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LUNAR EXPLORATION

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED EIGHTH CONGRESS

FIRST SESSION

NOVEMBER 6, 2003

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

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LUNAR EXPLORATION

THURSDAY, NOVEMBER 6, 2003

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 2:33 p.m. in room SR–253, Russell Senate Office Building, Hon. Sam Brownback, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. SAM BROWNBACK, U.S. SENATOR FROM KANSAS

Senator BROWNBACK. The hearing will come to order. Appreciate everybody being here today.

These are the building blocks that we need to move Congress forward on what's our vision and how we're going to move forward in space exploration. We've been holding a series of hearings on this topic, one a week or two ago about the International Space Station. This hearing is on lunar space exploration. We will continue to hold hearings in the future about where the United States should be going in space.

We are a space-faring nation, we will be in the future. We need to do it in both manned and unmanned missions. But right now we're a bit lost in space and not sure of the vision, where we're going, and we need to reestablish what that vision is and what it's going to be. And through these hearings, I hope to educate myself, educate some people in Congress, as well. What are the options, what are the costs, what are the risks, and where would we go? I think it's of vital importance that we do this for our future generations and for ourselves.

There are young men and women in Pittsburg, Kansas, that are yearning to dream, and unless we put a grand vision in front of them, I fear for their destinies. It's very, very important for us that we have a vision, that we move forward aggressively, help the young people in our country, and help us all. We need to move forward with a vision that's exciting, that's mobilizing, that stirs the soul. And I think we are on that task, to see where and how we can get that done.

The country is at a critical juncture. We must decide, as a nation, what the vision for space exploration should be, which is why we've called this hearing today. I want to examine all options before us—missions to the Moon, missions to Mars, the International Space Station, and the Space Shuttle. All of these options are presently before us. What we need to do now is evaluate our options and embrace a vision.

I've made it known over the past several months that I want this Subcommittee to explore a new vision for our space agency. To that end, we're here today to hear testimony from our distinguished panel on lunar exploration and what value it may serve our Nation to venture back for military, commercial, and discovery purposes. I hope our witnesses will share with us their ideas for a national vision.

I don't know for sure what our national vision should be, but the best way I've heard it stated so far is that we must dominate the Earth/Moon/Mars orbit for commercial, exploration, and military purposes. I hope that today's hearing will help bring focus to that idea.

But in the 1960s, we had the goal of getting a man on the Moon and returning him safely to Earth, and that served as an inspiration to so many across the Nation. Today, I'm afraid that America is lacking a similar vision. I'd like to see the U.S. embrace the idea of dominating the Earth, Moon, and Mars orbit. I think this is a goal that Americans can grasp onto. It gives industry a destination on which to focus, it gives government a goal to obtain, and it gives youth the hope of someday reaching Mars and beyond.

I'm honored to have such a distinguished panel of experts here today, and I look forward to the testimony regarding their thoughts and visions for lunar exploration.

I'd like to welcome back former Senator Jack Schmitt. Not only has Senator Schmitt served this Nation in Congress, he's also served our Nation as one of the last astronauts to walk on the Moon, during *Apollo 17.* He's Chairman of the Interlunar-Intermars Initiative, Incorporated.

Joining him at the table is Dr. David Criswell, Director of the Institute for Space System Operations, in Houston, Texas, along with Dr. Roger Angel, Director of the Center for Astronomical Adaptive Optics, at the University of Arizona, and Dr. Paul Spudis, visiting scientist, with the Lunar and Planetary Institute, in Houston, Texas.

All these gentlemen are distinguished in their accomplishments in the space field, and I look forward to hear their testimony this afternoon.

And, with that, Dr. Schmitt, Senator Schmitt, let's start with your testimony.

STATEMENT HON. HARRISON H. SCHMITT, CHAIRMAN, INTERLUNE-INTERMARS INITIATIVE, INC.

Dr. SCHMITT. Well, thank you, Mr. Chairman, not only for your remarks, but for the invitation to participate. It's good to be back in these familiar surroundings.

A return to Moon to stay, when it occurs, would be at least comparable to the first permanent settlement of America, if not to the movement of our species out of Africa, about 150,000 years ago. A return by Americans to the Moon at least 40 years after the end of the *Apollo 17* mission—and I say 40 years, even though it ended only 30 years ago; it's going to take us at least 10 years to get started again, I'm afraid—would represent a sustainable commitment to this endeavor. And I mean and emphasize "sustainable."

I must admit to being skeptical that the U.S. Government can be counted on to make such a sustained commitment, absent unanticipated circumstances comparable to those of the late 1950s and the early 1960s. Because of this skepticism, I have spent much of the last decade exploring what it would take for private investors to make such a commitment. At least it is clear that investors will stick with a project if it's presented to them with a credible business plan, credible execution, and a rate of return commensurate with the risk to invested capital. That, I can predict. I cannot predict what the government's going to do.

My colleagues at the Fusion Technology Institute of the University of Wisconsin-Madison, and the Interlune-Intermars Initiative, Inc., believe that such a commercially viable project exists in lunar helium-3, helium-3 to be used as a fuel for fusion electric power plants on Earth.

As background, global demand and need for energy will likely, in my estimation, increase by at least a factor of eight by the midpoint of the 21st century. This rapid rise from today will be due to a combination of population increase, roughly a factor of two, new energy-intensive technologies, aspirations for improved standards of living, and lower birth rates in less developed countries, and the need to mitigate the adverse consequences of climate warming or climate cooling, whichever way it may go. It is going to go one of those two directions.

Helium has two stabilized isotopes, helium–4, familiar to all who have received helium-filled balloons, and the even lighter isotope, but rarer isotope, helium-3. Lunar helium-3, arriving at the Moon as part of a solar wind, is embedded as a trace non-radioactive isotope in lunar soils. It represents one potential energy source, one of many, to meet this country's and this century's, rapidly escalating demand.

There is a resource base of helium-3 of about 10,000 metric tons just in the upper three meters of the titanium-rich soils of Mare Tranquillitatis. This, of course, was a region where Neil Armstrong landed in 1969. By the way, the current electrical energy use in the United States is about 40 tonnes of helium-3 equivalent energy. That's the annual use. It's about 40 tonnes equivalence.

The energy-equivalent value of helium–3 delivered to an operating fusion plant on Earth, if that were possible today, would be about $4 billion per tonne, relative to today's price of crude oil. These numbers illustrate the magnitude of the business opportunity for helium-3 fusion power, and why an old economic geologist, like myself, might get interested in the project.

Past technical activities on Earth and in deep space provide a strong base for initiating this enterprise. Also over the last decade, there has been historic progress in the development of inertial electrostatic confinement—that is IEC fusion—at the University of Wisconsin-Madison. Progress there includes the production of approximately one milowatt of steady-state power from the fusion of helium-3 and the heavy isotope of hydrogen deuterium.

Steady progress in IEC research, as well as basic physics, argue strongly that the IEC approach to fusion power has significantly more commercial viability than other fusion technologies. It will have inherently lower capital costs, higher energy conversion efficiency, a range of power from a few hundred megawatts upward, and little or no associated radioactivity or radioactive waste.

It should be noted, however, that IEC research has received no significant support as an alternative to Tokamak-based fusion from the Department of Energy. And, in fairness to DOE, that may be because they don't think we're ever going to go to our most abundant available supply, and that is the Moon.

On the question of international law relative to outer space, specifically the Outer Space Treaty of 1967, the only really operative treaty today, that treaty is permissive relative to property license and regulated commercial endeavors. Under the 1967 treaty, lunar resources can be extracted and owned, but national sovereignty cannot be asserted over the mining area or any other part of a celestial body.

The cost of capital for launch and basic operations will be carried by the helium-3 business enterprise. Thus, technology and facilities required for success of a lunar commercial enterprise involving helium-3, particularly heavy-lift launch and fusion technologies, will enable the conduct and reduce the cost of many other space activities, in addition to science, on and from the Moon. These other activities include exploration and settlement of Mars, asteroid interception and diversion, and various national security initiatives.

Again, Mr. Chairman, the lowest cost way to get to your aim of the Mars/Moon orbit around the Sun is by way of the Moon.

It is doubtful that the United States will initiate or sustain a return of humans to the Moon, absent a comparable set of circumstances as those facing the Congress and Presidents Eisenhower, Kennedy, and Johnson in the late 1950s and through the 1960s.

If government were to lead a return to deep space, then NASA today is probably not the agency to undertake a significant new program to return humans to deep space. NASA today lacks the critical mass of the youthful energy and imagination required for work in deep space. It also has become too bureaucratic and too risk-averse. Either a new agency would need to be created to implement such a program or NASA would need to be totally restructured, using the lessons of what has worked and what has not worked since it was created 45 years ago.

First, of particular importance would be the need for, most of the agency to be made up of engineers and technicians in their 20s, and managers in their 30s. Second, the reinstitution of design/engineering activities, in parallel with those of contractors. Third, the streamlining of management responsibility. The existing NASA would also need to undergo a major restructuring of its program management, risk management, and financial management structures. Total restructuring would be necessary to recreate the competence and discipline necessary to operate successfully in the much higher-risk and more complex deep-space environment relative to that in near-Earth orbit. Most important for a new NASA or a new agency would be a guarantee of sustained political—that is, financial—commitment to see the job through and to not turn back once a deep-space operational capability exists or accidents happen.

A sustained commitment includes not underfunding the effort. Underfunding since the early 1970s, has really been at the base of many of the problems that I have described. That is why I've been looking to a more predictable commitment from business investors.

Attaining a level of sustained operations for a core business in fusion power and lunar resources requires about 15 years and about $15 billion in private investment capital, as well as the successful interim marketing and profitable sales related to a variety of applied fusion technologies.

The time required, from startup to the deliver of the first hundred kilograms—that is, a year's supply—to the first operating thousand-megawatt fusion power plant on Earth, or its equivalent, will be a function of the rate at which capital is available, but probably no less than 10 years, due to the complexity of the endeavor.

Well, Mr. Chairman, a business and investor-based approach to return to the Moon to stay represents a clear alternative, in my mind at least, to initiatives by the U.S. Government or a coalition of other countries. A business-investor approach supported by the potential of lunar helium–3 fusion power and derivative technologies and resources offers the greatest likelihood of a predictable and sustained commitment to a return to deep space.

Thank you, Mr. Chairman. I'd be happy to take any questions from the Committee.

[The prepared statement of Dr. Schmitt follows:]

PREPARED STATEMENT OF HON. HARRISON H. SCHMITT, CHAIRMAN, INTERLUNE-INTERMARS INITIATIVE, INC.

Summary

Return to the Moon

A return to the Moon to stay would be at least comparable to the first permanent settlement of America if not to the movement of our species out of Africa.

I am skeptical that the U.S. Government can be counted on to make such a "sustained commitment" absent unanticipated circumstances comparable to those of the late 1950s and early 1960s. Therefore, I have spent much of the last decade exploring what it would take for private investors to make such a commitment. At least it is clear that investors will stick with a project if presented to them with a credible business plan and a rate of return commensurate with the risk to invested capital. My colleagues at the Fusion Technology Institute of the University of Wisconsin-Madison and the Interlune Intermars Initiative, Inc. believe that such a commercially viable project exists in lunar helium-3 used as a fuel for fusion electric power plants on Earth.

Lunar helium-3, arriving at the Moon as part of the solar wind, is imbedded as a trace, non-radioactive isotope in the lunar soils. There is a resource base of helium-3 about of 10,000 metric tonnes just in upper three meters of the titanium-rich soils of Mare Tranquillitatis. The energy equivalent value ofHelium-3 delivered to operating fusion power plants on Earth would be about $4 billion per tonne relative to today's coal. Coal, of course, supplies about half of the approximately $40 billion domestic electrical power market.

A business and investor based approach to a return to the Moon to stay represents a clear alternative to initiatives by the U.S. Government or by a coalition of other countries. A business-investor approach, supported by the potential of lunar Helium-3 fusion power, and derivative technologies and resources, offers the greatest likelihood of a predictable and sustained commitment to a return to deep space.

Oral Summary

Thank you, Mr. Chairman, for the invitation to participate in this hearing. It is good to be back in these familiar surroundings.

A return to the Moon to stay, when it occurs, will be a truly historic event. It would be at least comparable to the first permanent settlement of America if not to the movement of our species out of Africa.

The Apollo 17 mission on which I was privileged to fly in December 1972 was the most recent visit by human beings to the Moon, indeed to deep space. A return by Americans to the Moon at least 40 years after the end of the Apollo 17 mission probably would represent a commitment to return to stay. Otherwise, it is hard to imagine how a sustained commitment to return would develop in this country.

I must admit to being skeptical that the U.S. Government can be counted on to make such a "sustained commitment" absent unanticipated circumstances comparable to those of the late 1950s and early 1960s. Therefore, I have spent much of the last decade exploring what it would take for private investors to make such a commitment. At least it is clear that investors will stick with a project if presented to them with a credible business plan and a rate of return commensurate with the risk to invested capital. My colleagues at the Fusion Technology Institute of the University of Wisconsin-Madison and the Interlune-Intermars Initiative, Inc. believe that such a commercially viable project exists in lunar helium-3 used as a fuel for fusion electric power plants on Earth.

Global demand and need for energy will likely increase by at least a factor of eight by the mid-point of the 21st Century. This rapid rise will be due to a combination of population increase, new energy intensive technologies, aspirations for improved standards of living and lower birth rates in the less-developed world, and the need to mitigate the adverse consequences of climate warming or cooling.

Helium has two stable isotopes, helium 4, familiar to all who have received helium-filled balloons, and the even lighter helium 3. Lunar helium-3, arriving at the Moon as part of the solar wind, is imbedded as a trace, non-radioactive isotope in the lunar soils. It represents one potential energy source to meet this century's rapidly escalating demand. There is a resource base ofhelium-3 about of 10,000 metric tonnes just in upper three meters of the titanium-rich soils of Mare Tranquillitatis. This was the landing region for Neil Armstrong and Apollo 11 in 1969. The energy equivalent value of Helium-3 delivered to operating fusion power plants on Earth would be about $4 billion per tonne relative to today's coal. Coal, of course, supplies about half of the approximately $40 billion domestic electrical power market. These numbers illustrate the magnitude of the business opportunity for helium-3 fusion power to compete for the creation of new electrical capacity and the replacement of old during the 21st Century.

Past technical activities on Earth and in deep space provide a strong base for initiating this enterprise. Also, over the last decade, there has been historic progress in the development of inertial electrostatic confinement (IEC) fusion at the University of Wisconsin-Madison. Progress there includes the production of over a milliwatt of steady-state power from the fusion ofhelium-3 and deuterium. Steady progress in IEC research as well as basic physics argues strongly that the IEC approach to fusion power has significantly more commercial viability than other technologies pursued by the fusion community. It will have inherently lower capital costs, higher energy conversion efficiency, a range of power from a few hundred megawatts upward, and little or no associated radioactivity or radioactive waste. It should be noted, however, that IEC research has received no significant support as an alternative to Tokamak-based fusion from the Department of Energy in spite of that Department's large fusion technology budgets. The Office of Science and Technology Policy under several Administrations also has ignored this approach.

On the question of international law relative to outer space, specifically the Outer Space Treaty of 1967, that law is permissive relative to properly licensed and regulated commercial endeavors. Under the 1967 Treaty, lunar resources can be extracted and owned, but national sovereignty cannot be asserted over the mining area. If the Moon Agreement of 1979, however, is ever submitted to the Senate for ratification, it should be deep sixed.

The creation of capabilities to support helium-3 mining operations also will provide the opportunity to support NASA's human lunar and planetary research at much reduced cost, as the cost of capital for launch and basic operations will be carried by the business enterprise. Technology and facilities required for success of a lunar commercial enterprise, particularly heavy lift launch and fusion technologies, also will enable the conduct, and reduce the cost of many space activities in addition to science. These include exploration and settlement of Mars, asteroid interception and diversion, and various national security initiatives.

It is doubtful that the United States or any government will initiate or sustain a return of humans to the Moon absent a comparable set of circumstances as those facing the Congress and Presidents Eisenhower, Kennedy, and Johnson in the late 1950s and throughout 1960s. Huge unfunded "entitlement" liabilities and a lack of sustained media and therefore public interest will prevent the long-term commitment of resources and attention that such an effort requires.

