Testimony of
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Subcommittee on Space
Committee on Science, Space and Technology
United States House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today to discuss private sector lunar exploration. My name is George Sowers and I am a Professor of Practice at the Colorado School of Mines in Space Resources. Earlier this year, I retired from United Launch Alliance where I was Chief Scientist and Vice President of Advanced Programs.

Summary

- Space resources will be the third major economic revolution in human history.
  - Frees human progress from the resource constraints of Earth.
- Space resources are nearly infinite.
- Developing space resources will require a robust space economy.
  - Based on Free Market principles.
  - Must deliver value to consumers on Earth.
- Cislunar space, due to proximity with Earth, is the starting point.
- Economic development of the Moon will be critical to creating a robust cislunar economy.
- Propellant derived from water mined on the moon will be one of the first economically viable activities.
- Propellant from the Moon can dramatically reduce the cost of most space activities including missions to Mars.
- Government has several roles to play in developing the cislunar economy
  - Establishing a framework of rights, enforcing contracts and providing security.
  - Investing in basic science and technologies.
  - Participating in the cislunar economy as a customer.
  - Investing in infrastructure through public-private partnerships.

Introduction

The subject of today's hearing is of great interest to me. It is part of a larger topic—one that is truly revolutionary—that of bringing the resources of space into the economic sphere of humankind. There have been two major economic revolutions in human history: the agricultural revolution of 10,000 years ago which gave birth to human civilization and the industrial revolution of 300 years ago which gave rise to the tremendous increase in human well-being and prosperity we enjoy today. Space resources will be the third major economic revolution and will usher in an era of unprecedented prosperity and flourishing. Furthermore, the development of space resources will enable us to save the Earth as we unchain human progress from the constraints of Earth's ever diminishing resources. Table 1 shows the major economic revolution in human history.

Table 1. *Economic revolutions through human history.*

Revolution	Timeframe	Location	Energy Capture	Impact
Evolution of Modern Humans	~100,000 years ago	East Africa	4,000–5,000 kcal/cap/day	Spread throughout world
Agricultural	~10,000 years ago	Levant (hilly flanks)	10,000–30,000 kcal/cap/day	Increased population, empires, crowding, disease
Industrial	~300 years ago	England	50,000–230,000 kcal/cap/day	Manufacturing, mining, transportation, prosperity, pollution, climate change
Space Resources	10–50 years from now	Cislunar space	Hydrogen/oxygen propellants, solar power >>250,000 kcal/cap/day	Universal prosperity, green earth, reduce/eliminate scarcity

Compared to Earth, the resources available in space are virtually infinite. Consider. The power output of the sun is ten trillion times the entire world's power consumption. Just one metallic asteroid, 500 meters in diameter, contains more platinum group metals than have ever been mined. Finally, we now know, in large part through the efforts of NASA, that the inner solar system contains abundant quantities of water. If you have water, you have hydrogen and oxygen, which are the most efficient chemical propellants known. Water is the oil of space.

We know these resources exist. Bringing them within the economic sphere of humankind requires the machinery of a robust space economy. And that means harnessing the power of the free market. Competition in the free market spurs innovation leading to efficiency and growth. But the foundation of the free market is the consumer, the ordinary citizen—the taxpayer. The space economy must deliver value to consumers on Earth. Hence, the first place to begin is cislunar space: the Earth, the Moon and neighboring space to include near Earth objects (NEOs) or asteroids.

The geography of cislunar space determines the types of economic activities that might take place in various locations. The key locations are low Earth orbit (LEO), Geosynchronous orbit (GEO), Earth-Moon Lagrange point number one (EML1), low lunar orbit (LLO), the lunar surface or a near Earth object (NEO) or asteroid. Of critical

