Space Colonization—Benefits for the World

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Abstract. We have begun to colonize space, even to the extent of early space tourism. Our early Vostok, Mercury, Gemini, Apollo, Skylab, Spacehab, Mir and now ISS are humankind's first ventures toward colonization. Efforts are underway to provide short space tours, and endeavors such as the X-Prize are encouraging entrepreneurs to provide new systems. Many believe that extended space travel (colonization) will do for the 21st century what aviation did for the 20th. Our current concerns including terrorism, hunger, disease, and problems of air quality, safe abundant water, poverty, and weather vagaries tend to overshadow long-term activities such as Space Colonization in the minds of many. Our leading "think tanks" such as the Woodrow Wilson International Center for Scholars and the Brookings Institute do not rate space travel high on lists of future beneficial undertakings even though many of the concerns listed above are prominently featured. It is the contention of this paper that Space Colonization will lead toward solutions to many of the emerging problems of our Earth, both technological and sociological. The breadth of the enterprise far exceeds the scope of our normal single-purpose missions and, therefore, its benefits will be greater.

COLONY—"A BODY OF PEOPLE LIVING IN A NEW TERRITORY BUT RETAINING TIES WITH THE PARENT STATE"

It took 100,000 years for humans to get inches off the ground. Then, astonishingly, it took only 66 years to get from Kitty Hawk to the Moon. We have sent probes out of our solar system and have begun expoloration of our universe. Both robotic and human exploration of space is well underway and we have begun to colonize space, even to the extent of early space tourism. Our early Mercury, Gemini, Apollo, Skylab, Spacehab, Mir, and now ISS are humankind's first ventures toward colonizing space. Efforts are underway to provide short space tours and experiences and endeavors such as the X-prize are encouraging entrepreneurs to provide new systems. Many believe that space travel (colonization) will do for the 21st century what aviation did for the 20th. For purposes of definition, space colonization includes space-based operations in Earth orbit, in transit, and on planetary surfaces; robotic, automated, and human space exploration and data needs; tourism; development of space colonies and Mars; and other planetary terraforming activities. But why should we persevere in the face of terrorism, hunger, disease, and problems of air quality, safe abundant water, poverty, and weather vagaries to name a few of our current problems?

Recently, a "Global Foresight Workshop" was convened by the Woodrow Wilson International Center for Scholars, Foresight, and Governance Project (Smitherman, 2002). Organizers solicited goals from key agencies and organizations across the country and internationally through solicitations from United Nations University via the "Millennium Project." One hundred goals were submitted, which were then combined and condensed to 46 for workshop consideration. The top five goals based on high-ranking for overall global importance were as follows:

1. Provide clean food and water
2. Provide clean and abundant energy

3. Eliminate all major diseases
4. End slavery globally
5. Provide universal health care

Findings such as these are consistent with a Brookings Institute study that asked a group of academic historians, political scientists, sociologists and economists to forecast the most important achievements for the next 50 years. In this study, space endeavors such as exploration or colonization were not on the major list and were ranked low, among the least important accomplishments, even though the above goals were featured.

Although thus not viewed as a beneficial enterprise by many, it is our position that Space Colonization can help lead to solutions to many of the emerging problems of our Earth, such as those listed above, both technical and sociological. The breadth of the enterprise far exceeds our normal single-purpose missions and, therefore, its benefits are greater. Among the technical attributes of Space Colonization are the potential of developing low-cost, nonpolluting energy, enhanced food-production techniques, pollution/waste and water purification, development of disease-amelioration techniques, and the development of techniques to help protect Earth from potential meteoroid impact hazards (Siegfried, 1996).