If Government were to lead a return to deep space, the NASA of today is probably not the agency to undertake a significant new program to return humans to deep space, particularly the Moon and then to Mars. NASA today lacks the critical mass of youthful energy and imagination required for work in deep space. It also has become too bureaucratic and too risk-adverse. Either a new agency would need to be created to implement such a program or NASA would need to be totally restructured using the lessons of what has worked and has not worked since it was created 45 years ago. Of particular importance would be the need for most of the agency to be made up of engineers and technicians in their 20s and managers in their 30s, thereinstitution of design engineering activities in parallel with those of contractors, and the streamlining of management responsibility. The existing NASA also would need to undergo a major restructuring and streamlining of its program management, risk management, and financial management structures. Such total restructuring would be necessary to re-create the competence and discipline necessary to operate successfully in the much higher risk, and more complex deep space environment relative to that in near-earth orbit.

Most important for a new NASA or a new agency would be the guarantee of a sustained political (financial) commitment to see the job through and to not turn back once a deep space operational capability exists once again or accidents happen. At this point in history, we cannot count on the Government for such a sustained commitment. This includes not under-funding the effort-a huge problem still plaguing the Space Shuttle, the International Space Station, and other current and past programs. That is why I have been looking to a more predictable commitment from investors who have been given a credible business plan and a return on investment commensurable with the risk.

Attaining a level of sustaining operations for a core business in fusion power and lunar resources requires about 10–15 years and $10 billion to $15 billion of private investment capital as well as the successful interim marketing and profitable sales related to a variety of applied fusion technologies. The time required from start-up to the delivery of the first 100 kg years supply to the first operating 1000 megawatt fusion power plant on Earth will be a function of the rate at which capital is available, but probably no less than 10 years. This schedule also depends to some degree on the U.S. Government being actively supportive in matters involving taxes, regulations, and international law but no more so than is expected for other commercial endeavors. If the U.S. Government also provided an internal environment for research and development of important technologies, investors would be encouraged as well. As you are aware, the precursor to NASA, the National Advisory Committee on Aeronautics (NACA), provided similar assistance and antitrust protection to aeronautics industry research during most of the 20th Century.

A business and investor based approach to a return to the Moon to stay represents a clear alternative to initiatives by the U.S. Government or by a coalition of other countries. Although not yet certain of success, a business-investor approach, supported by the potential of lunar Helium-3 fusion power, and derivative technologies and resources, offers the greatest likelihood of a predictable and sustained commitment to a return to deep space.

Full Text

The Apollo 17 mission on which I was privileged to fly in December 1972 was the most recent visit by human beings to the Moon, indeed to deep space. A return by Americans to the Moon at least 40 years after the end of the Apollo 17 mission probably would represent a commitment to return to stay. Otherwise, it is hard to imagine how a sustained commitment to return would develop in this country.

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Global demand and need for energy will likely increase by at least a factor of eight by the mid-point of the 21st Century. This factor represents the total of a factor of two to stay even with population growth and a factor of four or more to meet the aspirations of people who wish to significantly improve their standards of living.

There is another unknown factor that will be necessary to mitigate the adverse effects of climate change, whether warming or cooling, and the demands of new, energy intensive technologies.

Helium has two stable isotopes, helium 4, familiar to all who have received helium-filled balloons, and the even lighter helium 3. Lunar helium-3, arriving at the Moon as part of the solar wind, is imbedded as a trace, non-radioactive isotope in the lunar soils. It represents one potential energy source to meet this century's rapidly escalating demand. There is a resource base of helium-3 of about 10,000 metric tonnes just in upper three meters of the titanium-rich soils of Mare Tranquillitatis. This was the landing region for Neil Armstrong and Apollo 11 in 1969. The energy equivalent value of Helium-3 delivered to operating fusion power plants on Earth would be about $4 billion per tonne relative to today's coal. Coal, of course, supplies about half of the approximately $40 billion domestic electrical power market. These numbers illustrate the magnitude of the business opportunity for helium-3 fusion power to compete for the creation of new electrical capacity and the replacement of old plant during the 21st Century.

Past technical activities on Earth and in deep space provide a strong base for initiating this enterprise. Such activities include access to and operations in deep space as well as the terrestrial mining and surface materials processing industries. Also, over the last decade, there has been historic progress in the development of inertial electrostatic confinement (IEC) fusion at the University of Wisconsin-Madison. Progress there includes the production of over a milliwatt of steady-state power from the fusion of helium-3 and deuterium. Steady progress in IEC research as well as basic physics argues strongly that the IEC approach to fusion power has significantly more commercial viability than other technologies pursued by the fusion community. It will have inherently lower capital costs, higher energy conversion efficiency, a range of power from a few hundred megawatts upward, and little or no associated radioactivity or radioactive waste. It should be noted, however, that IEC research has received no significant support as an alternative to Tokamak-based fusion from the Department of Energy in spite of that Department's large fusion technology budgets. The Office of Science and Technology Policy under several Administrations also has ignored this approach.

On the question of international law relative to outer space, specifically the Outer Space Treaty of 1967, that law is permissive relative to properly licensed and regulated commercial endeavors. Under the 1967 Treaty, lunar resources can be extracted and owned, but national sovereignty cannot be asserted over the mining area. If the Moon Agreement of 1979, however, is ever submitted to the Senate for ratification, it should be deep sixed. The uncertainty that this Agreement would create in terms of international management regimes would make it impossible to raise private capital for a return to the Moon for helium-3 and would seriously hamper if not prevent a successful initiative by the United States Government.

The general technologies required for the success of this enterprise are known. Mining, extraction, processing, and transportation of helium-3 to Earth requires innovations in engineering, particularly in light-weight, robotic mining systems, but no known new engineering concepts. By-products of lunar helium-3 extraction, largely hydrogen, oxygen, and water, have large potential markets in space and ultimately will add to the economic attractiveness of this business opportunity. Inertial electrostatic confinement (IEC) fusion technology appears be the most attractive and least capital intensive approach to terrestrial fusion power plants, although engineering challenges of scaling remain for this technology. Heavy lift launch costs comprise the largest cost uncertainty facing initial business planning, however, many factors, particularly long term production contracts, promise to lower these costs into the range of $1–2000 per kilogram versus about $70,000 per kilogram fully burdened for the Apollo Saturn V rocket.

A business enterprise based on lunar resources will be driven by cost considerations to minimize the number of humans required for the extraction of each unit of resource. Humans will be required, on the other hand, to prevent costly breakdowns of semi-robotic mining, processing, and delivery systems, to provide manual back-up to robotic or tele-robotic operation, and to support human activities in general. On the Moon, humans will provide instantaneous observation, interpretation, and assimilation of the environment in which they work and in the creative reaction to that environment. Human eyes, experience, judgement, ingenuity, and manipulative capabilities are unique in and of themselves and highly additive in synergistic and spontaneous interaction with instruments and robotic systems (see Appendix A).

Thus, the next return to the Moon will approach work on the lunar surface very pragmatically with humans in the roles of exploration geologist, mining geologist/engineer, heavy equipment operator/engineer, heavy equipment/robotic maintenance engineer, mine manager, and the like. During the early years of operations the number of personnel will be about six per mining/processing unit plus four support personnel per three mining/processing units. Cost considerations also will drive business to encourage or require personnel to settle, provide all medical care and recreation, and conduct most or all operations control on the Moon.

The creation of capabilities to support helium-3 mining operations also will provide the opportunity to support NASA's human lunar and planetary research at much reduced cost, as the cost of capital for launch and basic operations will be carried by the business enterprise. Science thus will be one of several ancillary profit centers for the business, but at a cost to scientists much below that of purely scientific effort to return to the Moon or explore Mars. Technology and facilities required for success of a lunar commercial enterprise, particularly heavy lift launch and fusion technologies, also will enable the conduct, and reduce the cost of many space activities in addition to science. These include exploration and settlement of Mars, asteroid interception and diversion, and various national security initiatives.

It is doubtful that the United States or any government will initiate or sustain a return of humans to the Moon absent a comparable set of circumstances as those facing the Congress and Presidents Eisenhower, Kennedy, and Johnson in the late 1950s and throughout 1960s. Huge unfunded "entitlement" liabilities and a lack of sustained media and therefore public interest will prevent the long-term commitment of resources and attention that such an effort requires. Even if tax-based funding commitments could be guaranteed, it is not a foregone conclusion that the competent and disciplined management system necessary to work in deep space would be created and sustained.

If Government were to lead a return to deep space, the NASA of today is probably not the agency to undertake a significant new program to return humans to deep space, particularly the Moon and then to Mars. NASA today lacks the critical mass of youthful energy and imagination required for work in deep space. It also has become too bureaucratic and too risk-adverse. Either a new agency would needed to implement such a program or NASA would need to be totally restructured using the lessons of what has worked and has not worked since it was created 45 years ago. Of particular importance would be for most of the agency to be made up of engineers and technicians in their 20s and managers in their 30s, the re-institution of design engineering activities in parallel with those of contractors, and the streamlining of management responsibility. The existing NASA also would need to undergo a major restructuring and streamlining of its program management, risk management, and financial management structures. Such total restructuring would be necessary to recreate the competence and discipline necessary to operate successfully in the much higher risk and more complex deep space environment relative to that in near-earth orbit.

Most important for a new NASA or a new agency would be the guarantee of a sustained political (financial) commitment to see the job through and to not turn back once a deep space operational capability exists once again or accidents happen. At this point in history, we cannot count on the Government for such a sustained commitment. This includes not under-funding the effort-a huge problem still plaguing the Space Shuttle, the International Space Station, and other current and past programs. That is why I have been looking to a more predictable commitment from investors who have been given a credible business plan and a return on investment commensurable with the risk.

Attaining a level of sustaining operations for a core business in fusion power and lunar resources requires about 10–15 years and $10 billion to $15 billion of private investment capital as well as the successful interim marketing and profitable sales related to a variety of applied fusion technologies. The time required from start-up to the delivery of the first 100 kg years supply to the first operating 1000 megawatt fusion power plant on Earth will be a function of the rate at which capital is available, but probably no less than 10 years. This schedule also depends to some degree on the U.S. Government being actively supportive in matters involving taxes, regulations, and international law but no more so than is expected for other commercial endeavors. If the U.S. Government also provided an internal environment for research and development of important technologies, investors would be encouraged as well. As you are aware, the precursor to NASA, the National Advisory Committee on Aeronautics (NACA), provided similar assistance and antitrust protection to aeronautics industry research during most of the 20th Century.

In spite of the large, long-term potential return on investment, access to capital markets for a lunar ^{3}He and terrestrial fusion power business will require a near-term return on investment, based on early applications of IEC fusion technology (10). Business plan development for commercial production and use of lunar Helium-3 requires a number of major steps all of which are necessary if long investor interest is to be attracted and held to the venture. The basic lunar resource endeavor would require a sustained commitment of investor capital for 10 to 15 years before there would be an adequate return on investment, far too long to expect to be competitive in the world's capital markets. Thus, "business bridges" with realistic and competitive returns on investment in three to five years will be necessary to reach the point where the lunar energy opportunity can attract the necessary investment capital. They include PET isotope production at point-of-use, therapeutic medical isotope production independent of fission reactors, nuclear waste transmutation, and mobile land mine and other explosive detection. Once fusion energy breakeven is exceeded, mobile, very long duration electrical power sources will be possible. These business bridges also should advance the development of the lunar energy technology base if at all possible.

A business and investor based approach to a return to the Moon to stay represents a clear alternative to initiatives by the U.S. Government or by a coalition of other countries. Although not yet certain of success, a business-investor approach, supported by the potential of lunar Helium-3 fusion power, and derivative technologies and resources, offers the greatest likelihood of a predictable and sustained commitment to a return to deep space.

Appendix A: Space Exploration and Development—Why Humans?

The term "space exploration" implies the exploration of the Moon, planets and asteroids, that is, "deep space," in contrast to continuing human activities in Earth orbit. Human activities in Earth orbit have less to do with exploration and more to do with international commitments, as in the case of the Space Station, and prestige and technological development, as in the case of China and Russia. There are also research opportunities, not fully recognized even after 40 years, that exploit the opportunities presented by being in Earth orbit.

Deep space exploration has been and should always be conducted with the best combination of human and robotic techniques. Many here will argue the value of robotics. I will just say that any data collection that can be successfully automated at reasonable cost should be. In general, human being's should not waste their time with activities such as surveying, systematic photography, and routine data collection. Robotic precursors into situations of undefined or uncertain risk also are clearly appropriate.

Direct human exploration, however, offers exceptional benefits that robotic exploration currently cannot and probably will not duplicate in the foreseeable future, certainly not at competitive costs. What we are really talking about here is the value of field geology. Many of my scientific colleagues, including the late Carl Sagan, have made the argument that everything we learned scientifically from Apollo exploration could have been done roboticly. Not only do the facts not support this claim, but such individuals and groups have never been forced to cost out such a robotic exploration program. I submit that robotic duplication of the vast scientific return of human exploration of six sites on the Moon would cost far more that the approximately $7 billion spent on science and probably more than the $100 million total cost of Apollo. Those are estimates in today's dollars.

What do humans bring to the table?

First, there is the human brain—a semi-quantitative super computer, with hundreds of millions years of research and development behind it and several million years of accelerated refinement based on the requirements for survival of our genus. This brain is both programmable and instantly re-programmable on the basis of training, experience, and preceding observations.

Second, there are the human eyes—a high resolution, stereo optical system of extraordinary dynamic range that also have resulted from hundreds of millions of years of trial and error. Integrated with the human brain, this system continuously adjusts to the changing optical and intellectual environment encountered during exploration of new situations. In that sense, field geological and biological exploration is little different from many other types of scientific research where integration of the eyes and brain are essential parts of successful inquiries into the workings of Nature.

Third, there are the human hands—a highly dexterous and sensitive bio mechanical system also integrated with the human brain as well as the human eyes and also particularly benefiting from several million years of recent development. We so far have grossly underutilized human hands during space exploration, but the potential is there to bring them fully to bear on future activities possibly through integration with robotic extensions or micro-mechanical device integration into gloves.

Fourth, there are human emotions-the spontaneous reaction to the exploration environment that brings creativity to bear on any new circumstance, opportunity, or problem. Human emotions also are the basis for public interest in support of space exploration, interest beyond that which can be engendered by robotic exploration. Human emotions further create the very special bond that space exploration has with young people, both those of all ages in school and those who wish to participate directly in such exploration.

Fifth, there is the natural urge of the human species to expand its accessible habitats and thus enhance the probability of its long-term survival. Deep space exploration by humans provides the foundations for long-term survival through the settlement of the Moon and Mars in this century and the Galaxy in the next.

Finally, there is a special benefit to deep space exploration by Americans—the continual transplantation of the institutions of freedom to those human settlements on the Moon and Mars. This is our special gift and our special obligation to the future.

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Senator BROWNBACK. Thank you, Mr. Schmitt, and thank you for those very provocative set of thoughts and ways we could go about it. I look forward to the discussion.

Dr. Angel?

STATEMENT OF J. ROGER P. ANGEL, PH.D., DIRECTOR, CENTER FOR ASTRONOMICAL ADAPTIVE OPTICS, UNIVERSITY OF ARIZONA, STEWARD OBSERVATORY

Dr. ANGEL. Thank you, Senator, for having me here.

I'm an astronomer at the University of Arizona, and quite a bit of my time has been spent——

Senator BROWNBACK. Dr. Angel, please pull that mike closer to you. Our technology's not that good here.

Dr. ANGEL. My time has been spent learning how to make large mirrors for ground-based telescopes, and we're about to put the largest ground telescope in Arizona. I think about the future of very big telescopes, both on the ground and in space, and I recently chaired a meeting supported by the Space Studies Board, looking at the uses for very large optics in space. That meeting involved astronomers, Earth scientists, various government agencies, Defense, and so on, and it was very exciting. A lot of these agencies, for different reasons, are interested in having much larger telescopes in space. If you focus these large telescopes down at the Earth, they give you higher resolution and you can see a bigger piece of the Earth from the geosynchronous orbit. Of course, these larger telescopes let us see further into space, which is very welcome for astronomers.

Although there are many different configurations of telescopes, sometimes more than one mirror, different wavelengths, there was a common interest, across the agencies, in learning how to make very precise optics for large mirrors and in having the infrastructure in space to put these telescopes in different places. And to view the Earth, you need to be in geosynchronous orbit. For astronomy, we're kind of torn, because being in low-Earth orbit, where we can do easy servicing, like the Hubble, has been enormously advantageous. We believe we won't be able to make these large telescopes unless we have some of the lessons learned from the Hubble and Space Station, about building big structures in space.

