KEYNOTE ADDRESS:

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First, I would like to thank the conference organizers for the opportunity to speak to you today, and I would like to thank the staff of the Space Studies Institute for the huge amount of work they have put into the organizing of this conference. The first such conference, although it was before the establishment of the biennial schedule, or the implementation of its current title, was in 1974, so we can legitimately regard this conference in 1999 as the 25th anniversary conference. Nineteen-ninety-nine marks another important anniversary, as it was thirty years ago, in 1969, when in Gerard O'Neill's physics class the realization first occurred, based on engineering calculations, that it would be possible using then-current technology to establish the permanent human habitation of space.

So, I begin my presentation with a look not forward, but rather back, to the second Princeton Conference, held in 1975, because I believe it indeed shows that the seeds were sown more than two decades ago for most of the future activities we will discuss here at this conference over the next few days. I would like to begin with a quote, from Gerard O'Neill, from his presentation at that 1975 meeting, entitled *The Space Manufacturing Facility Concept*.

I quote: "We define a space manufacturing facility as a permanent or very long term human community, in an orbit so high above the Earth or any other planetary body that it can use solar power continuously without frequent eclipsing. Such a community, once established, must be entirely self-sustaining rather than continuously resupplied from the Earth. It should be constructed from materials available in space, such as those of the lunar surface or the asteroids. The space manufacturing facility uses its free solar energy and its easy access to the materials of space to produce manufactured products whose end use is in a very high orbit or at escape distance.

The economic rationale of a space manufacturing facility is based on three elements. The first is energy: in free space, in a high orbit, not only is solar energy available continuously without interruption, but the total amount received in a year is about ten times as much as arrives on an equal area on the Earth's surface, even in the most cloud-free portions of the American southwest.

The second element is materials. The energy cost of lifting materials from the lunar surface to escape distance is about one twentieth as much as for lifting materials from the surface of the Earth. In addition, the Moon has no atmosphere, so a stationary launching device on the lunar surface can operate without atmospheric drag, and can be optimized for the most efficient payload size. Our estimates indicate that these two advantages would permit the lifting of lunar material to escape distance for the order of one percent of the overall cost that launch from the Earth would require. We call the device that does that job a mass-driver.

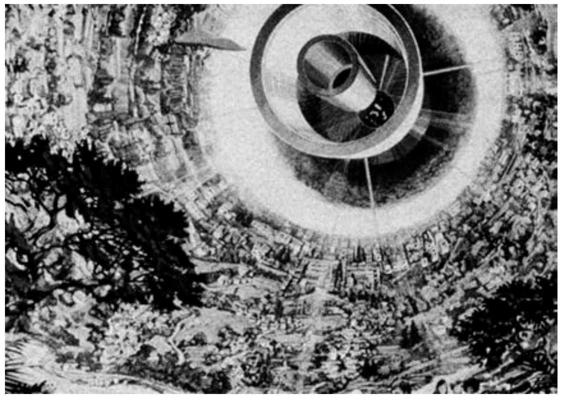
The third element in the economic rationale for space manufacturing facilities is that in free space, one has the availability of zero gravity, in which very large objects could be assembled free of all constraints of payload size. At the same time, perhaps only a few meters away, a comfortable habitat for living could exist, providing Earth-normal gravity by slow rotation."

As we look back nearly 25 years to these comments from Gerry O'Neill, we see the basis for activities we still support today. Specifically described in Gerry's words are certain key concepts, including the following:

- Habitats for permanent human residence in space.
- Self-sustaining infrastructure.
- Use of lunar materials.
- Use of asteroidal materials.
- The need for economic rationale
- The potential for solar power satellites.
- Mass-drivers as enabling technology.
- Zero gravity manufacturing.
- The processing in space of space-based materials.

