Hence, the use of renewable energy through space solar satellites can bring down the cost of fresh water substantially. Space-based solar power stations have six to 15 times greater capital utilization than equivalent-sized ground solar stations. Linking space solar power to reverse osmosis technology for large-scale drinking water supplies could be yet another major contribution of space.

Integrated Atmospheric Research In the last four decades, space observations through balloons, rocket experiments, satellites, recordings through sophisticated ground installations, experimental techniques, and instrumentation have provided valuable integrated information on atmospheric processes. What have we learnt from these atmospheric observations during the last four decades? What information enriched us? How is the atmosphere dynamically changing from the 20th century to now in the 21st century? We already know that the Earth is experiencing both stratospheric cooling (due to ozone hole) and tropospheric warming (due to increased greenhouse gases).

While the 20th century has witnessed CO_2 content in atmosphere going up to three parts per 10,000, in the early part of 21st century we are already experiencing 6 to 10 parts per 10,000. This is equivalent to nearly 30 billion tonnes of carbon dioxide injection to the atmosphere every year. The solution for preventing further damage to the atmosphere would be immediate adoption of energy independence through use of clean renewable sources of energy.

Disaster Management In many places in our planet, we experience severe disasters like earthquakes, tsunamis, and cyclones resulting in loss of life, loss of wealth and, in some cases, the destruction of decades of progress made by countries and their valuable cultural heritage. India has earthquake problems periodically in certain regions. The U.S. Japan, Turkey, Iran, and many other countries also suffer due to earthquakes.

Earthquakes and tsunamis are sub-terrain phenomena and predicting this from space observations would be a great challenge. Space scientists of multiple nations should work together to use satellite deep penetration images to predict the earthquake or shock wave propagation. Other possibilities are precise geodynamic measurement of strain accumulation by satellite to detect pre-slip, and electromagnetic phenomena prior to final rupture. The focus must be on earthquake forecasting with adequate warning so that people can move to safer areas. Space technology can also be used for forecasting and modeling of volcanic eruptions, land slides, avalanches, flash floods, storm surges, hurricanes, and tornadoes.

Potentially Dangerous Asteroids The space community has to keep monitoring the dynamics of all potentially dangerous asteroids. Asteroid 1950DA's rendezvous with Earth is predicted to be on March 16, 2880. The impact probability calculations initially indicated a serious condition of 1 in 300 which has to be continuously monitored. In such a crucial condition, we should aim to deflect or destroy this asteroid with the technology available.

SPACE MISSIONS (2050)

There is a need for certain specific priority areas in space technology and exploration.

> Mankind's 21st century thrust into space would herald in the world's next industrial revolution, what might be called the Space Industrial Revolution.

Geosynchronous Equatorial Orbit (GEO) is a well-utilized resource. The spacecraft orbiting in GEO are very high value resources. However, the life of these spacecraft are determined by component failure, capacity of fuel, internal energy systems, and space environment. While new design practices and technologies are constantly increasing the life of satellites, there is a requirement for extending the life of satellites through in-orbit maintenance such as diagnosis, replacement, recharging, powering, refueling, or de-boosting after use. This calls for creation of Space Satellite Service Stations for all the spacecraft in the GEO as a permanent international facility. Future satellites and payloads also have to be designed with self-healing capability and midlife maintenance.

Space Industrial Revolution Mankind's 21st-century thrust into space would herald in the world's next industrial revolution, what might be called the Space Industrial Revolution. This does not mean that the revolution will take place only in Space; it essentially means the creation of architectural and revolutionary changes leading to new space markets, systems, and technologies on a planetary scale. Such a Space Industrial Revolution will be triggered by the following missions that can address all segments of global space community. What are the possible drivers for such a Space Industrial Revolution? (Box 1)

The first major factor will be man's quest for perennial sources of clean energy such as solar and other renewable energies and thermonuclear fusion. Helium 3 from Moon is seen as a valuable fuel for thermonuclear reactors.

BOX 1: **Possible Drivers for a Space Industrial Revolution**

SPACE INDUSTRIAL REVOLUTION

Possible Drivers for a Space Industrial Revolution

- Man's quest for perennial sources of clean energy such as solar and other renewable energies, and thermonuclear fusion.
- Helium 3 from the Moon is seen as a valuable fuel for thermonuclear reactors.
- Mining in planets or asteroids.
- Moon could become a potential hub for interplanetary travel and interplanetary communications.
- Electromagnetic mass drivers powered by solar energy could provide low-cost transportation of lunar materials to space construction sites.