On the other hand, it's a very strong impetus to have these telescopes far from the Earth, because the Earth radiates heat, telescopes near the Earth are warm. But the farther you can get these telescopes from Earth, the telescopes become very cold, and then there are just wonderful things to do with cold telescopes. And we've seen that already with the Wilkinson MAP Telescope, which looked at the microwave background with SIRTF—that's just gone up the Webb Telescope. All these telescopes are taking advantage of the enormous low temperature, cryogenic temperatures, in space, to look for infrared waves. And some of the things we could look at in the future with a bigger telescope, that can see in the infrared, that's cold. For instance, I think—we hope to find planets like Earth around other stars, perhaps with smaller telescopes, but we have no idea whether these have life on them. If we had a big telescope, looking in the infrared, in space, we could actually analyze the light from these planets and see if they had life. Our own planet, you know, completely changed its composition because of life two billion years ago, and if that same composition happened in another planet, we could see it with one of these big telescopes.

And another great use, if we can get into the infrared, is that—the present understanding of our universe is that after the Big Bang, the universe went completely dark for hundreds of millions of years; and then, during that time, gravity gradually got this whole matter together into lumps; and then, finally, after a few hundred million years, this material exploded into the very first stars. And up to that time, there was only hydrogen and helium in the universe; but after this dark age, the first stars created the matter of which we're made, carbon and nitrogen and so on. And none of the telescopes today can see these first stars. This is, we think, all that happened. But with a big telescope, a cold one, we could actually see those stars, see when this happened, and see what was going on. So that would be another great goal.

So we have this division. In order to build these things, we need people, robots, some mixture, which we'll have to work out, but in order to operate them, we need to be far from the Earth.

So the other cold telescopes have gone to orbits—there's an orbit a million miles from the Earth, in the opposite direction to the Sun, where the spacecraft won't float away and where it can run cold, and that's where the Webb Telescope and the MAP Telescope are operating, or will operate. So I thought—these are hard to get people to. You can bring telescopes back to about the distance of the Moon without too much energy, but you would still have to get your servicing operation out to that distance.

So then is the question—and I'm sorry it's taken so long—but what about the Moon, itself, as a place to put telescopes? And in the place where Senator Schmitt went, there probably isn't a good place for the telescope, because it's very hot in the day and very cold at night. But there is an interesting place on the Moon, and that's the very South Pole of the Moon, here.

So I haven't been to the Moon, but I can go there in imagination. Let's go to the south pole and stand there, and what do we see? The Moon spins around an axis, which isn't tilted, like the Earth's, so—and it faces the Earth—so we see the Earth on the horizon, always there in one place. And during the month, we see the Sun go around the horizon. And so we can put up a very simple screen and make the telescope completely cold, because we can screen from the Earth's radiation and from the Sun. So we can get a cryogenic temperature. In fact, if we look around, we see that there's a crater right at the south pole, and down in the crater, it is cryogenic temperature already, so we could put our telescope there.

And then we notice that on the wall of the crater, the Sun always shines, because it's always going around the horizon. So our solar power can run continuously.

And then we notice another great thing. Senator Schmitt has pointed to helium as an asset, helium–3, but there's a very simple thing at the South Pole which is a huge asset, and that's water. There's water ice in these pole craters. And if you want to set up a base on the Moon, having water available and having electric power continuously available is terrific. So I think, independent of any telescopes, this would be a good place to have a base.

And then if we look up in the sky, it's perfect, like the clarity of vision that we have at any of the other places in space. There's no atmosphere. And then one thing we see is that if you look straight up, it's always the same stars up there. So we have a problem which I think we haven't thought about, and NASA hasn't thought about much yet. That is, there is gravity on the Moon. It's a lot less than on the Earth, but maybe we could build telescopes that we could steer around in this place, in this cryogenic environment. There's a very simple thing that we could do. That is, the job of looking for these first stars. We can look straight up, where the same stars are always there. So we could build a simple telescope—a big one, but dumb; it just sits there, looking straight up—that could do this job of finding the very first stars after the Big Bang.

So it's a very interesting place, as a base and for astronomy. I think my friends in astronomy would say, "Looking straight up is great, but we"—and I'd say, because the stars that have planets aren't straight up, they're wherever they want to be. So if we want to do a full job of astronomy, we would have to eventually learn how to make a telescope there that could at least see around the vertical axis to follow stars. But it is, I think, a very interesting place for really good astronomy.

I just want to finish. I hope that NASA planning, up to this point, has been, I think, more focused on going to the free orbiting sites, like where MAP and Webb are, but I hope they will consider telescopes on the Moon. And I think it should be an input where we think where we're going after Space Station and after Shuttle. What do we need to go? What do we need to do? I hope this will be one of the options that gets looked at very seriously.

[The prepared statement of Mr. Angel follows:]

PREPARED STATEMENT OF J. ROGER P. ANGEL, PH.D., DIRECTOR, CENTER FOR ASTRONOMICAL ADAPTIVE OPTICS, STEWARD OBSERVATORY, UNIVERSITY OF ARIZONA

CONSTRUCTION AND UTILIZATION OF LUNAR OBSERVATORIES

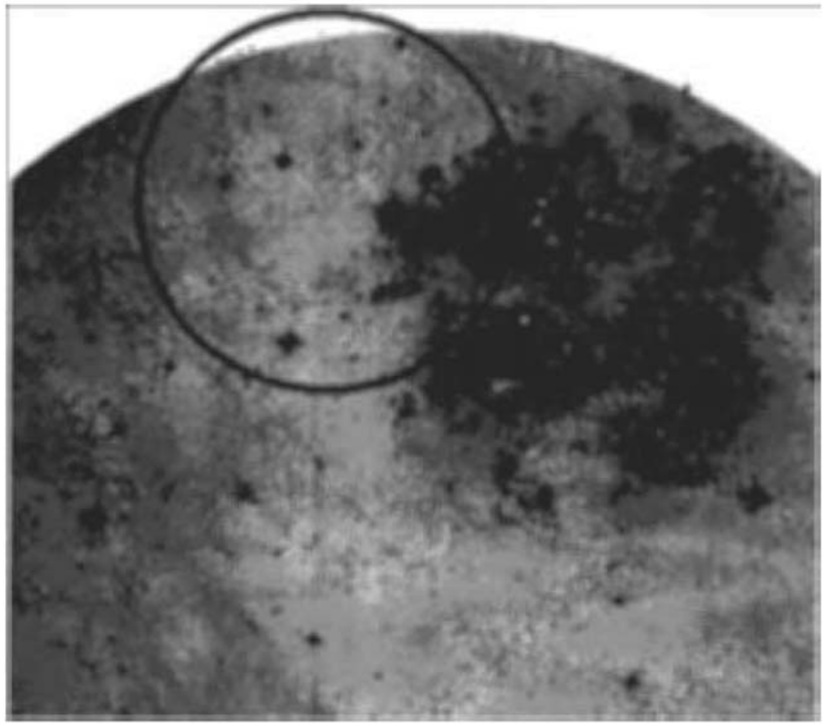
I am an astronomer at the University of Arizona, where big ground-based telescopes and their mirrors are made. We are now completing construction of the Large Binocular Telescope, which will become the single largest in the world.

In September this year I chaired a meeting sponsored by the National Academy of Science's Space Studies Board to look at future needs and technologies for large optics in space. We found broad interest in sizes beyond the 2.4 m Hubble and planned 6 m James Webb Space Telescopes, for astronomical research, for environmental studies and for defense. The different uses lead to different telescope configurations, wavelengths of operation (from ultraviolet to millimeter), and different optimum locations. But we found strong common interest across the agencies in developing technologies to make and control very big optical systems to exquisite, diffraction-limited quality and in the infrastructure to construct, deploy and service very large optical systems in space.

For Earth imaging and defense, the optical systems need to be near Earth, and geosynchronous orbits are especially valuable. For astronomy, operation in low Earth orbit, like Hubble Space Telescope, has the huge, proven advantage of astronaut access, but has limits because of the constant cycling in and out of sunlight. The major limit is that deep infrared observations are not possible, because they require a cryogenically cooled telescope, permanently shaded from solar light and far from the heat radiated by the warm Earth. The recently launched 0.9 m SIRTF telescope and the Webb telescope are in such locations.

Let me mention two different astronomical goals that would need even larger telescopes. One is detection of warm, Earth-sized planets around nearby stars like the sun. We expect to find them with bigger telescopes, but have no idea if they will have life. But we could find out by analyzing their spectra. Another goal will be to see the light of the first stars that has been on its way towards us through most of time. Our understanding is that the big bang created a uniform gas of just hydrogen and helium, and that after this cooled off the universe was completely dark and without form for hundreds of millions of years. And then there was light. Gravity had slowly pulled the gas together into lumps and then into to massive, brilliant stars, whose nuclear burning started to produce the elements like carbon and oxygen and iron from which the Earth and life are made.

We know a lot about the big bang, because it was so bright we can easily see and analyze its brilliant light, now cooled off to become radio waves. First seen from New Jersey, these were recently mapped out from Antarctica and by NASA's cryogenic WMAP spacecraft. Today we can only speculate on the first stars, but their light will now be in the form of faint heat waves. Given a very big, very cold telescope in space that stares for a year or more at the same spot, we could likely detect them and analyze their spectra.



The circle shows the 6° diameter field accessible to the zenith pointing telescope at the lunar south pole. Ultraviolet image recorded on the Moon by John Young and Charles Duke[5].

What we need for a such a telescope is find a way to combine the capability for maintenance and improvement of HST with operation at a remote, permanently shaded operation. Most thinking so far at NASA has focused on operation at the WMAP and proposed Webb location, in an orbit of the sun a million miles beyond Earth's (L2). Servicing would likely involve ferrying a telescope (or part of it) to a nearer orbit, but still 'l'4 million miles away, for more convenient access.

An alternative location for a very large telescope would be the lunar south pole, in the Shackleton crater where the sun never shines and cryogenic temperatures prevail. This would be convenient for construction and maintenance if there were a Moon base at the pole. The Moon has no atmosphere, so light from the stars would have the same pristine quality as in free space. Only the southern hemisphere would be observable, but this is not a major astronomical limitation.

The lunar south pole is a good choice for siting a lunar base, independent of any telescope. The craters are believed to contain water ice, most valuable than gold for the base[1]. Also, the crater rim has small areas of nearly eternal sunshine, simplifying problems of maintaining electric power and temperate living conditions[2]. Furthermore, the adjacent South-Pole-Aitken basin is the oldest and deepest impact crater on the Moon, and has been flagged for study in the recent NRC study[3].

Many technical, engineering and infrastructure issues remain to be explored. The Moon provides a platform on which to build big structures, but it also comes with gravity and weight, albeit at 1/6[1]th of the Earth's value. Freely-orbiting telescopes avoid the need for bearings and drives. Magnetic levitation on superconducting bearings might simplify the task of turning the telescope around during each month to track the stars. We would need to make sure the telescope optics are not compromised by vibrations or dust and condensed gas from the base.

Gravity can be turned to an advantage for the kind of telescope we need to look back to the first stars. These will be all over the sky, and a good place to look is straight overhead. From the Moon's pole the infrared sky is darkest overhead, and we can look at the same unchanging patch of sky for the years needed to study the extremely faint first stars. A specialized telescope for this work doesn't have to move. Very high resolution images could be made with multiple such telescopes laid out as an interferometer, with no moving parts. We may even be able to use a trick to make a telescope mirror looking straight up by spinning a thin layer of reflecting liquid in a big dish. A 6-m diameter telescope of very high quality has been built like this very inexpensively in Canada[4]. Bigger ones won't work on the Earth because the spinning makes a wind that ruffles the surface. But with no wind or air on the Moon, a 20 m or larger mirror might be made this way. A cryogenic liquid with evaporated gold coating would be used. A fixed telescope would not satisfy many astronomical goals, which need access over a good part of the sky. For example, the few nearby stars where we can hope to study Earth-like planets are randomly distributed all over the sky. But a liquid telescope at a manned base could undertake one of the challenging observations we have for big telescopes. Experience developed in this way at the base might then show that a fully-steerable big telescope would be practical on the Moon.

More details of the liquid mirror telescope and its scientific potential are give in the attached white paper.

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Senator BROWNBACK. Thank you, Dr. Angel. It was very thoughtful, very thought-provoking.

Dr. Criswell?

STATEMENT OF DR. DAVID R. CRISWELL, DIRECTOR, INSTITUTE FOR SPACE SYSTEMS OPERATIONS, UNIVERSITY OF HOUSTON AND UNIVERSITY OF HOUSTON-CLEAR LAKE

Dr. CRISWELL. Mr. Chairman and Members of the Subcommittee, I'm honored to have this opportunity to introduce a program for the economic and environmental security for Earth, and especially the United States of America, by meeting Earth's real electric power needs.

By 2050, approximately 10 billion people will live on Earth, demanding about five times the power now available. By then, solar power from the Moon could provide everyone clean, affordable, and sustainable electric power. No terrestrial options can provide the needed minimum of two kilowatts electric per person, or at least 20 terawatts globally.

Solar power bases will be built on the Moon that collect a small fraction of the Moon's dependable solar power and convert it into power beams that will dependably deliver lunar solar power to receivers on Earth. On Earth, each power beam will be transformed into electricity and distributed on demand through local electric power grids. Each terrestrial receiver can accept power directly from the Moon or indirectly, via relay satellites, when the receiver cannot view the Moon. The intensity of each power beam is restricted to 20 percent or less of the intensity of noontime sunlight.

Each power beam can be safely received, for example, in an industrially zoned area.

The Lunar Solar Power system does not require basic new technological developments. Adequate knowledge of the Moon and the essential technologies have been available since the late 1970s to design, build, and operate the LSP system. Automated machines and people would be sent to the Moon to build the lunar power bases. The machinery would build the power components from the common lunar dust and rocks, thereby avoiding the high cost of transporting materials from the Earth to the Moon. The LSP system is distributed and open. Thus, it can readily accommodate new manufacturing and operating technologies as they become available.

Engineers, scientists, astronauts, and managers skilled in mining, manufacturing, electronics, industrial production of commodities, and aerospace will create new wealth on the Moon. Thousands of tele-robotic workers in American facilities, primarily on Earth, will oversee the lunar machinery and maintain the LSP system.

Our national space program, in cooperation with advanced U.S. industries, can produce the LSP system for a small fraction of the cost of building equivalent power-generating capacity on Earth. Shuttle and Space-Station-derived systems and the LSP production machinery can be operational in space and on the Moon within a few years. A demonstration LSP system can quickly grow to 50 percent of average U.S. electric capacity, about two-tenths of a terawatt electric, within 15 years, and be profitable thereafter.

When LSP provides 20 terawatts of electric power to Earth, it can sell the electricity at one-fifth of today's costs, or about a tenth of a cent a kilowatt electric hour. At current electric prices in the U.S., LSP would generate approximately $9 trillion per year of net income.

Like hydroelectric dams, every power receiver on Earth can be an engine of clean economic growth. Gross world product can increase a factor of ten. The average annual per capita income of developing nations can increase from today's approximately $2,500 per year per person to the order of $20,000. Economically driven immigrations, such as from Mexico and Central America to the United States, will gradually decrease. Increasingly wealthy developing nations can generate new and rapidly growing markets for American goods and services. Lunar power can generate hydrogen to fuel cars at low cost and with no release of greenhouse gases. United States payments to other nations for oil, natural gas, petrochemicals, and commodities such as fertilizers will decrease. LSP industries will establish new high-value American jobs. LSP will generate major investment opportunities for Americans. The average American income could increase from today's approximately $35,000 a year per person to more than $150,000 per year per person.

By 2050, the LSP system could allow all human societies to prosper while nurturing, rather than consuming, the biosphere.

Thank you.

[The prepared statement of Dr. Criswell follows:]

PREPARED STATEMENT OF DR. DAVID R. CRISWELL, DIRECTOR, INSTITUTE FOR SPACE SYSTEMS OPERATIONS, UNIVERSITY OF HOUSTON AND UNIVERSITY OF HOUSTON-CLEAR LAKE

Mr. Chairman and Members of the Subcommittee:

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Solar power bases will be built on the Moon that collect a small fraction of the Moon's dependable solar power and convert it into power beams that will dependably deliver lunar solar power to receivers on Earth. On Earth each power beam will be transformed into electricity and distributed, on-demand, through local electric power grids. Each terrestrial receiver can accept power directly from the Moon or indirectly, via relay satellites, when the receiver cannot view the Moon. The intensity of each power beam is restricted to 20 percent, or less, of the intensity of noontime sunlight. Each power beam can be safely received, for example, in an industrially zoned area.