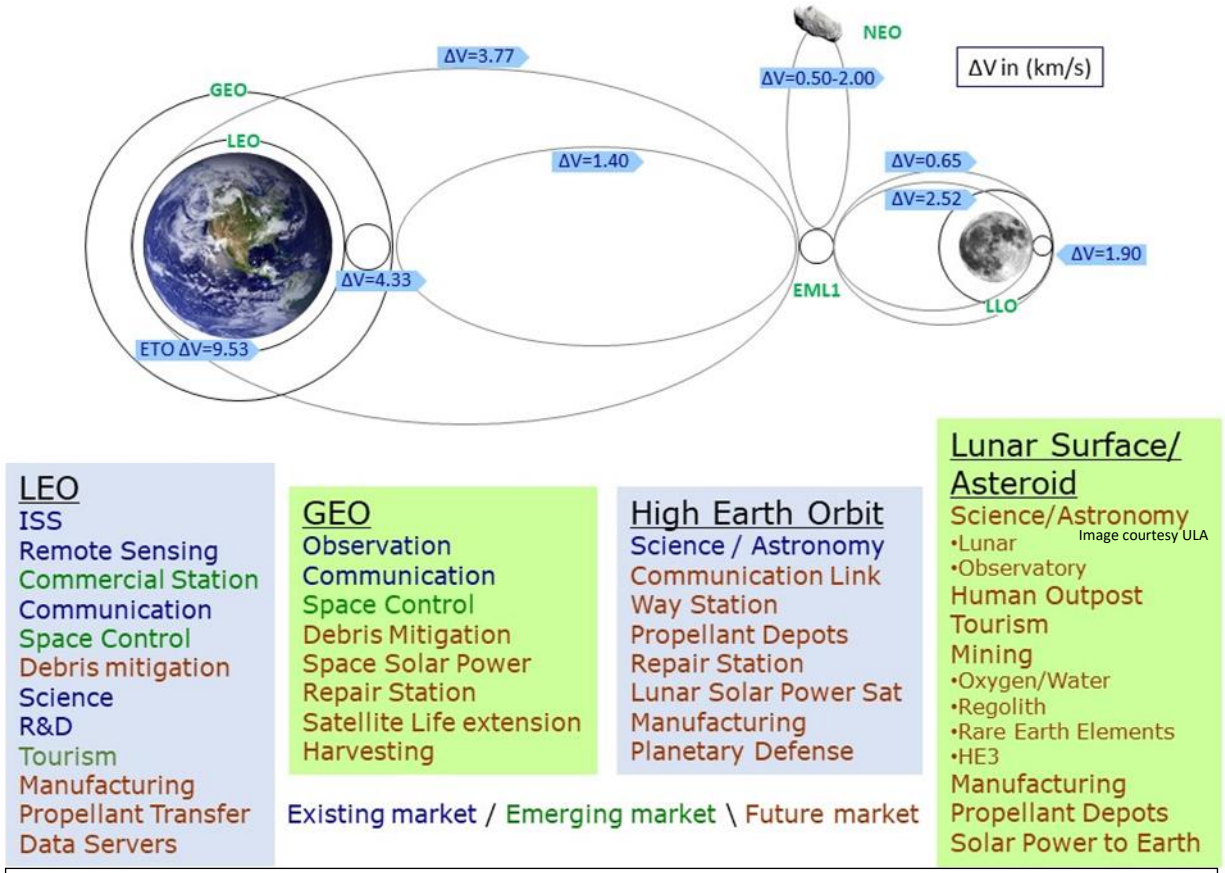

Figure 1. *The geography of cislunar space, the key locations, Delta V between them and potential economic activities.*

importance is the energy required to move from one location to another. A useful proxy for this energy is Delta V, the increment of velocity that must be added to a spacecraft to travel from one location to another. Figure 1 shows the relative locations in cislunar space, the delta V between the locations as well as some of the economic activities that might take place at key locations.

The Resource Potential of the Moon

The goal, then, of private sector exploration of the Moon is economic development. The extraction and utilization of lunar resources will be the cornerstone of that development.

The Moon is rich in resources that will drive the Cislunar Economy. The basic regolith can be used as raw material feeding manufacturing operations. Helium three, implanted by the solar wind, could be mined as fuel for fusion power plants. But the resource that will be most valuable in the near term is water processed into propellant. It happens that water is abundant at the lunar poles, billions of metric tons per pole by some estimates.