LOW-COST, NONPOLLUTING ABUNDANT ENERGY IS REQUIRED FOR SPACE COLONIZATION

The world population has finally recognized that we are polluting our nest. We are using energy at a prodigious rate (Fig. 1) (Siegfried, 1991). There is a demonstrated connection between the cost of energy, its availability and a nation's standard of living. Long-term clean energy sources must be provided to assist not only with our future needs, but also with those of all nations' current requirements. Energy sources are an important part of environmental thrusts. Nuclear research is progressing, but it does not promise near-term solutions and developing

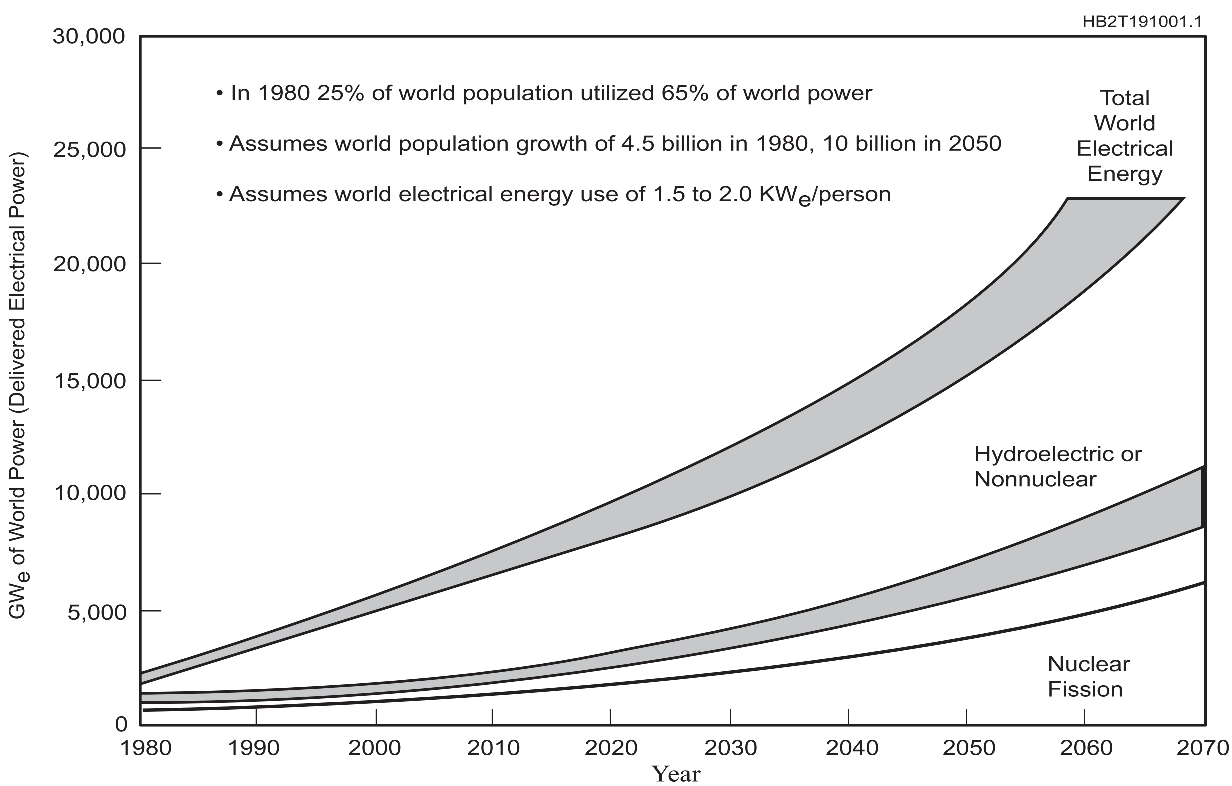

FIGURE 1. World Power Needs—Electrical Power.

nations are reaching a plateau of available power. The emerging nations' need for power must be balanced against potential environmental damage from such dangers as fossil fuel emissions (if there were enough fuel available), which could be greater than nuclear energy risks. Currently, the United States annually consumes approximately 3 trillion Kwh's of electrical energy and, if this rate grows at only 2% per year, by 2050 United States power requirements will be around 9 trillion Kwh's per year. Total world needs, assuming a very low use by developing nations (not a conservative estimate) easily exceeds an estimated 20 trillion Kwh's by 2050. Even with an attendant tripling of non-nuclear systems, such as hydroelectric to avoid fossil fuel depletion, nuclear power system generation would have to increase by a factor of 6 to meet requirements. This increase in nuclear energy production flies in the face of a rising discontent with adverse environmental effects of nuclear waste disposal, where some plants are being converted to utilize fossil fuels. A clean renewable source of energy must be found and implemented. Space Colonization can lead to solutions to this problem.