The Lunar Solar Power (LSP) System does not require basic new technological developments. Adequate knowledge of the Moon and the essential technologies have been available since the late 1970s to design, build, and operate the LSP System. Automated machines and people would be sent to the Moon to build the lunar power bases. The machines would build the power components from the common lunar dust and rocks, thereby avoiding the high cost of transporting materials from the Earth to the Moon. The LSP System is distributed and open. Thus, it can readily accommodate new manufacturing and operating technologies as they become available.

Engineers, scientists, astronauts, and managers skilled in mining, manufacturing, electronics, aerospace, and industrial production of commodities will create new wealth on the Moon. Thousands of tele-robotic workers in American facilities, primarily on Earth, will oversee the lunar machinery and maintain the LSP System.

Our national space program, in cooperation with advanced U.S. industries, can produce the LSP System for a small fraction of the cost of building equivalent power generating capabilities on Earth. Shuttle-and Space Station-derived systems and LSP production machinery can be in operation in space and on the Moon within a few years. A demonstration LSP System can grow quickly to 50 percent of averaged U.S. electric consumption, ~0.2 TWe, within 15 years and be profitable thereafter. When LSP provides 20 terawatts of electric power to Earth it can sell the electricity at one-fifth of today's cost or ~1 ¢/kWe-h. At current electric prices LSP would generate ~9 trillion dollars per year of net income.

Like hydroelectric dams, every power receiver on Earth can be an engine of clean economic growth. Gross World Product can increase a factor of 10. The average annual per capita income of Developing Nations can increase from today's $2,500 to ~$20,000. Economically driven emigrations, such as from Mexico and Central America to the United States, will gradually decrease.

Increasingly wealthy Developing Nations will generate new and rapidly growing markets for American goods and services. Lunar power can generate hydrogen to fuel cars at low cost and with no release of greenhouse gases. United States payments to other nations for oil, natural gas, petrochemicals, and commodities such as fertilizer will decrease. LSP industries will establish new, high-value American jobs. LSP will generate major investment opportunities for Americans. The average American income could increase from today's ~$35,000/y-person to more than $150,000/y-person.

By 2050, the LSP System would allow all human societies to prosper while nurturing rather than consuming the biosphere.

The Lunar Solar Power System and its general benefits are described in the attached four-page document.

Additional papers are available on these websites and via search engines (search on "David R. Criswell" or "Lunar Solar Power"):

The Industrial Physicist
http://www.tipmagazine.com

The World Energy Congress (17th and 18th)
http://www.worldenergy.org/wec-geis/

ATTACHMENTS

LUNAR SOLAR POWER (LSP) SYSTEM (Figure 1)

1. BASES ON THE MOON DEPENDABLY COLLECT SOLAR POWER AND CONVERT IT TO POWER BEAMS

2. THE POWER BEAMS ARE DIRECTED TO POWER RECEIVERS ON EARTH

3. POWER RECEIVERS CONVERT THE DEPENDABLE BEAMS TO PURE ELECTRICITY

4. POWER RECEIVERS SUPPLY CLEAN, ABUNDANT, AFFORDABLE, AND DEPENDABLE ELECTRIC POWER TO LOCAL AND REGIONAL POWER GRIDS ANYWHERE ON EARTH

LUNAR SOLAR POWER (LSP) SYSTEM AND BENEFITS

1. PROVIDES AMERICANS
   — Secure, dependable, abundant, clean, and affordable primary energy
   — Significant energy growth potential at low marginal cost
   — A new technical basis for rapidly growing and sustainable wealth
   — New high-quality jobs across a wide range of professions in a rapidly expanding global economy

2. PROVIDES AMERICA A NEW POLITICAL PARADIGM FOR ENERGY
   — Positive balance of payments from global sales of LSP electricity
   — Major new global revenue to U.S. organizations
   — "Marshall *Investment* Plan" for developing nations that increases American markets

3. ENABLES U.S.A. TO BE THE FIRST MAJOR "EARTH NURTURING" NATION
   — No industrial greenhouse gasses, nuclides, dust, etc.
   — No hazardous facilities (nuclear, dams, mines, etc.)
   — Reduced land use to provide energy and support industry
   — LSP input power completely balanced by reflecting sunlight back to space
   — Remediation of environmental damage
   — Completely clean electricity that enables completely clean recycling of goods
   — Non-polluting services and transport
      - Production of hydrogen for clean fuels
      - Production of recyclable synthetic petroleum from air and water

4. ENABLES
   — Growing American wealth and population beyond Earth
   — Routine travel between Earth and orbit and the Moon
   — Secure and huge off-Earth private and government data, information, communications, and observation systems
   — Planetary protection
      - Solar shields to adjust solar flux onto Earth
      - LSP beams that gently deflect dangerous asteroids and comets far from Earth

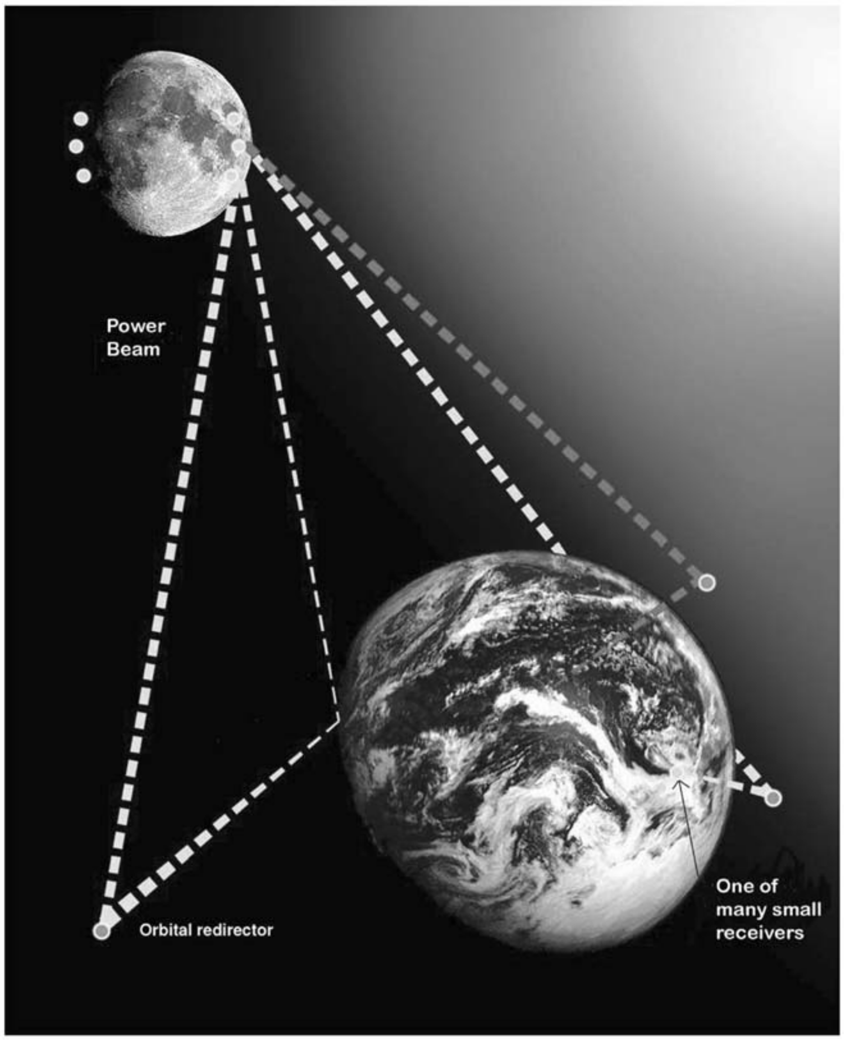

Figure 1. Lunar Solar Power System

IMPLEMENTATION OF THE LUNAR SOLAR POWER SYSTEM

For nine years the United States invested 180 B$ (1996$s) in Apollo and, since, ~380 B$ in civil space. It is time to focus our space program to reap major commercial rewards.

	ACTIONS	DONE BY
1.	Establish and support core organizing group	2003
2.	Build and demonstrate on the Earth the LSP demonstration power plots a. Collect solar power b. Convert the solar power to beams of 10 – 12 cm radio waves c. Transmit test-level power beams from the Earth to receivers on unmanned lunar landers	2005
3.	Demonstrate LSP power plots on the Moon (Figure 2)	2006

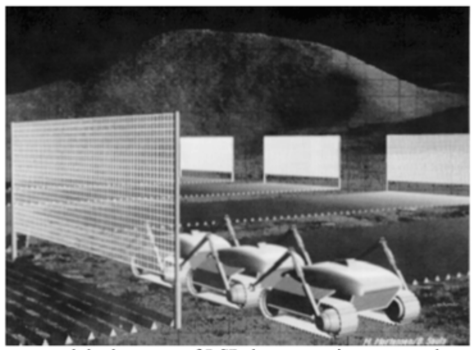

Figure 2. Automated deployment of LSP demonstration power plots on the Moon

4.	Utilize international laws to enable development of commercial electric power installations on the Moon and enable private investment	2006
5.	Build and demonstrate on the Earth the machines (Figure 3, items #4, #5, and #6) that construct the power plots (items #1, #2, and #3)	2006
6.	Establish large-scale transportation between the Earth and the Moon using government and then privatized systems	2008
7.	Demonstrate production of power plots on the moon (Figure 3, items #1, #2, and #3, using equipment #4, #5, and #6)	2008
8.	Establish a government LSP production base on the Moon and then privatize it (Figure 3)	2009
9.	First commercial rectenna on Earth feeds LSP electricity into the grid (Figure 4)	2011
10.	Begin building LSP manufacturing systems on the moon (Figure 3, item #6)	2011
11.	Provide all new electrical power capacity for the United States	2015
12.	Expand production systems and LSP power bases to ≥20 TWe and enable global prosperity of ≥300 T$/y (≥30,000 $/y-person) and high-return investment opportunities for Americans (Figures 1 and 4)	2040

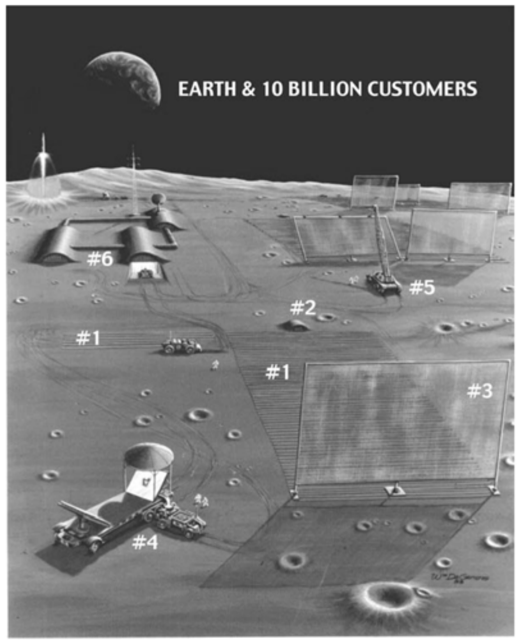

Figure 3. Demonstration LSP power base and a few power plots, each plot composed of solar arrays (#1), radio wave transmitters (#2), and sub-reflectors (#3)

Figure 4. Commercial power receiver, built over farm land, accepting an invisible power beam and feeding clean electric power to a large city and its region

Senator BROWNBACK. Thank you very much, Dr. Criswell, for those thoughts, and I look forward to questioning and discussing them with you. They're quite provocative, as well.

Dr. Spudis, thank you very much for joining us.

STATEMENT OF DR. PAUL D. SPUDIS, PLANETARY SCIENTIST, LUNAR AND PLANETARY INSTITUTE

Dr. SPUDIS. Mr. Chairman, Members of the Committee, thank you for inviting me here today to testify on the subject of lunar exploration and the U.S. Space Program.

Although we conducted our initial visits to the Moon over 30 years ago, several recent discoveries indicate that a return offers many benefits to the Nation. In addition to being a scientifically rich object for study, the Moon offers abundant material and energy resources, the feedstock of an industrial space infrastructure. Once established, this will give us continuous routine access to Earth-Moon space and beyond.

The value of the Moon as a destination has not escaped the notice of other countries. At least four new robotic missions are currently being either flown or prepared by Europe, India, Japan, and China. Advance planning for human missions in many of these countries is already underway.

With me today is Dr. Bill Stone, a leading explorer and expedition leader. The following points represent our joint thinking as to why the Nation needs to return to the Moon and why that return should take place now, rather than later.

Point one. NASA needs a politically viable mission, and both Shuttle and ISS are losing appeal as space exploration. Since the loss of Columbia, we have seen much soul searching over the meaning of our space efforts. A sense has developed that missions to low-Earth orbit, while technically qualifying as spaceflight, leave much to be desired as exploration. Any new focus in space must have direct and clear benefits to the Nation. What the Nation needs is a Lewis-and-Clark-class mission, one that opens the space frontier to the expansion of commerce.

Point two. Human missions to Mars are too technically challenging and too expensive to be feasible national space goals within the next decade. The current state of technology barely supports the idea that we can go there with people. A Mars mission would cost hundreds of billions of dollars and take more than a decade. The rationale for such a trip is ill-defined beyond the vague notion that Mars may have once harbored primitive cellular life. Such a speculation, while intriguing, cannot justify a massive expenditure of Federal money.

Point three. Other possible destinations for people in space are perceived to be either too arcane or too uninteresting to garner broad national support. Missions to the Lagrangian Points are useful departure points to other destinations, but contain nothing there themselves, except what we put there. As a program, they are, thus, Space Station 2, in a different place. Asteroids, the leftover debris of planetary formation, take weeks or months to reach, and, once we get there, offer little diversity of process, scenery, or terrain. Asteroids will be useful in the future for resource utilization, but they have little appeal as an exciting human destination.

Point four. The Moon is close, accessible with existing systems, and has resources that we can use to create a true space-faring economy. The Moon is an ideal target for our next destination in space. It is only 3 days away, and accessible with existing launch and space assets. We can use the resources of the Moon to create access for people and machines to all points of Earth-Moon space. In going to the Moon, our new mission is to learn how to use off-planet resources.

Point five. We can conduct a wide variety of important scientific research on the Moon, ranging from planetary science to astronomy and high-energy physics. The Moon is a natural laboratory for planetary and space science. In particular, it offers a detailed record of the impact history in the Earth-Moon system, including the major impact episodes responsible for the extinction of life on Earth. Further study can illuminate not only our early history, but possibly our fate.

Point six. Hydrogen, probably in the form of water ice, exists at both poles of the Moon and can be extracted and processed into rocket propellent and life-support consumables. In 1994, the Department of Defense Clementine Mission, which I was fortunate enough to be involved in as a science team member, discovered water ice in the dark areas near the South Pole of the Moon, a discovery later confirmed by NASA's Lunar Prospector. This water ice is stable because the floors of the polar craters never receive sunlight and are, hence, very cold. At least 10 billion tons of hydrogen are available at the lunar poles, a volume of water equivalent to the Great Salt Lake. This material can be collected and used to make hydrogen and oxygen, rocket propellent for transport, and be used as water and oxygen to support human life on the Moon and in space.

Point seven. We can be back on the Moon with 5 to 7 years for only a modest increase in existing space budgets. We can return to the Moon using existing or Shuttle-derived launch systems and Station-derived hardware. Missions can be staged from and return to the International Space Station. A complete program includes robotic precursor missions and the initial human visits to the Moon within 5 years, and production of usable lunar resource commodities within 7 years. An alternative implementation that focuses on cost reduction and early return on investment is described in Dr. Stone's "Shackelton Crater Expedition," attached to my testimony. No matter which implementation is selected, lunar return is feasible from both a budgetary and technical perspective.

Point eight. The establishment of a space economy based on the use of lunar resources will enable routine travel, with people, throughout the Earth-Moon system. By learning to characterize, extract, and use lunar resources, we free ourselves from the surly bonds of Earth. Operations in space become routine and inexpensive. This goal, while challenging, is within our current technical means, or modest extensions of them. For humanity to have a future in space, we must learn to live off the land.

Point nine. The establishment of an Earth-Moon economy enhances national security and commerce. The availability of cheap lunar fuel in low-Earth orbit will change the way national security assets are designed and deployed. It will dramatically reduce the cost of procurement of such assets, while extending their useful life, service life, by enabling routine access for maintenance and repair.

Point ten. The infrastructure created by a return to the Moon will allow us to travel to the planets in the future more safely and cost effectively. Routine travel to the Moon also means routine access to the gravitationally stable Lagrangian points, from which economical missions to the planets, including Mars, can be staged using lunar propellent. Thus, a program to develop and use resources from the Moon is not a diversion from other goals, it is an enabling activity.