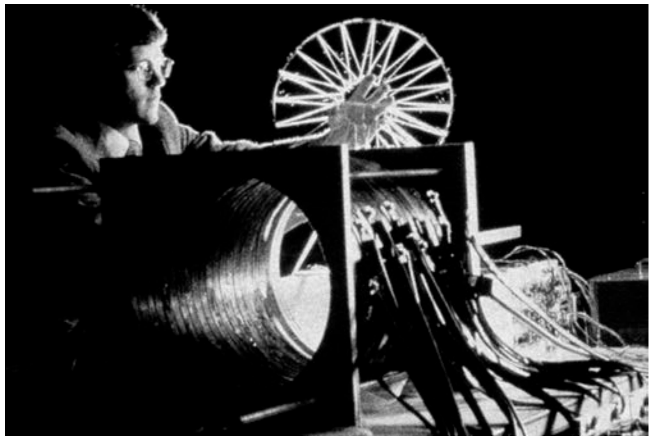
I would like now to take this opportunity to look with you at slides drawn from the historical archives of this meeting. They serve to illustrate several of the key concepts just enumerated. They are key concepts for the establishment of routine space-based manufacturing and commercial operations. All of these concepts have been the subject of serious scientific study, much if not all of it supported in some way by SSI, and in many cases through direct SSI sponsorship. Much of this research has been performed by people in this room today.

If we go back to 1969, we see designs for human space habitats, space colonies, based on a model of two cylindrical units tethered together. With further study it became increasingly clear that for a variety of reasons, including improved manufacturabilty, it made more sense to pursue spherical rather than cylindrical living chambers.



Fundamental to any large-scale space manufacturing endeavor is the delivery to the point of manufacture of large amounts of raw materials. The mass-driver concept was originally conceived for the delivery of lunar material to LaGrange points, where materials processing and manufacture would occur. Mass-driver one, constructed here at MIT with funding from SSI, is shown here.

Because of relatively low forces of acceleration achieved, a lunar-based machine based on mass-driver-one performance would require a long acceleration tube. Mass-driver-two, testing a push-pull approach, and realized a greater acceleration than mass-driver-one. The last mass-driver built was version three, with a half-meter inner diameter, and realizing a still larger acceleration. Shown with the machine is Dr. Les Snively. Shown below is the progression in performance of the mass drivers. Note that mass driver 3 realized an approximately 50 fold improvement in performance over mass driver 1. Such an improvement in acceleration would require a concomitantly shorter flight tube to realize lunar escape velocity.



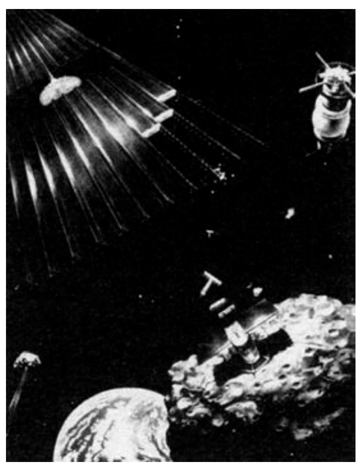
Machine	**Acceleration**	**Length for Lunar Launch**
Mass Driver I	33 g’s	8905 meters
Mass Driver II	500 g’s	587 meters
Mass Driver III	1,800 g’s	160 meters

Note that mass driver technology has also been pursued in the context of propelling asteroids to desired destinations for manufacturing operations. Also contemplated has been the tethering of asteroids for delivery to point of use.

Once raw materials are delivered to their point of use, processing will be required in most cases. The glass-glass composite material, researched by Brandt Goldsworthy with SSI support, is one example of how crude materials may be processed into engineerable materials at the point of use.

Generating the heat required to produce such materials, without complex machines, has been studied. Such approaches may include the use of solar collectors. One such Earth-based device is shown below.

Realistic economic drivers will be critical to realization of a vision with large numbers of people living and working in space. Solar power satellites have been considered in depth for this purpose, including work that will be presented by Seth Potter at this conference. Seth's work at New York University was funded by SSI. One design for a solar power satellite is shown here.