Three potential energy sources are described in Table 1. Helium 3, solar power satellites (SPS), and a lunar (solar) power system (LPS) all have significant feedback potential for other commercial applications. A space-based energy system would be global in scale and funding and would thus be a challenging goal for macro-engineering management to achieve. This management experience would be globally shared and would be utilized for other global projects. Robotics and artificial intelligence would also benefit from the use of smart and capable robots to autonomously conduct such functions as space assembly and lunar mining and processing. Computer systems would be extended in capacity and reliability, energy-transfer technology would be enhanced, and materials research would quest for more efficient space systems and learn to utilize in-situ materials. SPS and LPS will require advancement in photovoltaic cell technology. This quest can also influence transportation technology because at least one of the solutions could lead to more efficient space propulsion. This would reduce travel times and minimize exposure to potentially debilitating space environments.

TABLE 1. Space-Based Energy Sources.

Helium-3 system concept	■ Helium-3 is mined on lunar surface and transported to Earth for use in fusion reactors ■ Deuterium and He-3 fuse cleanly and produce little radiation or waste ■ We estimate that enough He-3 is on lunar surface to satisfy current world energy needs for 1000 years
Solar Power Satellite (SPS) concept	■ Four to six satellites in geosynchronous Earth orbit transmitting solar energy to the surface ■ 10 GW of electric power per satellite ■ Use lunar materials for construction of SPS and transportation system to place in geosynchronous orbit
Lunar Power System (LPS) concept	■ LPS will collect solar energy on lunar surface and transmit back to Earth ■ LPS used first to power lunar base to demonstrate technology

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SPACE COLONIZATION MUST HAVE LOW-WATER, LOW-PESTICIDE PLANT GROWTH AND WASTE AND WATER PURITY CONTROL

Two of the items listed here represent major concerns of most developed nations and are emerging concerns in developing nations. A technological revolution is needed to address food shortages to allow adequate nutrition for our exploding world population in concert with ever-growing water shortages, and a growing realization that our current pesticide methods are polluting our planet. While previous short-duration human space programs have depended on open-loop life support systems, Space Colonization cannot. Development of a closed-cycle bio-regenerative controlled ecological life support system (CELSS) would lead to world benefits. Areas of CELSS development are listed in Table 2. Many long-term (and pressing short-term) world problem solutions can be approached by reaching for the stars. For example, Shimizu Corporation is most interested in bio-regenerative systems as a path toward solution of Tokyo's waste management problems.

TABLE 2. Critical CELSS Development Areas.

Plant growth in controlled environment	■ Select crop plants for nutritional value and productivity ■ Optimize and control plant growth response ■ Develop support systems to allow growth in closed chambers
Waste processing and nutrient recovery	■ Develop energy-efficient waste processor to convert plant and human waste into plant nutrients and water ■ Develop biomass processor to convert some portion of inedible plant materials into dietary supplements
Atmosphere revitalization	■ Develop technology for makeup nitrogen generation ■ Remove CO_2 reduction by-products ■ Improve trace contaminant control and monitor
Plant growth in reduced or microgravity	■ Study crop plant productivity with microgravity as worst case ■ Determine ability of support systems to function in microgravity ■ Perform multiple-generation studies in space radiation flow-g environment
Plant growth in controlled environment	■ Develop laboratory system to investigate microbial interactions and toxicology ■ Determine control strategies to provide stable life support system
Water management	■ Eliminate urine pretest chemicals ■ Regenerate or eliminate post-treatment filter and sorbent beds ■ Improve quality monitoring