America needs a challenging, vigorous space program, one with a mission that inspires and enriches. It must relate to important national needs, yet push the boundaries of the possible. It must serve larger national concerns, beyond scientific endeavors. A return to the Moon fulfills these goals. It is a technical challenge to the Nation. It creates security for America by assuring access to and control of our assets in Earth-Moon space. It creates wealth in new markets by producing commodities of high commercial value. It stimulates and inspires the next generation by giving them the chance to experience spaceflight for themselves. A return to the Moon is the right destination for America.

Thank you for your attention. I would be happy to answer any questions.

[The prepared statement of Dr. Spudis follows:]

PREPARED STATEMENT OF DR. PAUL D. SPUDIS, PLANETARY SCIENTIST, LUNAR AND PLANETARY INSTITUTE

Mr. Chairman and members of the Committee, thank you for inviting me here today to testify on the subject of lunar exploration and the U.S. space program.

I want to discuss a new destination for America in space—the Moon. Although we conducted our initial visits to that body over 30 years ago, we have recently made several important discoveries that indicate a return to the Moon offers many advantages and benefits to the Nation. In addition to being a scientifically rich object for study, the Moon offers abundant material and energy resources, the feedstock of an industrial space infrastructure. Once established, such an infrastructure will revolutionize space travel, assuring us of continuous, routine access to cislunar space (*i.e.,* the space between and around Earth and Moon) and beyond. The value of the Moon as a space destination has not escaped the notice of other countries—at least four new robotic missions are currently being flown or prepared by Europe, India, Japan, and China and advanced planning for human missions in many of these countries is already underway.

With me here today is Dr. Bill Stone, a prominent explorer and expedition leader. The points which I will present represent our joint thinking as to WHY the Nation needs to return to the Moon and why that return should take place NOW rather than later.

(1) NASA needs a politically viable mission and both Shuttle and ISS are losing appeal as "space exploration." America needs a compelling space program!

Forty years ago, America made a decision to go to the Moon, starting from a state of primitive technology and vast ignorance. We accomplished this great feat within 8 years, giving us for the first time the ability to travel to another world. We now have a commercial launch industry that each year lifts a mass equivalent to an Apollo mission to geosynchronous orbit. Its mission accomplished, NASA looked to other programs to keep the dream of space flight alive. Shuttle was presented as an affordable means to low Earth orbit. Space Station was planned as both a laboratory in orbit and a way station to the rest of the Solar System. Meanwhile, the Moon largely was ignored as an object worthy of study in its own right, as a natural space station to provision and enable space flight farther a field, and as a center of commerce and national security.

NASA's current problems are partly technical, but mostly related to the fact that it no longer has a mission, as in its early "Days of Glory." Forty years ago, its mission was to beat the Soviets to the Moon, a clear goal articulated by the national leadership and presented with a deadline (by the end of the decade). Now, the agency looks for a mission, but has yet to find one, at least, one perceived by government and the American people as worthy of long-term commitment. In the absence of such a goal, we drift between projects and have some success, but nothing is cumulative, where each step builds upon and extends the capability of the step preceding it.

A new national focus in space must have a direct and clear benefit to the American public. Pure science and the search for life are not defensible justifications. As Dr. Stone has put it recently, what the Nation needs is a Lewis and Clark-class mission—one that opens the frontier to the expansion of the external commerce of the United States (through the general participation of its people and industry) and to the enhancement of the security of the Nation. The recent loss of Shuttle Columbia has only heightened the perception that we are adrift in space, with no long-term goals or direction. Death and risk are part of life and not to be feared, especially in the field of exploration, but for death to have meaning, the objectives of such exploration must be significant. Great nations do great (and ambitious) things. The Apollo project was one such example; a return to the Moon to learn how to live off-planet can be another.

(2) Human missions to Mars currently are too technically challenging and too expensive to be feasible national space goals within the next decade.

Although much attention is given to the idea of human missions to Mars as the next big goal in space, such a journey is at present beyond our technical and economic capabilities. The large amount of discretionary money needed for such a journey is simply not available in the Federal budget nor would it be wisely spent on going to Mars in an Apollo-style "flags-and-footprints" program. The principal justification of a manned Mars mission is scientific and such a rationale cannot sustain a large investment in the eyes of the taxpaying public. Mars awaits exploration by people some time in the future, after we have learned how to live and work routinely in space and how to make use of the resources available on other worlds to break the costly ties to Earth-based rocket transport of materiel.

American government has a history of supporting long-term, big engineering projects, provided that such efforts contribute to goals related to national and economic security (*e.g.,* the Panama Canal, the Apollo program). The nation needs a mission whose purpose relates to these important, enduring objectives. A return to the Moon is such a goal. Indeed, it is a necessary goal and the only economically-justifiable goal at this time.

(3) Other possible destinations for people in space are perceived to be either too uninteresting (asteroids) or too arcane (telescopes in deep space) to enjoy "widespread" national support.

Among other possible space destinations for people are the Lagranian (L-) points (imaginary spots in space that move in sync with Earth, Moon, Sun or other objects) and the minor planets, better known as asteroids. The Lagranian points have many advantages for the staging of missions that go elsewhere, but the only thing they contain is what we put there. In that sense, they are similar to low Earth orbit and significant activity at the L-points, without travel beyond them to more interesting destinations, would resemble another International Space Station put in a different location. Asteroids have great potential for exploration and exploitation of resources and may eventually become an important destination as a class of objects. However, the times required to reach asteroids can equal the months-long transit times for Mars missions, without the variety of activities that could be undertaken at the end of such a trip. Thus, although specialized missions to these destinations can be imagined, they do not present a compelling return on investment nor the scientific or operational variety that other missions possess.

(4) The Moon is close, accessible with existing systems, and has resources that we can use to create a true, economical space-faring infrastructure

The Moon is a scientific and economic treasure trove, easily reachable with existing systems and infrastructure that can revolutionize our national strategic and economic posture in space. The dark areas near the poles of the Moon contain significant amounts (at least 10 billion tons) of hydrogen, most probably in the form of water ice. This ice can be mined to support human life on the Moon and in space and to make rocket propellant (liquid hydrogen and oxygen). Moreover, we can return to the Moon using the existing infrastructure of Shuttle and Shuttle-derived launch systems and the ISS for only a modest increase in the space budget within the next five years.

The "mission" of this program is to go to the Moon to learn how to use off-planet resources to make space flight easier and cheaper in the future. Rocket propellant made on the Moon will permit routine access to cislunar space by both people and machines, which is vital to the servicing and protection of national strategic assets and for the repair and refurbishing of commercial satellites. The availability of cheap propellant in low Earth orbit would completely change the way engineers design spacecraft and the way companies and the government think of investing in space assets. It would serve to dramatically reduce the cost of space infrastructure to both the government and to the private sector, thus spurring economic investment (and profit).

(5) The Moon is a scientific treasure house and a unique resource, on which important research, ranging from planetary science to astronomy and high-energy physics, can be conducted.

Generally considered a simple, primitive body, the Moon is actually a small planet of surprising complexity. Moreover, the period of its most active geological evolution, between 4 and 3 billion years ago, corresponds to a "missing chapter" of Earth history. The processes that work on the Moon—impact, volcanism, and tectonism (deformation of the crust)—are the same ones that affect all of the rocky bodies of the inner solar system, including the Earth. Because the Moon has no atmosphere or running water, its ancient surface is preserved in nearly pristine form and its geological story can be read with clarity and understanding. Because the Moon is Earth's companion in space, it retains a record of the history of this corner of the Solar System, vital knowledge unavailable on any other planetary object.

Of all the scientific benefits of Apollo, appreciation of the importance of impact, or the collision of solid bodies, in planetary evolution must rank highest. Before we went to the Moon, we had to understand the physical and chemical effects of these collisions, events completely beyond the scale of human experience. Of limited application at first, this new knowledge turned out to have profound consequences. We now believe that large-body collisions periodically wipe out species and families on Earth, most notably, the extinction of dinosaurs 65 million years ago. The telltale residue of such large body impacts in Earth's past is recognized because of knowledge we acquired about impact from the Moon. Additional knowledge still resides there; while the Earth's surface record has been largely erased by the dynamic processes of erosion and crustal recycling, the ancient lunar surface retains this impact history. When we return to the Moon, we will examine this record in detail and learn about its evolution as well as our own.

Because the Moon has no atmosphere and is a quiet, stable body, it is the premier place in space to observe the universe. Telescopes erected on the lunar surface will possess many advantages. The Moon's level of seismic activity is orders of magnitude lower than that of Earth. The lack of an atmosphere permits clear viewing, with no spectrally opaque windows to contend with; the entire electromagnetic spectrum is visible from the Moon's surface. Its slow rotation (one lunar day is 708 hours long, about 28 terrestrial days) means that there are long times of darkness for observation. Even during the lunar day, brighter sky objects are visible through the reflected surface glare. The far side of the Moon is permanently shielded from the din of electromagnetic noise produced by our industrial civilization. There are areas of perpetual darkness and sunlight near the poles of the Moon. The dark regions are very cold, only a few tens of degrees above absolute zero and these natural "cold traps" can be used to passively cool infrared detectors. Thus, telescopes installed near the lunar poles can both see entire celestial hemispheres all at once and with infrared detectors, cooled for "free," courtesy of the cold traps.

(6) Hydrogen, probably in the form of water ice, exists at the poles of the Moon that can be extracted and processed into rocket propellant and life-support consumables

The joint DOD–NASA Clementine mission was flown in 1994. Designed to test sensors developed for the Strategic Defense Initiative (SDI), Clementine was an amazing success story. This small spacecraft was designed, built, and flown within the short time span of 24 months for a total cost of about $150 M (FY 2003 dollars), including the launch vehicle. Clementine made global maps of the mineral and elemental content of the Moon, mapped the shape and topography of its surface with laser altimetry, and gave us our first good look at the intriguing and unique polar regions of the Moon. Clementine did not carry instruments specifically designed to look for water at the poles, but an ingenious improvisation used the spacecraft communications antenna to beam radio waves into the polar regions; radio echoes were observed using the Deep Space Network dishes. Results indicated that material with reflection characteristics similar to ice are found in the permanently dark areas near the south pole. This major discovery was subsequently confirmed by a different experiment flown on NASA's Lunar Prospector spacecraft four years later in 1998.

The Moon contains no internal water; all water is added to it over geological time by the impact of comets and water-bearing asteroids. The dark areas near the poles are very cold, only a few degrees above absolute zero. Thus, any water that gets into these polar "cold traps" cannot get out so over time, significant quantities accumulate. Our current best estimate is that over 10 billion cubic meters of water exist at the lunar poles, an amount equal to the volume of Utah's Great Salt Lake—without the salt! Although hydrogen and oxygen can be extracted directly from the lunar soil (solar wind hydrogen is implanted on the dust grains of the surface, allowing the production of propellant and water directly from the bone-dry dust), such processing is difficult and energy-expensive. Polar water has the advantage of already being in a concentrated useful form, greatly simplifying scenarios for lunar return and habitation. Broken down into hydrogen and oxygen, water is a vital substance both for human life support and rocket propellant. Water from the lunar cold traps advances our space-faring infrastructure by creating our first space "filling station."

The poles of the Moon are useful from yet another resource perspective—the areas of permanent darkness are in proximity to areas of near-permanent sunlight. Because the Moon's axis of rotation is nearly perpendicular to the plane of the ecliptic, the sun always appears on or near the horizon at the poles. If you're in a hole, you never see the Sun; if you're on a peak, you always see it. We have identified several areas near both the north and south poles of the Moon that offer near-constant sun illumination. Moreover, such areas are in darkness for short periods, interrupting longer periods of illumination. Thus, an outpost or establishment in these areas will have the advantage of being in sunlight for the generation of electrical power (via solar cells) and in a benign thermal environment (because the sun is always at grazing incidence); such a location never experiences the temperature extremes found on the lunar equator (from 100° to –150° C). The poles of the Moon are inviting "oases" in near-Earth space.

(7) Current launch systems, infrastructure, and space hardware can be adapted to this mission and we can be back on the Moon within five to seven years for only a modest increase in existing space budgets.

America built the mighty Saturn V forty years ago to launch men and machines to the Moon in one fell swoop. Indeed, this technical approach was so successful, it has dominated the thinking on lunar return for decades. One feature of nearly all lunar return architectures of the past twenty years is the initial requirement to build or re-build the heavy lift launch capability of the Saturn V or its equivalent. Parts of the Saturn V were literally hand-made, making it a very expensive spacecraft. Development of any new launch vehicle is an enormously expensive proposition. What is needed is an architecture that accomplishes the goal of lunar return with the least amount of new vehicle development possible. Such a plan will allow us to concentrate our efforts and energies on the most important aspects of the mission—learning how to use the Moon's resources to support space flight.

One possible architecture for lunar return devised by the Office of Exploration at the Johnson Space Center has several advantages. First, and most importantly, it uses the Space Shuttle (or an unmanned derivative of it), augmented by existing expendable boosters, to deliver the pieces of the lunar spacecraft to orbit. Thus, from the start, we eliminate one of the biggest sources of cost from the equation, the requirement to develop a new heavy-lift launch vehicle. This plan uses existing expendable launch vehicle (ELV) technology to deliver the cargo elements of the lunar return to low Earth orbit—lander, habitat, and transfer stage. Assembled into a package in Earth orbit, these items are then transferred to a point about 4/5 of the way to the Moon, the Moon-Earth Lagranian point 1 (L1). The L1 point orbits the Earth with the Moon such that it appears "motionless" to both bodies. Its non-motion relative to Earth and Moon has the advantage of allowing us to wait for favorable alignments of these bodies and the Space Station in various phases of the mission. Because there is no requirement for quick transit, cargo elements can take advantage of innovative technologies such as solar electric propulsion and weak stability boundaries between Earth, Sun, and Moon to make long, spiraling trips out to L1, thus requiring less propellant mass. These unmanned cargo spacecraft can take several months to get to their destinations. The habitat module can be landed on the Moon by remote control, activated, and await the arrival of its occupants from Earth.

The crew is launched separately on a Shuttle launch and uses a chemical stage and a quick transfer trajectory to reach the L1 depot in a few days. The crew then transfers to the lunar lander/habitat, descends to the surface and conducts the surface mission. As mentioned above, the preferred landing site is an area near one of the Moon's poles; the south pole is most attractive from the perspective of science and operations (see the attached "Shackleton Crater Expedition" proposal submitted to the Committee by Dr. Stone). The goal of our mission is to learn how to mine the resources of the Moon as we build up surface infrastructure to permit an ever-larger scale of operations. Thus, each mission brings new components to the surface and the size and capability of the lunar outpost grows over time. Most importantly, the use of lunar-derived propellants means that more than 80 percent of the spacecraft weight on return to Earth orbit need not be brought from Earth. A properly designed mission will return to Earth not only with sufficient fuel to take the craft back to the Moon for another run, but also to provide a surplus for sale in low Earth orbit. It is this act that creates the Earth-Moon economy and demonstrates a positive return on investment.

On return, the L1 depot provides a safe haven for the crew while they wait several days for the orbital plane of ISS to align itself with the return path of the crew vehicle. Rather than directly entering the atmosphere as Apollo did, the crew return vehicle uses aerocapture to brake into Earth orbit, rendezvous with the ISS, and thus, it becomes available for use in the next lunar mission.

In addition to its technical advantages, this architecture offers important programmatic benefits. It does not require the development of a new heavy lift launcher. We conduct our lunar mission from the ISS and return to it afterwards, making the Station an essential component of humanity's movement into the Solar System. The use of the L1 point as a staging depot allows us to wait for proper alignments of the Earth and Moon; the energy requirements to go nearly anywhere beyond this point are very low. The use of newly developed, low-thrust propulsion (*i.e.,* solar-electric) for cargo elements drives new technology development. We will acquire new technical innovation as a by-product of the program, not as a critical requirement of the architecture.

The importance of using the Shuttle or Shuttle-derived launch vehicles and commercial launch assets in this architecture should not be underestimated. Costs in space launch are almost completely dominated by the costs of people and infrastructure. To create a new launch system requires new infrastructure, new people, new training. Such costs can make up significant fractions of the total program. By using existing systems, we can concentrate our resources on new equipment and technology, focused on the goal of finding, characterizing, processing, and using lunar resources as soon as possible.

(8) A return to the Moon gives the Nation a challenging mission and creates capability for the future, by allowing us to routinely travel at will, with people, throughout the Earth-Moon system.