Mining in planets or asteroids would need innovative methods for exploring, processing, and transporting large quantities of rare materials to Earth. The Moon could become a potential transportation hub for interplanetary travel. The Moon's sky is clear to waves of all frequencies. With interplanetary communication systems located on the far side, the Moon would also shield these communication stations from the continuous radio emissions from the Earth. Hence the Moon has potential to become a "Telecommunications Hub" for interplanetary communications also.

The Moon also has other advantages as a source of construction materials for near-Earth orbit. Its weak surface gravity is only one-sixth as strong as Earth's. As a result, in combination with its small diameter, it takes less than 5% as much energy to boost materials from the lunar surface into orbit compared with the launch energy needed from Earth's surface into orbit. Electromagnetic mass drivers powered by solar energy could provide low-cost transportation of lunar materials to space construction sites.

Low-gravity manufacturing holds tremendous promise for mankind in new materials and medicines. Studies also have shown that the needs of 12 workers could be met by a 16-meter diameter inflatable habitat. This would contain facilities for exercise, operations control, clean up, lab work, hydroponics gardening, a wardroom, private crew quarters, dust-removing devices for lunar surface work, an airlock, and lunar rover and lander vehicles.

Concerning habitat on Mars: As Professor UR Rao, former Chairman of the Indian Space Research Organization (ISRO), says, space scientists are habituated to protecting systems against single point failures; so, in the longer-term, creation of extra-terrestrial habitat in Mars should be studied as a fail-safe mechanism for our problems on earth. How would we create livable conditions on Mars?

Moon-Based Solar Power Stations Space solar power stations have been studied extensively during the past 30 to 40 years. However, non-availability of low cost, fully reusable space transportation has denied mankind the benefit of space solar power stations in geo-stationary and other orbits.

The Moon is the ideal environment for large-area solar converters. The solar flux to the lunar surface is predicable and dependable. There is no air or water to degrade large-area thin film devices. The Moon is extremely quiet mechanically. It is devoid of weather, significant seismic activity, and biological processes that degrade terrestrial equipment. Solar collectors can be made that are unaffected by decades of exposure to solar cosmic rays and the solar wind. Sensitive circuitry and wiring can be buried under a few to tens of centimeters of lunar soil and completely protected against solar radiation, temperature extremes, and micrometeorites. Studies also have shown that it is technically and economically feasible to provide about 100,000 GWe of solar electric energy from facilities on the Moon.

Cost of Access to Space If we have to achieve these along with the full potential of space benefits with current applications, there is one major problem we have to solve. That is, how are we going to make the cost of access to space affordable? The question hinges on creating space markets and developing cutting-edge technologies to make low-cost access to space a reality. The future of the Space Industrial Revolution created by a space exploration initiative would hinge greatly on new means of safe, affordable access to near-Earth space, as the platform for deep space exploration.

It is becoming clear that the present level of markets for communication are getting saturated. Optical fiber technologies are providing large band width for terrestrial communications. The life of satellites in orbit having increased 12 to 15 years, along with advanced technology with higher bandwidth for transponders, have further reduced the demand for telecommunication satellites. The current cost of access to space for information missions such as telecommunication, remote sensing, and navigation varies from US $10,000 to US $20,000 per kg in low-Earth orbit. Hence, with the market saturated, the future of space exploration requires that the space industry move out of the present era of information collection missions, into an era of mass missions. There is a need to reduce the cost of access by two to three orders of magnitude. It is only by such reduction in cost of access to space that mankind can hope to harvest the benefits of space exploration by 2050.

> We need the great minds of current space scientists to articulate to the young the space vision for the next 50 years and the challenges we face.

The payload fraction of current generation expendable launch vehicles in the world does not exceed 1% or 2% of the launch weight. Thus to put one or two tonnes in space requires more than 100 tonnes of launch mass, most of which—nearly 70%—is oxygen. Such gigantic rocket-based space transportation systems, with marginal payload fractions, are wholly uneconomical for carrying out mass missions and to carry freight and people to and from the moon.