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SPACE COLONIZATION MAY LEAD TO HUMAN PHYSIOLOGY, AGING, AND DISEASE AMELIORATION

Many current human problems are the result of failures of the body's natural immune system. We can diagnose many of these problems and have made great strides in ameliorating the symptoms, but to date, understanding immune system function and enhancement is seminal. Both United States and Russian long-term space missions have induced similar red blood cell and immune system changes. Hematological and immunological changes observed during, or after, space missions have been quite consistent. Decreases in red cell mass were reported in Gemini, Apollo, Skylab and Soyuz, and Mir programs—probably due to diminished rates of erythrocyte production. Space flight at microgravity levels may produce changes in white blood cell morphology and a compromise of the immune system. Skylab studies indicated a decrease in the number of T lymphocytes and some impairment in their function. Certain United States and Russian findings suggest that space flight induces a transient impairment in immune system function at the cellular level. Space flight offers a clinical laboratory unlike any place on Earth that may lead to an improved understanding of the function of the human immune system. Perhaps cures of aging, HIV, and other immune function-related illnesses can result from a comprehensive approach to Space Colonization.

SPACE COLONIZATION CAN HELP PROTECT EARTH FROM ASTEROID AND METEORITE HAZARDS (NEAR-EARTH-OBJECT IMPACTS)

Over the last decade a large mass of evidence has been accumulated indicating that near-Earth-object (NEO) impact events constitute a real hazard to Earth. Congress held hearings on the phenomenon in 1998, and NASA created a small NEO program. Since 1988, a total (as of 7 August 2002) of some many thousand near-Earth objects (of which about 1,000 are larger that 1 km in diameter) have been catalogued that are potentially hazardous to Earth. New discoveries are accelerating. In just the last few months, a 2-mile-wide crater was discovered in Iraq dating from around 2000 to 3000 B.C. This impact was potentially responsible for the decline of several early civilizations. A similar crater was recently discovered in the North Sea. Major events have occurred twice in the last hundred years in remote areas where an object exploded near the Earth's surface bur did not impact (such as in Russia). If either of these events had occurred over a populated area the death toll would have been enormous. Our armed forces are concerned that an asteroid strike could be interpreted as a nuclear attack, thus triggering retaliation. What higher goals could Space Colonization have than in helping to prevent the destruction of human life and to ensure the future of civilization? The odds of an object 1 km in diameter impacting Earth in this century range between 1 in 1,500 and 1 in 5,000 depending on the assumptions made. A 1-km-diameter meteoroid impact would create a crater 5 miles wide. The death toll would depend on the impact point. A hit at Ground Zero in New York would kill millions of people and Manhattan Island (and much of the surrounding area) would disappear. The resulting disruption to the Earth's environment would be immeasurable by today's standards. A concerted Space Colonization impetus could provide platforms for early warning and could, potentially, aid in deflection of threatening objects. NEO detection and deflection is a goal that furthers international cooperation in space and Space Colonization. Many nations can contribute and the multiple dimensions of the challenge would allow participation in many ways—from telescopes for conducting surveys, to studies of lunar and other planet impacts, to journeys to the comets. The Moon is a natural laboratory for the study of impact events. A lunar colony would facilitate such study and could provide a base for defensive action. Lunar and Mars cyclers could be a part of Space Colonization that would provide survey sites and become bases for mining the NEOs as a resource base for space construction. The infrastructure of Space Colonization would serve a similar purpose to the solar system as did that of the United States Interstate Highway system or the flood control and land reclamation in the American West did for the United States development. In short, it would allow civilization to expand into the high frontier.

SPACE COLONIZATION WILL HAVE MANY BENEFICIAL ASPECTS

A complete list of potential world benefits from Space Colonization is lengthy, even when confined to technological items. Included are access to space resources that include quantities of almost every resource we have on Earth except fossil fuels; an improved understanding of the complex systems that comprise our climate; conducting experiments in chemistry, biology, physiology, and even sociology that cannot be conducted here on Earth; and developing new technologies for use on Earth. All are the bounty of Space Colonization.