Implementation of this objective for our national space program would have the result of establishing a robust transportation infrastructure, capable of delivering people and machines throughout cislunar space. Make no mistake—learning to use the resources of the Moon or any other planetary object will be a challenging technical task. We must learn to use machines in remote, hostile environments, working under difficult conditions with ore bodies of small concentration. The unique polar environment of the Moon, with its zones of near-permanent illumination and permanent darkness, provides its own challenges. But for humanity to have a future, we must learn to use the materials available off-planet. We are fortunate that the Moon offers us a nearby, "safe" laboratory to take our first steps in using space resources. Initial blunders in mining tactics or feedstock processing are better practiced at a location three days from Earth than from one many months away.

A mission learning to use these lunar resources is scalable in both level of effort and the types of commodities to be produced. We begin by using the resources that are the easiest to extract. Thus, a logical first product is water derived from the lunar polar deposits. Water is producible here regardless of the nature of the polar volatiles—ice of cometary origin is easily collected and purified, but even if the polar materials are composed of molecular hydrogen, this substance can be combined with oxygen extracted from rocks and soil (through a variety of processes) to make water. Water is easily stored and used as a life-sustaining substance for people or broken down into its constituent hydrogen and oxygen for use of rocket propellant.

Although we currently possess enough information to plan a lunar return now, investment in a few robotic precursors would be greatly beneficial. We should map the polar deposits of the Moon from orbit using imaging radar to "see" the ice in the dark regions. Such mapping could establish the details of the ice location and its thickness, purity, and physical state. The next step should be to land small robotic probes to conduct in place chemical analyses of the material. Although we expect water ice to dominate the deposit, cometary cores are made up of many different substances, including methane, ammonia, and organic molecules, all of which are potentially useful resources. We need to inventory these species, determine their chemical and isotopic properties, and their physical nature and environment. Just as the way for Apollo was paved by such missions as Ranger and Surveyor, a set of robotic precursor missions, conducted in parallel with the planning of the manned expeditions, can make subsequent human missions safer and more productive.

After the first robotic missions have documented the nature of the deposits, focused research efforts would be undertaken to develop the machinery needed to be transported to the lunar base as part of the manned expedition. There, human-tended processes and principles will be established and validated, thus paving the way to commercialization of the mining, extraction and production of lunar hydrogen and oxygen.

(9) This new mission will create routine access to cislunar space for people and machines, which directly relates to important national economic and strategic goals.

By learning space survival skills close to home, we create new opportunities for exploration, utilization, and wealth creation. Space will no longer be a hostile place that we tentatively visit for short periods; it becomes instead a permanent part of our world. Achieving routine freedom of cislunar space makes America more secure (by enabling larger, cheaper, and routinely maintainable assets on orbit) and more prosperous (by opening an essentially limitless new frontier.)

As a nation, we rely on a variety of government assets in cislunar space, ranging from weather satellites to GPS systems to a wide variety of reconnaissance satellites. In addition, commercial spacecraft continue to make up a multi-billion dollar market, providing telephone, Internet, radio and video services. America has invested billions in this infrastructure. Yet at the moment, we have no way to service, repair, refurbish or protect any of these spacecraft. They are vulnerable to severe damage or permanent loss. If we lose a satellite, it must be replaced. From redesign though fabrication and launch, such replacement takes years and involves extraordinary investment in the design and fabrication so as to make them as reliable as possible.

We cannot now access these spacecraft because it is not feasible to maintain a man-tended servicing capability in Earth orbit—the costs of launching orbital transfer vehicles and propellant would be excessive (it costs around $10,000 to launch one pound to low Earth orbit). Creating the ability to refuel in orbit, using propellant derived from the Moon, would revolutionize the way we view and use our national space infrastructure. Satellites could be repaired, rather than abandoned. Assets can be protected rather than written off. Very large satellite complexes could be built and serviced over long periods, creating new capabilities and expanding bandwidth (the new commodity of the information society) for a wide variety of purposes. And along the way, we will create opportunities and make discoveries.

A return to the Moon, with the purpose of learning to mine and use its resources, thus creates a new paradigm for space operations. Space becomes a part of America's industrial world, not an exotic environment for arcane studies. Such a mission ties our space program to its original roots in making us more secure and more prosperous. But it also enables a broader series of scientific and exploratory opportunities. If we can create a spacefaring infrastructure that can routinely access cislunar space, we have a system that can take us to the planets.

(10) The infrastructure created by a return to the Moon will allow us to travel to the planets in the future more safely and cost effectively.

This benefit comes in two forms. First, developing and using lunar resources can enable flight throughout the Solar System by permitting the fueling the interplanetary craft with materiel already in orbit, saving the enormous costs of launch from Earth's surface. Second, the processes and procedures that we learn on the Moon are lessons that will be applied to all future space operations. To successfully mine the Moon, we must learn how to use machines and people in tandem, each taking advantage of the other's strengths. The issue isn't "people or robots?" in space; it's "how can we best use people and robots in space?" People bring the unique abilities of cognition and experience to exploration and discovery; robots possess extraordinary stamina, strength, and sensory abilities. We can learn on the Moon how to best combine these two complementary skill mixes to maximize our exploratory and exploitation abilities.

Return to the Moon will allow us to regain operational experience on another world. The activities on the Moon make future planetary missions less risky because we gain this valuable experience in an environment close to Earth, yet on a distinct and unique alien world. Systems and procedures can be tested, vetted, revised and re-checked. Exploring a planet is a difficult task to tackle green; learning to live and work on the Moon gives us a chance to crawl before we have to walk in planetary exploration and surface operations.

The establishment of the Earth-Moon economy may be best accomplished through an independently organized Federal expedition along the lines of the Lewis and Clark expedition. Dr. Stone, who is eminently qualified to lead such an expedition, has prepared the Shackleton Crater Expedition proposal (attached to this testimony) to elaborate upon this alternative organizational strategy. One of the fundamental tenets of this approach is to take a business stance on cost control with the objective of demonstrating a positive return on investment. Such an approach would take advantage of the best that NASA and other Federal agencies have to offer, while streamlining the costs through a series of hard-nosed business approaches.

A lunar program has many benefits to society in general. America needs a challenging, vigorous space program. Such a program has served as an inspiration to the young for the last 50 years and it can still serve that function. It must present a mission that inspires and enriches. It must relate to important national needs yet push the boundaries of the possible. It must serve larger national concerns beyond scientific endeavors. A return to the Moon fulfills these goals. It is a technical challenge to the Nation. It creates security for America by assuring access and control of our assets in cislunar space. It creates wealth and new markets by producing commodities of great commercial value. It stimulates and inspires the next generation by giving them the chance to travel and experience space flight for themselves. A return to the Moon is the right destination for America.

Thank you for your attention.

ATTACHMENT

Invited Presentation to: International Lunar Conference, Waikoloa, Hawaii, November 16–21, 2003

RETURN TO THE MOON: A NEW DESTINATION FOR THE AMERICAN SPACE PROGRAM

Paul D. Spudis—Applied Physics Laboratory—Laurel, MD

NASA has no future plans for human exploration of space beyond completion of the International Space Station (ISS). Yet human space flight makes up the bulk of the agency's budget and is also the source of most of the public support the space program retains. Without a new follow-on goal, human space flight will stagnate and the entire civil space program may be in jeopardy.

Although many claim that only a manned Mars mission will draw the necessary public support, the initiation of such a program is unlikely for two reasons: it's too technically challenging for at least another decade and will cost more money than Congress can be reasonably expected to provide. Although alternative destinations beyond LEO are imaginable (*e.g.,* Lagranian points), in the public mind, they differ little from being simply ISS at a different location.

In contrast, the Moon is a small, nearby planet of immense intellectual and economic value. The Moon is a natural laboratory for planetary science, displaying many of the geological processes that operate on all the terrestrial planets. Moreover, the lunar surface preserves the early history of the Earth-Moon system, a record erased from the dynamic, active surface of the Earth. The Moon is a superb platform for observing the universe, with an airless, stable surface, long night-times, and a far side permanently shielded from the radio static of Earth. By understanding the specifics of the human-machine partnership, a new technique of exploration that maximizes the strengths and minimizes the weaknesses of using people and robots to explore space, we can learn to live and work in space on the Moon. The Moon contains abundant resources of material and energy for use in space and on the lunar surface. The recent discovery of large amounts of hydrogen in the polar regions show that extraction and use of lunar resources may be easier than we had originally thought.

Our return to the Moon can be accomplished using the existing infrastructure that supports Shuttle and ISS. Launch of components can be done with Shuttle or STS-derived cargo vehicles and Delta-IV–H vehicles. Cargo flights can emplace a staging node at Earth-Moon L1, from which lunar surface missions would be staged. Human crews can depart and return from ISS or another LEO location. Lunar landers would descend from the L1 node, delivering both robotic cargo and human crews, land, and conduct the surface mission. After return to L1, the crew could await re-alignment of the orbital plane of ISS, upon which they would return to Earth orbit, using aerocapture. This architecture allows us to return to the Moon with minimal development of new hardware and technology and use the ISS as a staging platform, making that program more directly relevant to future human exploration of space.

The mission of a lunar return should be to learn how to use off-planet resources. Such a mission is technically challenging, but within relatively easy reach. It gives NASA a task that is directly relevant to future American national and commercial interests in space, thus making it politically palatable. Learning how to identify, characterize, extract and use off-planet resources is a task that we must learn if humanity is to have a future in space. By providing the ability to refuel spacecraft in orbit, this mission will establish routine access to cislunar space for both people and machines. Freeing us from the cumbersome logistical bonds of Earth, a return to the Moon will be the first step towards both true space independence and to the planets beyond.

Senator BROWNBACK. That's excellent. I look forward to the discussion.

Senator Nelson can't stay with us very much longer, so, Senator Nelson, questions or comments? They'd be welcome at this time.

Senator NELSON. Thank you, Mr. Chairman.

I want to say my personal thanks to you for having these kind of hearings that will stimulate us. I agree with Senator Schmitt's statement about the need for sustained political and financial commitment to see the job through and not turn back, and that's something that he's had an experience with in the Apollo Program when it got cutoff. Continuing on with your comments, not underfunding the effort, a huge problem facing the Space Shuttle and the Space Station.

So your argument here is, you'd be able to attract investors to go to the Moon for this effort to mine helium-3. Now, it's hard to believe, but you made a presentation 10 years ago, at my invitation, to the Space Business Roundtable. What has changed, in a decade, in your thinking and your refinement of us being able to go and help our energy crisis?

Dr. SCHMITT. Two things, Senator. One is, we've made tremendous progress in the research at the University of Wisconsin-Madison, where we do have sustained fusion going on in these small reactors—and they are small; they're about this size [indicating]—at what may seem like a very low level, but it's more than anybody else has ever done, now at about a milliwatt. But the other thing, the second thing, that's changed is that we now know that, beginning at about a watt of sustained fusion power, there are near-term commercial applications, what I started to call "bridging businesses," that can help bootstrap your way to the point of where investors could ultimately be asked to invest in the lunar enterprise.

I'm not naive enough to think that you can ask—that some investor's going to—well, it would be nice if they would—but would let me play with their capital for 10 or 15 years before they got a return on investment.

So we've been looking at these interim businesses, these bridging businesses. And the first one, at about a watt of fusion power, taking several thousand kilowatts to produce, but still about a watt of fusion power, is the production of positron radio isotypes for PET diagnostic-use, positron-emitting tomography.

The second application, as power levels go up, will probably be in the detection—using a neutron-producing mix in the detection of explosives, and particularly portable landmine detection, robotic landmine detection. That would be, of course—the customer there would be primarily the government.

Another potential use, at higher power levels, is the transmutation of existing fission waste. The helium-3/helium-3 reaction or the helium-3/deuterium reaction both produce protons as their primary reaction product. And protons have a very interesting property, in that if you engineer the exposure of isotopes to them, and particularly the radioactive isotypes, you can change them to either stable isotopes or to very short-lived isotopes, so that that problem starts to go away much, much faster than it will under any other scenario that's been discussed. When you reach a point of breakeven—that is, where your power in is equal to or less than the power out, fusion power out—then, of course, you have a number of different applications for these relatively small portable devices.

The nice thing about the IEC, the inertial electrostatic confinement fusion technology, is that it lends itself to modular power sources. In fact, you can even begin to think in terms of having a helium-3 powered aircraft at about the size of the old KC–135. It looks as if—back of the envelope, now, calculations—looks as if, for the fuel load of that size airplane, you could have a fusion power plant onboard for basically continuous flight.

Now, I talk to my Air Force friends, and they say, "Well, we don't quite know what we would do with that," and I don't know if you would use that. But the point is, we're creating a technology base that is going to have an increasing number of applications. As Dr. Criswell has said, when you start to get into these kinds of arenas where you're really stretching yourself to do new things, then you just can't anticipate the applications that these technologies will have, both direct and indirect.

Senator NELSON. The basic thrust, in addition to these refinements that you have just indicated for the record, but the basic thrust of your proposal, is as you had presented it a decade ago, which is to go to the Moon, mine helium-3, bring that back, and let that be the major source of our energy as we start to deplete our other sources of energy.

Dr. SCHMITT. That's correct. At least one of the options. There are going to be other options. And, in fact, one of the things that we've been doing at Wisconsin, also, is trying to develop a method—a paradigm, if you will—by which we can compare different sources of energy, future sources as well as current sources, on an apples-to-apples basis. And that's why it's important that what Dr. Criswell has talked about be developed, as what we've talked about be developed, to the point of where you have enough information and data that you can actually make comparisons to see what, in the final analysis, your bus bar cost is going to be of the electricity coming out at the end. And that is a very important part of developing future energy policy, is to see what those bus bar costs are actually going to be for various options.

There are a lot of options for future energy supplies. Fission—clearly, advanced fission power systems are a very important potential part of that mix. We just have politically tied our hands, in this country at least, in using those. Other countries haven't been quite so squeamish about the use of fission power.

We have ace-in-the-hole of fossil fuels. Fossil fuels are not going to run out for a long time. It's just a question of price. Again, putting on my economic-geology hat, you raise the price, and I know a lot people who'll go out there and find you a lot more fossil fuels. And that's what's going to happen for awhile, until we have these alternatives. Because a lot of us, geologists included, do not think that it is exactly prudent to depend on getting to this factor of five, factor of eight—whatever number you pick, but it's going to be large—increase in energy supply and demand using fossil fuels. It's just, for the long-term, probably not a prudent choice, whatever you may think about global climate change.

Senator NELSON. And not only global climate change, but the question of the defense interests of the United States——

Dr. SCHMITT. Exactly.

Senator NELSON.—if we're dependent on a part of the world where we're having so much difficulty right now——

Dr. SCHMITT. Exactly. It would——

Senator NELSON.—because they happen to have the oil reserves.

Dr. SCHMITT. Having alternatives to fossil fuels, at least to crude oil, and, indeed, to natural gas, increasingly to natural gas, would change our foreign-policy picture significantly, to put it mildly.

Senator NELSON. Just to conclude—and thank you for your generosity, Mr. Chairman, so that I can get to this caucus meeting—but I remember distinctly, 10 years ago you said that approximately 45,000 pounds of helium-3 would provide the energy sources for the United States for one entire year. Is that still an up-to-date calculation?

Dr. SCHMITT. Yes, well, I think probably—I hope what I said was about 40 metric tons, which would be about 80-—significantly over 80-—do I have that right, Dave?—80,000 pounds.

Senator NELSON. So it's cargo bay of two Space Shuttles, then——

Dr. SCHMITT. Yes.

Senator NELSON.—instead of one. I had——

Dr. SCHMITT. Our energy—you're right—ten years ago, the numbers were less than what they are today. Our energy consumption is going up fairly fast.

Senator NELSON. That's right, it's been 10 years, hasn't it?

Dr. SCHMITT. Yes, I think we were using a figure closer to 45—you're absolutely right now that I think about it—-closer to 45,000 pounds in those days. It's increased.

Senator NELSON. Well, thank you, Mr. Chairman. That's just another reason for us to be concerned. It's almost like a time warp for me here. The energy demand in America is twice, almost twice, as much as what it was 10 years ago, based on the theory that you need 80,000 pounds now instead of 45,000 pounds.

Dr. SCHMITT. Yes, it's going up quite fast.

Senator NELSON. Thank you.

Dr. SCHMITT. We've been at this too long, Senator.

Senator NELSON. By the way, I was on FOX News Sunday with Tony Snow, and I laid out this theory, and he was quite intrigued with it. Senator Schmitt, you might want to follow up with that.