Studies in India have shown that the greatest economy through the highest payload fractions are obtained when fully reusable space transportation systems are designed that carry no oxidizer at launch, but gather liquid oxygen while the spacecraft ascends directly from Earth to orbit in a single stage. These studies in India suggest that an "aerobic" space transportation vehicle can indeed have a 15% payload fraction for a launch weight of 270 tonnes. This type of space plane has the potential to increase the payload fraction to 30% for higher take-off weight. For such heavy lift space planes, with 10 times the payload fraction and 100 times reuse, the cost of payload in orbit can be reduced dramatically by several orders of magnitude lower than the cost of access to space with expandable launch vehicles.

While space industrialization and space exploration will expand initially using the current-generation launch vehicles, the real value of space exploration for human advancement will occur only when mankind builds fully reusable space transportation systems with very high payload efficiencies. This will become available when the technology of oxygen liquefaction in high-speed flight in Earth's atmosphere is mastered. This technology also will be useful for mass collection from the atmosphere of other planets at a later stage in space exploration.

Maintaining Peace in Space We must recognize the necessity for the world's space community to avoid terrestrial geo-political conflict to be drawn into outer space, thus threatening the space assets belonging to all mankind. This leads to the need for an International Space Force made up of all nations wishing to participate and contribute to protect world space assets in a manner which will enable peaceful exploitation of space on a global cooperative basis.

CHALLENGES BEFORE THE SPACE RESEARCH COMMUNITY

Space research has many challenges that can stimulate intellectually alert and young minds. But the attraction for the youth of today to take up science or technology as a career option has many lucrative diversions. The future of space research cannot be as green as it was in the last 50 years, if we, the space scientists, do not ensure a steady stream of youngsters embracing the discipline. For this to happen, the scientists of today must come up with a steady fountain of ideas that would attract the students. This is a great challenge. We need the great minds of current space scientists to articulate to the young the space vision for the next 50 years and the challenges we face. Space does not have geographic borders and why should those who pursue space research have any borders?

Space Missions 2050 The following space missions should be considered by the space community, with a goal that they be fully accomplished before the year 2050.

1. Evolving a Global Strategic Plan for space industrialization so as to create large-scale markets and advanced space systems and technologies, for clean energy, drinking water, tele-education, tele-medicine, communications, resource management and science; and for undertaking planetary exploration missions.

2. Implementing a Global Partnership Mission in advanced space transportation, charged with the goal of reducing the cost of access to space by two orders of magnitude to US $200 per kg, using identified core competencies, responsibilities, and equitable funding by partners, encouraging innovation and new concepts through two parallel international teams.

3. Developing and deploying in-orbit Space Satellite Service Stations for enhancing the life of spacecraft in GEO as a permanent international facility.

CONCLUSION

Since the dawn of the space era in 1957, space science and technology have enhanced our knowledge of Earth, atmosphere, and outer space. They have improved the quality of life for the human race. Our space vision for the next 50 years has to consolidate these benefits and expand them further to address crucial issues faced by humanity in energy, environment, water, and minerals. Above all, we have to keep upper most in our mind the need for an alternate habitat for the human race in our solar system. The crucial mission for the global space community is to realize a dramatic reduction in the cost of access to space.

To meet this challenge, the scientific community can draw inspiration from the saying of Maharishi Patanjali, about 2,500 years ago: "When you are inspired by some great purpose, some extraordinary project, all your thoughts break their bounds. Your mind transcends limitations, your consciousness expands in every direction, and you find yourself in a new, great, and wonderful world. Dormant forces, faculties, and talents come alive, and you discover yourself to be a greater person by far than you ever dreamt yourself to be."

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ABOUT THE AUTHOR

Dr. A.P.J. Abdul Kalam is one of India's most celebrated scientists and was President of the Republic of India from 2002 through 2007. An aeronautical engineer by training, Dr. Kalam played a critical part in developing India's nuclear weapons program as well as establishing and leading India's space program. He was the Chief Executive of the Indian Integrated Guided Missile Development Programme which led the way for India's missile development and was Chief Scientific Advisor to the Indian Defense Minister at the time of India's nuclear tests. He was also a leader in the development of India's Satellite Launch Vehicle development. He has received many honorary degrees and other honors, including India's highest civilian award, Bharat Ratna. He is the author of many books, including an autobiography, *Wings of Fire.*

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