There are also many sociological benefits of Space Colonization. We must remember that such an endeavor cannot be implemented by one any agency or single government. A world policy would be needed. In the United States, the combined efforts of NASA, DOE, DOI, DOT, DOC, and others would be focused in addition to our broad industrial base and the commercial world. It should be noted that the eventual space tourism market (tapping in to the world annual $3,400 billion market or the United States $120 billion per year "adventure travel" market) (Reichert, 1999) will not be based on the work of isolated government agencies but, rather, evolve from a synergistic combination of government, travel industry, hotel chains, civil engineering, and, yes, a modified version of industry as we know it today. The change in emphasis from our present single-objective missions to a broadband Space Colonization infrastructure will create employment here on Earth and in space for millions of people and will profoundly change our daily life on Earth. This venue, initiated by short suborbital followed by short orbital and then orbital hotel stays (Collins, 2000) has already begun with brief visits to the ISS. Once systems evolve that can reduce the cost of a "space ticket" to some $10,000 to $50,000 US, the market will grow. Fig 2 is typical of studies on space tourism passengers that could be expected vs. costs of the trip.

Space Colonization Will Influence the Sociology of Our World

Included herein are jobs and education incentives and potential synergistic effects of Space Colonization. As a model, we will utilize United States data because similar worldwide data are not available. The general effect of civil space on the United States economy is summarized in Table 3, based on data from 1990. Over and above the direct benefits received by the states having major aerospace industry, there are indirect benefits to all states, for people buy goods and services (such as cars) with the money they earn. This can range from 4-to-1 ratios in the major states benefited to as high as 10-to-1 ratios in states such as Michigan, Oklahoma, and Kentucky. The numbers here are the number of dollars realized for every dollar spent.

Past Spin-Offs

A summary of spin-offs and feedback from civil space programs is shown in Table 4. These data are further augmented by information shown in Table 5, which contains an estimate of the dollar value (in millions of 1990 US dollars) of technological pull-throughs subdivided by end use. The data were generated by the Chapman Group in the late 1980's. These data are derived from space programs that were not specifically structured to produce product benefits. Table 6 shows examples of critical technologies with potential commercial value as determined by the NASA Science Technology Council.