Senator BROWNBACK. Thank you very much——

Senator NELSON. Thank you.

Senator BROWNBACK.—Astronaut Nelson, along with the Senator. It brings a lot of expertise to this that's deeply appreciated.

There's testimony I have from the TransOrbital Group. They weren't able to have a witness here today, but I would asked unanimous consent that it be placed in the record, and there's no objection to doing that.

[The information referred to follows:]

TRANSORBITAL, INC.
Alexandria, VA, November 2003

OPPORTUNITIES FOR COMMERCIAL EXPLORATION & UTILIZATION OF THE MOON

Introduction

TransOrbital, Inc. is the first and only commercial company to be issued permits by the U.S. State Department and NOAA for a commercial mission to the moon. In December of 2002 TransOrbital launched from the Baikonur Cosmodrome in the Ukraine a lunar orbiter test article which is currently in orbit around the earth. In mid to late 2004 TransOrbital will launch the full scale Trailblazer lunar orbiter, which will be the first commercial venture to the moon. It is the intention of TransOrbital to show that technology has advanced to the point where deep space capabilities that once were only within the grasp of governments can now be cost effectively used by commercial businesses and that a commercial business case can be made for a permanent commercial presence on the moon and beyond. Although not specifically dependent on government funding, TransOrbital believes that public/private partnerships directed towards the creation of a deep space commercial infrastructure can mitigate the costs for U.S. Government space programs and the commercialization of deep space. For example: if the U.S. Government continued and expanded the recently introduced practice of purchasing space related data and services from the private sector the U.S. space program could be more cost-effective and at the same time assist in the development of the commercial space industries to the Moon and beyond.

TransOrbital, Inc.

TransOrbital, Inc. was incorporated in 1998 to develop the infrastructure for exploration and commercial utilization of the Moon and, eventually, deep space. The company is based in Alexandria, Virginia and is privately held. TransOrbital is currently the leading candidate for the first commercial venture to the moon.

TransOrbital has already launched a test satellite into Earth orbit on December 20, 2002 and expects to launch a full-scale mission to the moon in mid to late 2004. TransOrbital is the only company currently licensed by the U.S. State Department and NOAA for a commercial venture to the moon. TransOrbital is the only company that has been able to demonstrate a business case for going to the moon and for maintaining a permanent commercial infrastructure on the moon. TransOrbital is a primary example of how small companies can utilize today's technology in establishing commercial ventures in deep space. With tax incentives, public/private partnerships, legislative support on commercial issues and technology transfers/assistance from governmental agencies there is ample opportunity for the creation of a innovative new space program based upon small-business dynamics, deep space commercialization and the associated job creations that can come from such a dynamic and forward thinking synergy between the current space programs and future commercial space opportunities.

Trailblazer

In mid- to late-2004, TransOrbital expects to launch the first commercial lunar mission: *TrailBlazer®*. The primary purpose of *TrailBlazer* is to acquire high definition imagery of the Moon and other objects of interest. Although there is certainly a scientific object to this, the primary market for this imagery is commercial: movies, advertising, and sponsorship, education, maps and literature. In addition to the images taken by the spacecraft itself, we will be taking video of the assembly of the spacecraft and of the launch so that interested individuals around the world can be involved in a space program with web participation. The images will also be of value to others planning lunar missions, particularly lunar landers. Additional revenues will come from the carriage of private cargo to the lunar surface, and two scientific packages/experiments.

Trailblazer will launch onboard the ISC Kosmotras *Dnepr,* a Russian SS–18 ICBM converted for commercial use. The *Dnepr* will launch the *TrailBlazer* into a circular Earth orbit at approximately 650 km altitude. Almost immediately following separation from the upper stage, the solid TLI (Trans-Lunar Injection) kick-motor will fire and propel the spacecraft into a 4-day Apollo-style trajectory to the Moon. The kick motor and the attached interstage (see Figure 1) will separate from the spacecraft and impact the Moon. During the trans-Lunar cruise flight, the spacecraft will gather a great deal of imagery of the flight, including the ejected booster, the receding Earth, and the approaching Moon, in both video and panoramic still views.

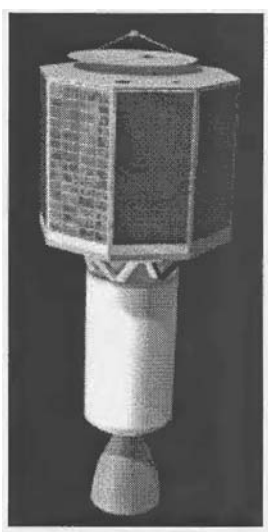

Figure 1 - *TrailBlazer* spacecraft with solid motor attached.

Once the spacecraft has reached the moon, it will fire its on-board thruster and enter an elliptical, polar orbit around the Moon. Over the course of up to ninety days *Trailblazer* will be able to image the entire surface of the Moon and deliver a high-definition atlas of the lunar surface. Images are taken over a 1-hour pass while the spacecraft is nearest the Moon. While the NASA/BMDO (Ballistic Missile Defense Organization) INRL (Naval Research Lab) probe *Clementine* returned a very good set of images of the lunar surface, these were all taken with the sun almost directly overhead, while the lunar science community would prefer the lighting to be from the side, which shows better surface details. *TrailBlazer* will orbit so that the Sun is about 15 degrees above the horizon, which should give excellent shadowing of the surface features.

Immediately after entering lunar orbit, *TrailBlazer* will revisit one of the most famous of all of the Apollo scenes: the Earth rising majestically over the limb of the Moon—Earthrise (see Figure 2). In high-definition video lasting over 10 minutes, this will be nothing short of magnificent.

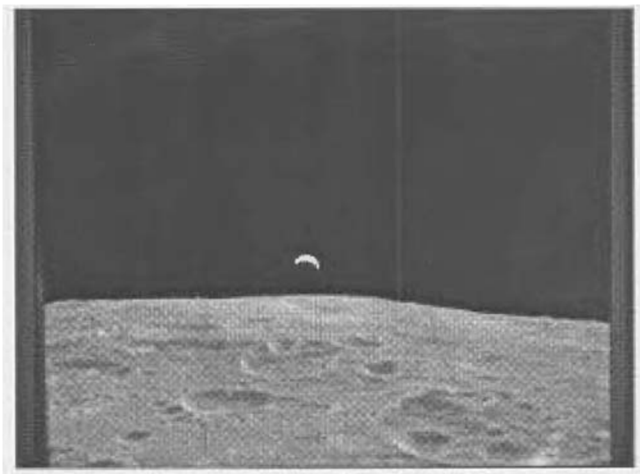

Figure 2 - Apollo Earthrise

When the lunar surface atlas images are complete, *TrailBlazer's* orbit will be lowered so that the point of closest approach is less than 10 miles Figure 2—Apollo Earth rise above the surface. This will allow us to view, with a high degree of detail, specific small targets such as the U.S. Surveyor and Apollo and the Russian Lunakhod landing sites, as well as other areas that are of special interest. In particular, we wish to image several areas that may serve as sites for future space landings, including "Angus Bay" *(Mare Anguis,* just off of *Mare Crisium),* and the polar regions. Because of the irregular gravity of the Moon-due to its small size and the "mascons" (mass concentrations) caused by the upwelling of lava into large impact craters, any orbit this low requires constant maintenance and *TrailBlazer's* fuel will be exhausted after a few days. Before the fuel is totally gone, and the spacecraft goes out of control, it will be aimed at an area well away from any site of historical or particular geologic value and impacted into the surface. As much as possible, video will be returned during the final descent, which should be quite spectacular.

In addition to the cameras, a selection of inert payloads will be placed onto *TrailBlazer* and carried to the lunar surface in its final descent. One of these will be a time capsule, consisting of a metal disk with micro-etched images on its surface. At our website, given below, you can enter one or more pages of words and text to be inscribed on this disk for future lunar explorers to find. Although the spacecraft will be destroyed by the impact, the disk will be carried inside of an especially hardened time capsule that will survive the impact of Trailblazer on the Moons surface.

Three scientific and technical projects round out the *Trailblazer* mission. The spacecraft will be carrying a radiometer constructed by a group in Italy in order to study the radio interference levels at a proposed site on the lunar far side for a radio-astronomy observatory. Also, TransOrbital has been funded by the Foundation for the International Non-government Development of Space (FINDS) to study the use of Global Positioning Satellite signals for location in near-Earth space. Finally, the spacecraft will be testing algorithms associated with the Interplanetary Internet protocols developed by NASA and private researchers for extending Internet communications into space.

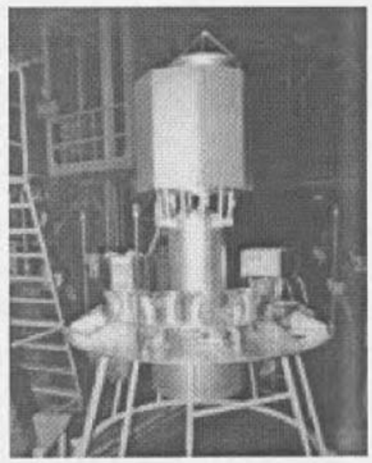

Figure 3 - TrailBlazer test article prior to launch

In an important first step, TransOrbital, Inc. launched an inert *TrailBlazer* test article in December of 2002. This launch allowed the company to test and verify the integration and communications procedures required for using the *Dnepr* launch vehicle. The test article is currently in Earth orbit at an altitude of 650 km. Figure 3 shows the test article during launch vehicle integration, at the Yuzhnoye Design Office in the Ukraine.

Future Missions

Following *TrailBlazer,* TransOrbital, Inc. plans a series of lunar landers. Like *TrailBlazer* the *Electra* landers—depicted in Figure 4—will perform a variety of functions, including support of scientific exploration, gathering imagery for entertainment and artistic purposes, and most significantly the establishment of secure data servers on the Moon.

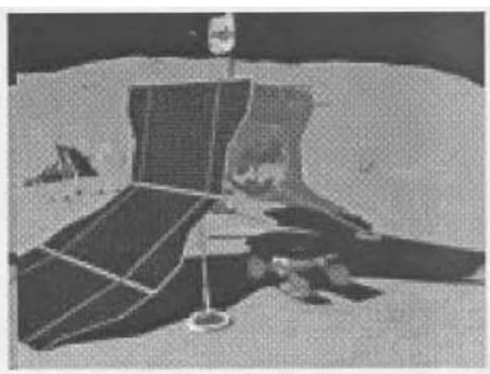

Figure 4 - Electra Lunar Lander, with rover

Commercial Space Exploration

None of the work that TransOrbital, or any of the other private space concerns, has accomplished would be possible without the technological development that NASA has accomplished over the past 30-some years. We believe that the technology and the market place have now developed to the point where some of the work that is currently performed exclusively by government space programs can be transitioned to the private sector, encouraging efficiency and the creation of new jobs and markets. This is similar to the way that the communications satellite industry has succeeded in creating a profitable commercial enterprise by transitioning NASA technologies and innovations. For instance, TransOrbital believes that many activities that currently performed by communications satellites could be performed more efficiently by relays and data servers located on the moon.

TransOrbital would like to encourage the U.S. Government to continue and expand the recently introduced practice of purchasing science data and services from the private sector. Such projects as the $50M Earth imaging Scientific Data Purchasing Project recently concluded at NASA Stennis Space Center show the value of such purchases. Both NOAA (the National Oceanographic and Atmospheric Administration) and the Department of Defense have a successful history of similar agreements under the Brooks Act and the A–76 processes. This practice should be expanded to include space science data, in particular lunar data. It would fit well within the recently published NASA Announcement of Opportunity (AO 030SS–03) for New Frontier missions, including missions leading to the proposed Lunar Aitken-basin sample return.

Although these data purchases are most helpful, opportunities should be expanded to give private industry an even greater role in space exploration and commercial development of space. Some suggestions include:

- Encouraging NASA, NOAA, and the DOD to serve as "private/public partners" for multi-purpose commercial space missions, specifically allowing them to co exist with commercial operations. AO 030SS–03 specifies that NASA can participate in "missions of opportunity", but doesn't encourage private/public partnerships. Private/public partnerships would assist private companies in the acquisition of funding for multi-purpose commercial space missions.
- Providing tax incentives for commercial space operations. If successful, commercial space (beyond the Comsat and Earth-imaging industries) would provide significant levels of employment and encourage private sector investment. Ultimately the creation of jobs and investment capital would generate significant business and individual tax revenues while at the same time reducing the cost of U.S. government expenditures on space related programs. Historically tax incentives have been extremely effective in the creation of new industry.
- Having NASA provide data and technical support services, either under CRDA (Cooperative Research and Development Agreement) or through open forum commercial exchanges. NASA has unparalleled analysis capabilities, and much is available commercially through technology transfer. Most small businesses would not have the capital to create the kind of infrastructure and database support available through NASA. However if NASA could provide support services, information, technology, ground station support etc. along with preferential contract pricing, There is an opportunity for public/private commercial agreements that can assist both NASA and small commercial enterprises in the development of a deep space commercial infrastructure.
- Recognition that, especially for small commercial companies, international cooperation is essential for providing a cost-competitive product. For instance, presently the only economically feasible launch provider for *TrailBlazer* is the Russian *Dnepr*. TransOrbital has put significant time and effort into ensuring that our use of the *Dnepr* satisfies all State Department ITAR control requirements. Unfortunately despite this effort regulatory and institutional barriers make it almost impossible to launch any NASA or other U.S. Government payload on the *Dnepr,* or any other non-U.S. launch vehicle. While there is a history of NASA and U.S. Government agency launches from Russian launch vehicles there is currently no defined protocol for the use of foreign based launch vehicles that could be used for public/private partnership commercial space launches. While it is appropriate to consider all ITAR concerns the commercial space industry is very much a worldwide business. Expediting the ability of American small space related companies to participate in the acquisition of services on a worldwide basis would enhance the growth potential of American small commercial deep space companies.
- Opening up the International Space Station as soon as possible to true commercial operations on a rental basis. Currently, there are significant regulatory and reporting blocks to use of ISS for commercial purposes which, technically, are not required. Lunar exploration would be greatly enhanced by being able to use ISS as a staging area for assembly and retrieval of spacecraft.

- Passing legislation to encourage the commercial exploration and utilization of space-based resources. Right now, there is very little legislative backing for commercial operations beyond communications and remote-sensing spacecraft. While TrailBlazer will demonstrate that commercial lunar operations are viable, companies may be reluctant to take chances that their base of operations may be declared "a common heritage of mankind" and taken from them. Territorial imperatives is an issue which will become more and more requisite of definition in deep space as commercial and governmental entities establish positions on the moon and elsewhere. The issue of property rights, land-use, right of access, right of-way, and commercial exploitation are all issues that will need definition and structural protocols in the very near future.
- Recognize the necessity for low-cost launch opportunities within the Continental United States. TransOrbital has contracted for low-cost Russian launch vehicles which are converted ICBM missiles that would otherwise be destroyed under the START treaties. The United States has similar missiles which can be converted for commercial use as well but they have not been made available to the general commercial marketplace. There are currently severe restrictions as to how U.S. ICBMs can be utilized in commercial space programs. Removing these restrictions and converting existing U.S. missiles would provide an inventory of low-cost launch vehicles for small commercial companies similar to what is currently being done by the Russian commercial launch companies. Utilizing the U.S. missiles for the creation of new American industries and to help mitigate the cost of U.S. space programs would be an excellent opportunity for commercial growth in the United States and the commercialization of space.

Conclusion

Advances in technology and the availability of a wide variety of goods and services—many originating in NASA and DOD programs mean that space exploration and the utilization of space-based resources are now within the reach of commercial companies. Communications and remote-sensing spacecraft have proven that the utilization of near Earth space is commercially viable. TransOrbital, Inc.'s *TrailBlazer* spacecraft will demonstrate the viability of lunar exploration. As has been demonstrated in initial efforts by NOAA and the DOD, the purchase of scientific data and services from commercial suppliers is a cost-effective practice. Continuing and expanding this practice to include lunar exploration and other deep-space commercial development/research will be an efficient way to gather good scientific data and to create a permanent commercial infrastructure in space to support both private and public enterprises. Cost-sharing between the public and private sectors offers an opportunity for the commercialization of a deep space infrastructure while at the same time offering cost efficiencies for government based space programs.

Senator BROWNBACK. Tutor me, gentlemen. I've got some questions, and I want to understand some items. I want to start with Dr. Spudis, if I could.

You say we can go back to the Moon, with current technology, using even the Space Shuttle or its technology to get back, and can do it within a period of five to 7 years. Is that right?