A variety of designs for solar power satellites have been considered, another of which is shown here. The area required on Earth for beamed microwave collection is not extensive, being comparable to areas now used for experimental solar power collection facilities such as exist now in the desert southwest. Microwave fluxes in the collection areas would not preclude even the grazing of animals under the collectors.

A very practical, if perhaps less glamorous idea to facilitate space development, that has been championed by the SSI, as well as individuals in this audience, is the reuse of Space Shuttle external fuel tanks for inexpensive development of living areas. An unmodified fuel tank could provide a shell for construction of useful living quarters. The interior of such tanks is impressively large, providing space sufficient or many potential uses.

One of SSI's most key roles has been to act as a catalyst for the scientific and engineering activities of others, leading to the furtherment of space development. One serious concern for the development of human activities in space is the scarcity of hydrogen. SSI championed the idea of a lunar pole probe searching for ice at the Moon's poles.

The general concept of a lunar polar probe with instrumentation suitable for the detection of lunar polar ice was initially taken up in the form of the Clementine probe. Clementine was launched at no expense to SSI after Gerry O'Neill's death in 1992, carrying a dedication to Gerry. The probe did detect signatures suggesting the presence of lunar polar ice. A follow-up "Discovery Mission" by NASA built and launched the Lunar Prospecter, which was designed by SSI. It has since sent back proof that water exists on the Moon. Below is pictured the SSI Lunar Prospector mockup.

The group gathered in this room today has supported these activities over the last 25 years and more. This is evidenced by the presentations being given here over these next few days. From the preliminary agenda we have, for example, Thomas Taylor speaking on a variation on the theme of space habitats, being those created for space tourism. This addresses a possible economic driver as well. And Robert McMillan will speak about the search for those near-Earth materials, such as asteroids, that may be most economically brought to the point of processing and manufacture.

Several talks we will hear at this conference move beyond the specific concepts described in Gerry O'Neill's quotation that I read a few minutes ago, but generally extend the basic ideas into new implementations. Among these, Robert Waldron will discuss Resource Utilization Processes for Mars and its Moons, which considers resources other than the lunar and asteroidal ones that were the primary focus of Gerry O'Neill back in 1975. Stephen Gillett is speaking on Molecular Nanotechnology, a technology that did not exist at the time of the 1975 conference, but that may be brought to bear for space manufacturing, and could eliminate the need for some of the hands-on work of humans. Derek Tidman will discuss the slingatron concept, that might replace the mass driver in at least some of its functions, but still contributes to the general idea of inexpensively getting materials to where we need them for space manufacturing. Gerald Falbel will discuss using the Moon itself as a solar power satellite.

Some may find it peculiar that I, as a biochemist, would be delivering this address to you, or that I would be involved in S SI at all. I sometimes find this peculiar myself, and that serves to induce me to ask myself questions about what I might possibly bring to this venture. Allow me to tell you a little bit about what I do, and how I believe it may apply in some way to the mission of all of us in this conference. Let me start by going back to the quotation I used to open this address.

Those remarks, from Gerard O'Neill's presentation at the 1975 conference, were largely about economics. Gerry understood that the move into space could only ultimately be driven and sustained by economic forces. Any venture of this magnitude will ultimately be driven by economic forces, whether it is exploration of the new world financed by European Monarchs, the development of the western United States, driven by a young, growing country on the edge of a new frontier, or the adventurous, forward looking members of all countries of this Earth, on the edge of a new frontier called space, separated from us only by a few hundred miles, but much more significantly by our planetary atmosphere and Earth's gravitational well.