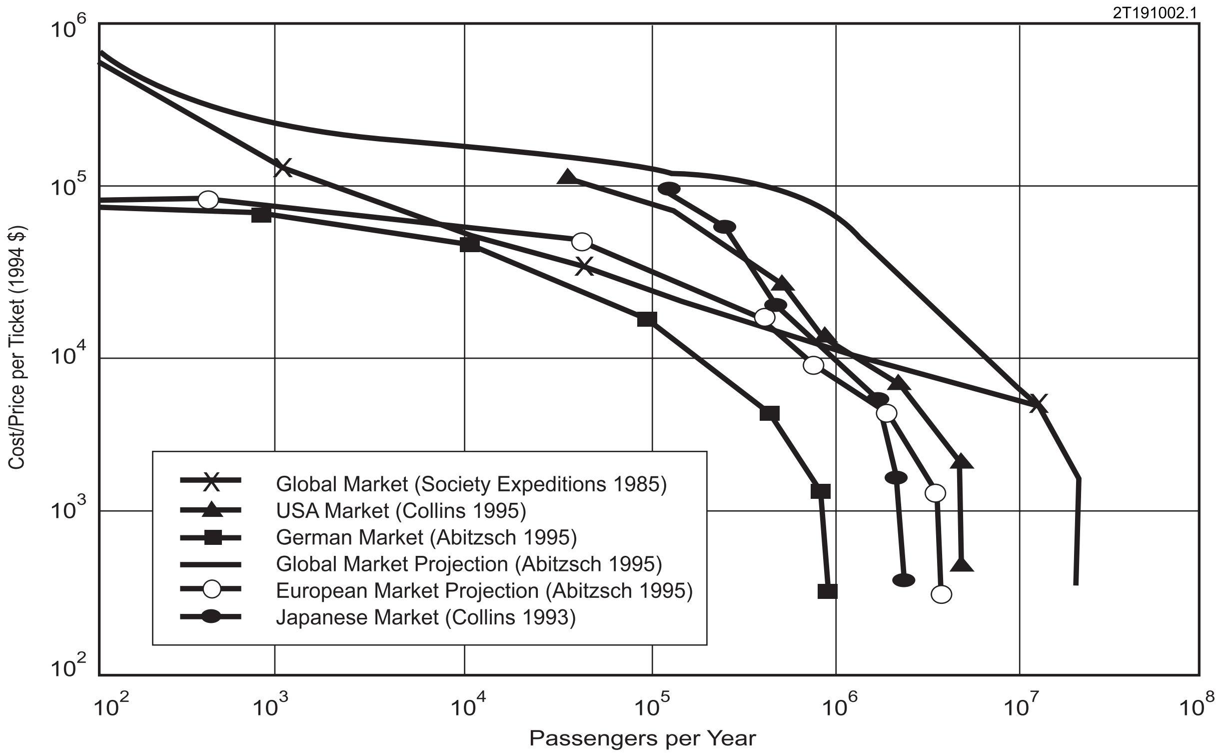

FIGURE 2. Expected Passengers As a Function of the Cost/Price per Ticket.

TABLE 3. How Does the United States Economy Relate to Civil Space?

■ Method of measurement	■ Direct: Those states awarded NASA procurement dollars ■ Indirect: Those states producing goods and services required by recipients of NASA procurement awards ■ Number of jobs created: White and blue collar
■ Highlights of FY90 $12.3 billion procurement expenditures created, directly and indirectly	■ 237,000 jobs in private industry ■ $23.2 billion in total industry sales ■ $500 million in corporate-funded R&D ■ $2.4 billion in corporate profits ■ $7.4 billion in federal, state, and local tax revenues
■ States benefiting most from United States space program are those with large aerospace industries, but other states also benefit significantly	■ Arkansas, Oklahoma, Illinois, and Michigan show high ratios of gain per NASA dollar spent in the United States
■ Many industries other than aerospace benefit from NASA procurement as indicated by high economic multipliers	■ Only 17% of jobs created fall in engineering and science categories

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TABLE 4. What Were Past Spin-Offs and Feedback from Civil Space?

■ Over 32,000 spin-offs, NASA does not accurately track dollar value	■ Estimated dollar value: $10 to $100 billion
■ Most important spin-off: United States aerospace industry still No. 1	■ One of few United States industries with close government and industry cooperation in R&D ■ DOD and DOE are major parts of it all ■ Difficult to point to one factor–perhaps total NASA/DOD/ DOE budget
■ Second most important spin-off: technical and practical knowledge of what can and should be done in space–how space and Earth relate	■ Weather satellites, Earth sciences, and natural disaster monitoring
■ Third most important spin-off: specific hardware and software	■ Almost all small items, individual dollar values are not large ■ NASA tracks and documents many through Technical Utilization and Patent Office

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TABLE 5. Dollar Value of Technical Pull-Throughs (in Millions).

End Use Description	No. of Cases	Cases with Sales Savings	Sales	Benefits Savings	Realized Total
Communication and Data Processing	51	32	171,007	51,964	222,971
Energy	30	13	203,500	15,613	219,113
Industrial (manufacturing and processing)	170	107	5,767,649	67,837	5,835,486
Medical	61	31	2,003,036	30,613	2,033,649
Consumer Products	24	18	1,278,294	524	1,278,818
Public Safety	27	16	347,888	555	348,443
Transportation	40	18	9,887,865	116,623	10,004,488
Environmental	16	11	16,962	21,788	38,750
Other	22	13	1,654,989	10,232	1,665,221
Total	**441**	**259**	**$21,331,190**	**$315,749**	**$21,646,939**

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TABLE 6. NSTC–Critical Technologies with Commercial Applications.