Dr. SPUDIS. That's my belief, yes, sir.

Senator BROWNBACK. Now, what do you base that upon?

Dr. SPUDIS. Well, fundamentally there's no magic involved here. We know what's involved in going back to the Moon. It involves building vehicles that can transfer between orbits, from low-Earth orbit to lunar-transfer orbit and then down to the lunar surface. It involves rocket technology that's fairly much off the shelf. It's merely a matter of getting the mass and the engines and the propellent in the right place at the right time.

The reason I emphasize using existing facilities is because they are adequate. We have a lot of money invested in Shuttle and Shuttle infrastructure, and there's no reason why that infrastructure cannot be used to build the launch systems that we want.

Senator BROWNBACK. On a specific point, can we use the Space Shuttle craft to go back to the Moon?

Dr. SPUDIS. In part, yes, sir. You can use the Shuttle to launch components, but also you can use the existing expendable launch vehicles to do it. But, more than that, you can take Shuttle parts and build an unmanned heavy-lift vehicle with them. There was a concept NASA had a few years ago called Shuttle C, which basically took used Shuttle main engines and the external tank and the solid-rocket stack, and basically attach it to a big cargo carrier, and that can put between 60 and 70 metric tons into low-Earth orbit. So, in fact, we have a heavy-lift vehicle right now.

Senator BROWNBACK. Can you use the Shuttle spacecraft itself to take humans back to the Moon?

Dr. SPUDIS. You couldn't take the whole—it wouldn't be cost-effective or smart to fly the whole Shuttle to the Moon, because a lot of the mass, the airframe, of the Shuttle is specifically related to the reentry—the wings and the thermal protection system. What you would do is, you would use the Shuttle to ferry the crews back and forth to low-Earth orbit, just as they do now with Space Station. You would build a separate vehicle, based on Shuttle and Station-derived hardware, to go to the Moon.

Senator BROWNBACK. From low-Earth orbit.

Dr. SPUDIS. From low-Earth orbit, yes.

Senator BROWNBACK. Do you think that's a better route to go than just go back to the *Apollo* type of design where you're launching from the Earth and heading to the Moon?

Dr. SPUDIS. I do, because the *Apollo* design was a magnificent machine, but it was specifically designed as a one-off. Each mission was a set of equipment that was designed to transport one crew to the surface and back, and then that equipment was thrown away. If you go look in the Air and Space Museum down the street, there's the *Apollo 11* command module. That's the only thing that came back from the 360-foot-high *Apollo 5* stack, *Saturn 5* stack. And, what's more, *Saturn 5* lifted 100 metric tons to low-Earth orbit. The problem was, it's a very expensive vehicle, on a recurring basis, because parts of it were literally handmade. And what we need to do is to use equipment that we can reuse. That's where we're really going to make spaceflight more routine and more common, is to reuse equipment and not throw it away after one use.

Senator BROWNBACK. But the Shuttle is enormously expensive.

Dr. SPUDIS. It is. And we're spending that money, whether the Shuttle is flying or not. The Shuttle is expensive right now, even though it's sitting on the ground down at the Cape. And what I'm trying to look at is a way to use the existing infrastructure in which there's a very large capital investment down at Cape Kennedy, to basically build rockets and a transport system that will allow us to do this.

Now, there are other ways to approach this. You can imagine an architecture—in the attachment you have, Dr. Stone's "Shackelton Expedition," he looks at using commercial launch vehicles, and concludes that you can do this all with expendable launch vehicles.

So the reason you use heavy lift is to get big chunks in orbit at once. There's no reason why you can't assemble it in smaller pieces brought up by existing smaller launch vehicles.

Senator BROWNBACK. You mentioned about a Lewis and Clark type of mission, and several of you mentioned getting the private sector involved. And I note some people in the audience that have talked about getting the private sector much more involved. How do we do that? Should we be contracting with people in the private sector, saying, "We want you to do the Moon trip. What do you bid it at?" And doing this on a private sector bidding-it-out basis and run by the private sector?

Dr. SPUDIS. Well, there are a lot of possibilities. I've always thought that the purpose of Federal involvement in space exploration is to do the risky—high-risk development things that private industry won't invest in. But once that's done, once the technology is demonstrated, you should turn it over to the private-sector activity.

To give you an example, the commercial launch industry in this country puts into geosynchronous orbit a mass equivalent to an *Apollo* launch every year. Now, that industry did not exist 40 years ago, and largely it was created on the technology base that came from *Apollo.* So, in that sense, you always have the private sector following governmental activity.

But there are other more innovative ways you can look at it. One thing you might consider is to establish a joint program office that would have direct authority from the executive to implement a specific plan to return to the Moon. That would involve various Federal agencies, such as NASA, Defense Department, Department of Energy, and then that could also partner with private-sector entities, as well. So there are a lot of innovative ways to look at managing this, more than just making this a NASA program.

Senator BROWNBACK. Yes, that's an interesting point.

Dr. Spudis, you mentioned that Europe, India, Japan, and China all have robotic missions to the Moon in some stage right now?

Dr. SPUDIS. That's correct. Right now, the Europeans are actually en route to the Moon with a mission called SMART–1 that was launched about a month ago, and it's using solar-electric propulsion, so it's going to take about 18 months to get to the Moon. It uses a very low-thrust, high-ISP engine that loops around the Earth multiple times and gradually reaches the Moon.

Japan has two lunar missions in the works that I am aware of. One is actually a set of two penetrators that will hard land into the Moon and search for seismic evidence for a lunar core. The other one is a very large spacecraft, a two-ton spacecraft, that will do remote sensing from orbit.

The Indians have announced that they are planning to send a lunar obiter in 2008. And I have read reports that the Chinese are not only planning to send orbiters and landers, but they are also looking at architectures designed to send people to the Moon, as well.

Senator BROWNBACK. In what timeframe, on the Chinese?

Dr. SPUDIS. It's very vague, but my understanding, they talk about robotic missions within the next few years, and they certainly talk about human missions within a decade.

Senator BROWNBACK. Dr. Angel, the telescopes on the Moon that you talked about, where does this rank in the astronomy community as far as their depth of support and interest in putting telescopes on the Moon? Is this their top priority item? Is this one of those, "Well, if you've got the money, it would be nice to do"?

Where does this rank in their interest for exploration and research purposes?

Dr. ANGEL. I think there's a lot of enthusiasm for building telescopes and looking beyond what we're now engaged in, which is the James Webb Telescope. I would say that the idea of going to the Moon is a new one, and I think the thinking up to now has been more to go to the same remote places that we put telescopes that don't need servicing.

So I think the astronomy community—I'm a bit ahead of them right—is looking hard at what the Moon would do——

Senator BROWNBACK. Meaning they haven't been looking at it, because they just didn't see this as a feasible thing that we would even consider doing?

Dr. ANGEL. I think there's always a second-guessing about what you think NASA is going to be interested in supporting. And it's certainly true, for the last decade, that NASA has not encouraged thinking about the Moon as a site for astronomy or that kind of development.

Dr. SCHMITT. Put very kindly.

[Laughter.]

Dr. ANGEL. But, I've tried to take a problem, have an issue and say, well, what's it really like there? And I think that the hurdle has been that telescopes on the Moon do have to work in the presence of gravity, and if you're fighting that, that makes it harder. So, other things being equal, if you can figure out how to get the manned support for a big telescope somewhere else, maybe you would prefer that. If there's a strong interest in a base on the Moon—and I subscribe to a lot of the views here—then if that were there and it were at the south pole, then I think the astronomical potential there is very high.

Senator BROWNBACK. And the support from the community would be very high at that point in time if this is seen as a real possibility?

Dr. ANGEL. I think the nervousness in the community is to be the tail on a very big dog. So if you put all your hopes into placing a big telescope on the Moon, you join an enormous enterprise over which you have very little influence.

Again, it's back to this issue of there being a commitment to sustain this kind of effort? Because there are less ambitious ways that you could get at least some of your astronomy done and feel that it was more in your control.

So I think if one felt that this was really going to happen, there was really going to be a base, then I think there would be enormous enthusiasm to do things there. But if you feel you're going to go down a few years down this road and then it's abandoned, and you've basically set back your effort that you might have gone in another direction.

Senator BROWNBACK. By what sort of factor would the view of the Hubble Space Telescope improve, if we were to place telescopes on the Moon? Would we be able to get 20 percent better reach, and be able to get 30 percent better definition, are we talking in multiples here, if we have telescopes properly placed on the Moon?

Dr. ANGEL. Well, I had looked at the sensitivity of the James Webb Telescope, which is a six meter telescope that we're now engaged in. If we put a 20 meter telescope on the south pole of the Moon, and there are two things that let you see deeper and further and fainter. One is a bigger aperture, and that makes a sharper image, collects more light, and the other is just to wait for an enormously long time, which is what—the Hubble, in looking at its very deep views of the universe, collected light for a couple of weeks on the same patch of sky. If you're at the south pole of the Moon, you can look 24 hours a day for years at the same patch, and if you do that, you can see even a hundred times fainter than the Webb Telescope. So it's a very specialized job, right, with just drilling into the universe in one patch, go as deep as you can. That's what it would take to see these first stars.

So this is not just a small increment on what—all the plans at the moment, which go as far as the Webb Telescope. We could go a lot deeper if we made this observatory and used it for a long time.

Senator BROWNBACK. Whoever wants to take this question, I would appreciate you jumping in, or maybe a couple of you would. There's a lot of discussion about going to Mars. Dr. Spudis, you addressed a portion of that in your testimony. And I think there are some thinking that you go to the Moon to get to Mars. Address this issue for me. Are these exclusive matters—I mean, given likely budgetary constraints—that you pick either the Moon or Mars? Or is the Moon essential to making it to Mars and learning? Give me your thoughts about how this ties in with a Mars mission.

Dr. SPUDIS. Well, the way I see it is that what you want to do on the Moon is to learn how to use off-planet resources. And if you can do that, you've not only opened up the way to Mars, you've opened up the way to anywhere else you want to go. Effectively, by making propellent on the Moon and making the commodities you need to support human life, you've basically created the ability to move throughout the Earth-Moon system, throughout cislunar space. And if you can do that, certainly you can—that propellent can be used to send future missions to Mars. So it's not really a diversion, it's more—I consider it more of an enabling technology.

Right now, to go to Mars would require an amazing amount of money, probably an amount of investment that this country is not willing to put up. But, more than that, I think that you need to gather more experience in space. You need to gather experience in planetary surface operations, in using resources, and in actually building an infrastructure. So that's the value of going to the Moon, relative to a Mars mission. If you go to the Moon and do this, you will automatically make it easier to go to Mars in the future.

Dr. SCHMITT. Mr. Chairman——

Senator BROWNBACK. Senator?

Dr. SCHMITT.—it's not an accident that our umbrella little corporate entity is called Interlune-Intermars, because we think that the cheapest and probably the fastest way to get human beings to Mars and begin the exploration and settlement of that planet is by way of the Moon, through commercial development of the technology base that's necessary to go to the Moon and to extract its resources. And the reason I say that is that if you can get investors to bear the capital burden of that development, then the price to the government or other entity that decides that it wants to fund a mission to Mars is significantly less. In addition, the development of this particular type of fusion technology has a very, very clear application to interplanetary propulsion systems through which you can accelerate and decelerate continuously and change the dynamics of actually performing Mars exploration.

But in contrast to what Dr. Spudis has said, we feel if you're going to depend primarily on a commercial endeavor, then you're going to have to have a rocket system that, through mass production—or through long-term production contracts, better put—reaches a cost, a payload cost, to lunar injection of about $2,000 a kilogram or less. We've done some business modeling studies at the University of Wisconsin, the business school there, and right now it looks like you've got to get down into that range. We don't think Shuttle-derived hardware can do that. We don't think the government can do that. It's going to take, I think, the initiative and the constraints of a commercial enterprise to drive those costs to that level.

We would look at an up-rated *Saturn 5,* call it a *Saturn 6,* as sort of a baseline system to evaluate and then to compare other systems to, because it was a very successful technology, and it's a technology that would benefit from long-term production contracts, as well as from modernized manufacturing and design systems.

With respect to the role the government could play in all of this to facilitate it and to make investors more comfortable, we have more recently been looking at—encouraging the government, NASA maybe in particular, to take on, in this field, an NACA-like responsibility. That's the National Advisory Committee on Aeronautics that was the precursor to NASA and, during the last century, had so much to do with enabling the development of the technologies, it ultimately became the foundations of the commercial aircraft industry.

That model is a very good model for certain things, and we think it could be utilized as a way to attack and accelerate technology development that would be necessary for commercial enterprises in space across the board, not just those enterprises going to the Moon.

But as a partnership with government, we think that would be a very, very difficult managerial nut to crack, frankly. And either you need NASA or a new agency to take this on, or you need to be primarily looking at investors to take it on. I don't think there's a good middle ground. We've looked at that, evaluated it, and it looks like a very, very tough row to hoe.

Senator BROWNBACK. Dr. Spudis suggested that one of the routes might be an interagency operation. I think, if I get your testimony correct, that it might be done by a group, because you have military objectives, exploration objectives, research, commercial objectives, and you would be going across a number of different agencies to do this project.

Dr. SCHMITT. I think there's a lot of history, Mr. Chairman, to say that those kind of endeavors don't work very well. They're very, very hard to manage. And it's probably better to see that there is a central focus, either within the private sector or within the government, for the development of the capability, and then that capability is utilized independently by other entities.

As a matter of fact, if you go back in history, President Eisenhower debated with himself whether or not there would be a NASA or whether missile development would be spread—concentrated missile development within one agency, or it would be spread out between several agencies. And he decided on the latter. And I think it has been to the benefit—although not without its problems, but to the gross benefit, the general benefit—of the development of rocket technologies for the Air Force, the Navy, and the Army were left with separate responsibilities in the development of rocket systems, because they had very special applications of those rocket systems. If it had all been concentrated in one agency in the Department of Defense, then I think there probably never would have been a NASA, for one thing.

Senator BROWNBACK. Dr. Criswell, did you have anything else that you would like to add to any of your testimony or any of these questions?

Dr. CRISWELL. Yes. The statement is often made in the literature that we have major sources of fossil fuel that can last for centuries. And that is true, but what you usually don't hear is the statement, the flip side of that statement, that the majority of people in the world will stay dirt-poor. Right now, a billion people are rich with energy; the other five are not. In 2050, a billion people will be rich with energy—probably not as many in this country as there are now, or in OECD—but nine billion people will be poor.

I've identified 33 options that could bring the world up to a minimum level of energy use, about two kilowatts electric per person by 2050, that can get the cost low enough that the five to nine billion people could afford it, that would be clean, that would be independent of the biosphere, that used technologies that you can understand now. And I've only identified one, and that's this lunar option.

It was an unusual career path that I took out of Rice, where I did my Ph.D., back when *Apollo* was just starting. And for the first 7 years at the Lunar Science Institute, I managed the first 3,500 proposals submitted to NASA for lunar science. That was full peer-review activity, and a lot of scientists there depended on the data and the samples brought back by Dr. Schmitt. We don't usually realize that the U.S. and the world has invested over a billion dollars already in understanding what we did on the Moon, the samples, and the environment since then.

We, as a Nation, have expended almost $650 billion on our civilian space program. World technology relevant to the Lunar Solar Power system is basically electronics, an that's been the source, major source, of wealth for this nation, if not for the world, for the past 30 years.

We have all the pieces to do this. We could get through the R&D phase for about .08 percent per year, for the next 6 years, of our gross product. We could get through the full implementation phase in 35 years for a quarter of a percent of our present gross national product. That could lead to a factor-of-ten increase in gross world product. It could remove from Earth the need to fight wars over scarce energy resources, and to have independent control of those energy sources so that they do not pollute the biosphere.

Essentially, by establishing the production of new wealth on the Moon through commodities, making of commodities to do the things I'm talking about, you change the future of the human race.

Senator BROWNBACK. A powerful statement, and very interesting.

Gentlemen, thank you very much for joining me here today and building this case up for returning to the Moon. I think we're at an exciting point. We're at a key moment where things are being reviewed for real possibility and sustainability. I'm very aware of the stop-and-start nature that we've been going over the past two decades in space programs, and we can't afford to do that again. And this has to be a vision that's sustainable, that's real, that has buy-in from the American public, that is sufficient to lift the soul. And so that's why we're spending this time. Let's chew through this a step at a time and get to what really is something that can work.

Appreciate very much your expertise and your sharing of it. The hearing's adjourned.

[Whereupon, at 3:40 p.m., the hearing was adjourned.]

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