In my own experience, I am privileged to be a part of a grand scientific adventure of a magnitude unprecedented by anything since the Manhattan Project of more than 50 years ago. My company, Perkin-Elmer (now PE Corporation) announced last year that we would set up a business unit called Celera Genomics, the mission of which would be the sequencing of the entire human genome, the three and a half billion letters of information that spell out the code for making an entire human being. By act of congress at the beginning of the 90s the government committed to this same task, allocating a budget of 3 billion dollars, with an expected completion date of 2005. By 1998, roughly half way through the program, it is estimated that only about six percent of the genome had been sequenced. That by an international consortium consisting of huge factory-like laboratories, with primary efforts in the US, Great Britain, France and Japan. Celera Genomics announced boldly that it would complete the task, actually 10 sequences being generated from 5 individuals, ten times the sequencing of the previously planned effort, in two years, which is less than one-fifth the time allocated by the government-financed effort, and at a total cost of $300 million dollars, or one-tenth the government allocated amount. The result of this was at first a hostile attack on the approach committed to by Celera, followed by reluctant consideration that it might work, followed by wholesale acceptance, signaled by the NIH announcing early this year that it would substantially reallocate its budget for the next two years to finishing the task by 2001 using essentially the same approach as that committed to by Celera.

What messages can we take from this that may apply to our own efforts to begin the permanent movement of human activity into space? First is that, as Gerry O'Neill recognized in his 1975 presentation, the drivers for any effort of this magnitude must be fundamentally economic. Celera Genomics economic model calls for the generation of a commercially available database, highly annotated with information going far beyond the basic human genetic sequence, with powerful search capabilities. The primary driver for this is the value of such a database to the understanding of human disease and consequently to the development of pharmaceuticals. Pharmaceutical companies currently spend tens of billions of dollars per year on Research & Development, and see their future in medicines based on genetic information.

For the permanent movement of humans into space, such compelling economic drivers must be identified, and must be plausible as to their potential profitability. I note that in this conference you will hear from a number of individuals whose messages will likely reflect this view. For example, we have Amanda Moore speaking on Privatization, Commercialization and Competition, Mike Ryan speaking on Business Scenarios for Space Development, and Yanai Zvi Siegal, speaking on A Business Analysis for Commercial Space Development and Solar Power Satellite Systems. As we all know, in addition to solar power satellites there exists now also a company devoted specifically to the acquisition and mining of rich asteroidal resources. Some of our ideas may fail to pass economic analysis, and that is OK, as long as one or more provides a compelling, believable story of how our efforts in space will sustain themselves economically.

A second message I would like to borrow from the Celera story is dear to the hearts of any of us who have been involved in SSI, that is, that one significant measure of one's far-reaching success in any endeavor is the extent to which their efforts serve to catalyze the efforts of others. I remember some years ago as a number of us were debating what should be in SSI's mission statement that we all felt strongly that somehow the concept of catalysis must be captured in SSI's mission. For Celera, their efforts have catalyzed the acceleration of the government-funded human genome project. We will all benefit from that acceleration through the nearer-term completion of the acquisition of human genetic information. Even my company will benefit from the competition, both because it produces the instrumentation and chemistries that enable genetic analysis, and will sell those to both the governments and its own sequencing efforts, and because its own mission will be more focused, knowing that others are nipping at our heels. We in this room need to find ways of catalyzing the activities of others, and ideally of doing such a good job of this that more than one venture will be competing to be first to develop the most convenient, commercially viable near-term concepts. With an ultimately unlimited frontier the concept of such competition may seem strange, but at the same time I am seeing right now first hand how such competition, if it develops, can add excitement, focus and a huge sense of urgency to an endeavor.

A third message I take from the Celera example is that capturing the imaginations of the population, and getting the issues before the public for debate, is a nearly essential component of the equation. More than twenty years ago there was articulated such an imagination-capturing vision for space development: that ALL humans who wanted to could have a chance to participate in the adventure. Not all public debate on such matters, whether it is sequencing the human genome or moving people permanently into space, will be positive, nor probably should it be. But if we can get the debate going again in the publics imaginations there will be those among them, if our story makes sense, who will want to participate, and who will join the parade, and get this topic that has been too quietly in the background since shortly after the last Apollo mission, back into the public spotlight.

As this group of engineers and scientists talk among ourselves this week about what we believe in our hearts, let’s also think SERIOUSLY about how we can get our mission back into the public's imagination.