Area	Technology Elements
Adaptive automation	■ Artificial intelligence, expert systems, neural networks, nonlinear dynamics and control, sensing and perception, human factors (man and machine interface), knowledge representation and acquisition, fuzzy logic networks
Information acquisition, processing, and display	■ Sensor systems, neural networks, artificial intelligence, expert systems, advanced displays, virtual displays, advanced computer systems, algorithm development, superconductivity devices
Transportation	■ Computational methods (fluids and solid mechanics, integrated design), aeronautics and space propulsion systems, high-strength and density airframe and engine structural materials, adaptive vehicle and system control and operations, composite structure
Materials	■ Materials and processing: metallics, ceramics, organics, composites; manufacturing technologies: processing, automation, quality control; nano-tube structure
Optical communication and photonics	■ Free space optical communications, optoelectronics, optical computer and processors
Nano-technology and nano-electronics	■ Semiconductor patterning and etching, nano-sensors, quantum wave effects on electronic performance
Energy generation and photovoltaic energy conversion electro-chemical systems	■ Batteries and fuel cells, power management, Stirling power conversion, space environmental effects, electrophysics, solar concentration, heat receivers, and radiation
NSTC: NASA Science Technology Council	

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Education

Problems within the education program in the United States have been analyzed many times. Rising illiteracy, 35% of all scientist and engineers being foreign born, and the 50% or higher foreign doctorate candidates who return to their country of origin after receiving degrees are examples. United States science and engineering schools are recognized throughout the world for their standards of excellence, but the number of United States students is declining based on a decreasing interest by the younger generation in the sciences and engineering. We must encourage young students to select engineering and science for studies as is happening in the rest of the world. Space Colonization can provide that stimulus. During the Apollo program, as NASA spending increased, so, too, did the number of doctorates received (Fig. 3). When NASA spending decreased following the Apollo program, so did the number of doctorates received a few years later (Collins, 2000). This time lag occurred because many students were well on their way to achieving their degrees. Once it was clear that funding and federal support had been reduced, the student population plummeted. We now face the prospect of many of the people trained in the sciences reaching retirement. Where are the replacements? A long-term worldwide commitment to Space Colonization could help. We must convince our present elementary school students to commit to science and engineering for these are the keys to our future.

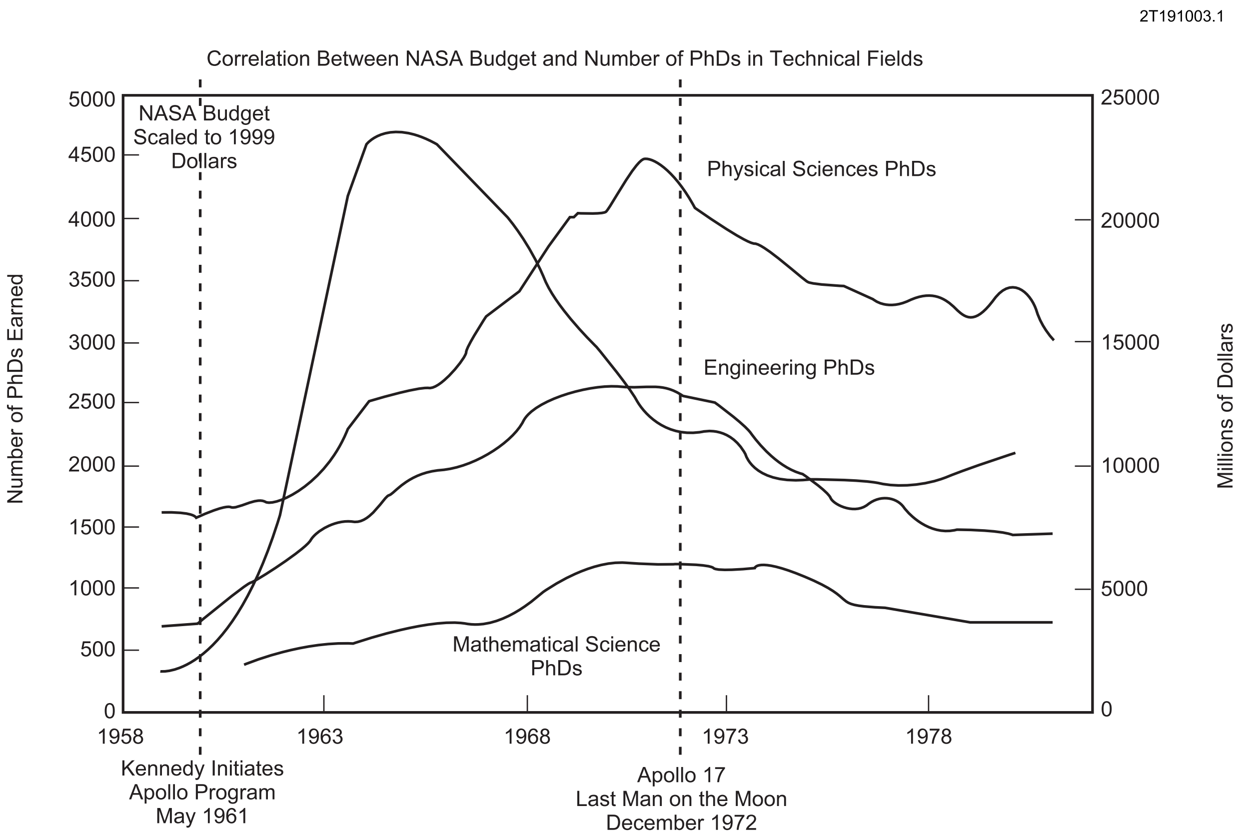

FIGURE 3. NASA Budget and Technical PhDs.

Intangible Benefits

Aside from the more demonstrable returns that would come from Space Colonization, there are a host of intangible benefits (U.S. Office of Management and Budget, 2000; Mankins, 2001; Mankins, 1997; Siegfried, 2000a; Siegfried, 1999). Mankind has always been goal-driven. The accessibility of journeys to space destinations could become a great motivational factor to the general population and a goal for emerging societies (Koelle, 2002). It could become a new commercial industry similar to the explosive growth of travel and adventure trips spawned by the jet age. We could expand our living space, create at least a second home for Earth-based life forms through development of lunar colonics and, eventually, perhaps terraforming Mars. We can potentially sublimate some of our ethnic strife in a common reach to the universe. We will better understand our Earth's environment and evolutionary history and rekindle the spirit of adventure that we experienced during the frontier days. Space Colonization will benefit from burgeoning technology here on Earth but will also spawn the creation of as-yet-undreamed leaps. It could lead to potential storage or disposal venues for waste material and, by its very nature, provide the impetus for whole new generations of transportation, housing, and environmental control systems. The development of low-cost access systems will spawn flight rates similar to our terrestrial tourist frequencies and, coupled with the development of new space businesses and a space infrastructure, will implement humankind's expansion throughout space. It has been 30 years since we left our Moon. It is time to return, this time to stay (Siegfried, 1997; Siegfried, 2001; Siegfried, 2000b).

SUMMARY

Space Colonization will become an integral part of our 21st century global future. Its effects will be analogous to the great changes that the aviation industry catalyzed in the past century. Many of the needs of the Earth's burgeonizing population can be ameliorated by the science and technology emanating from a broad endeavor to reach for the stars. Establishing broad new goals will provide motivation for our young. Formation of the colonization industry will provide many jobs and may potentially serve to sublimate ethnic strife. As the adventure travel industry here on Earth has grown through provision of adventure, drama, mystery, heroism, and hope for the future, so too will Space Colonization provide value to humankind.

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