One year ago June, while at United Launch Alliance, I became the first person to offer to buy propellant in space. I set a price for propellant bought either on the lunar surface ($500/kg) or in a high Earth orbit like the first Earth-Moon Lagrange point ($1000/kg). It turns out that if you can buy propellant in orbit for less than it costs to ship it there from Earth, the business case can close. At these prices, the cost of any activity beyond low Earth orbit becomes dramatically reduced. For example, the cost to deliver mass to the surface of the Moon will be reduced by a factor of three. The cost of a Mars mission will be similarly reduced. So, you can see that the water on the Moon is an immensely valuable resource. Strategically we should view the poles of the Moon as the next Persian Gulf. Figure 2 shows the cost of propellant at various places within cislunar space.

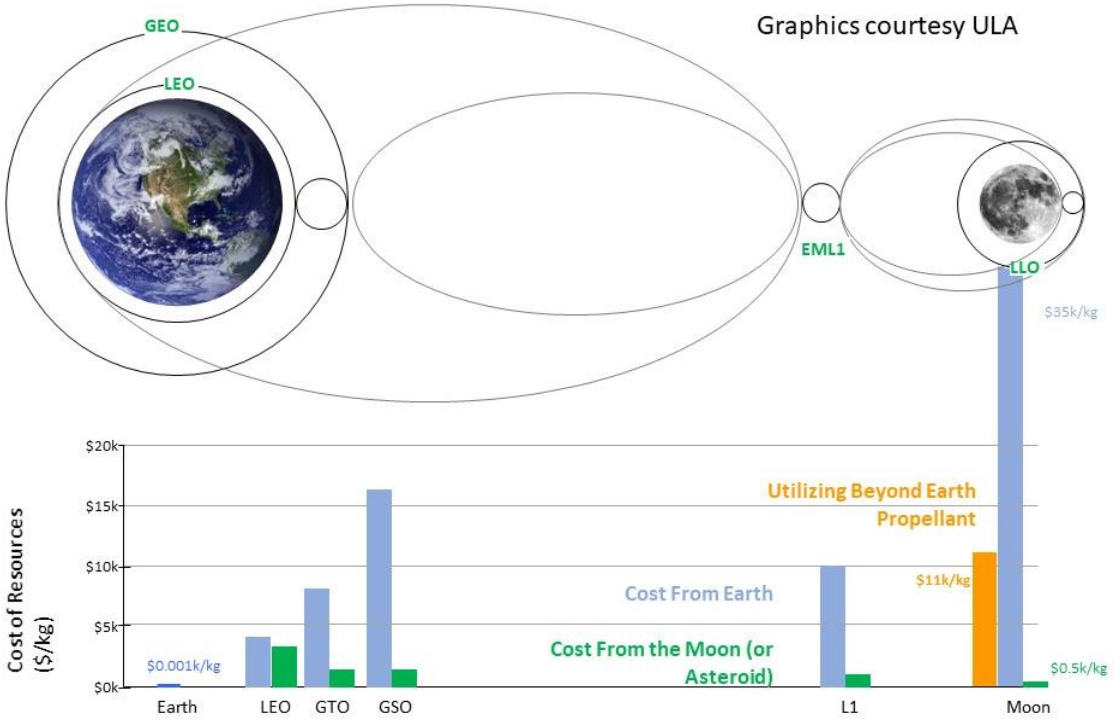

Figure 2. *The cost of propellant if shipped from earth (blue) or sourced in space (green).*

The Role of Government

I've described the Cislunar Economy as a free market and in general, a free market means commercial entities doing business with other commercial entities. But the operation of a free market requires government to establish a framework of rights, enforce contracts and provide security. These things are part of the machinery of a robust space economy and are essential to reduce business uncertainty and enable private sector investment.

Beyond the minimal, there is much the government can do to stimulate the creation of the Cislunar Economy. First is to invest in basic science to characterize the resources and develop the technologies to exploit them. One approach would be for NASA to establish a Space Resources Institute, partnering with both academia and industry, domestic and international, to solve some of the basic problems common to all.

Second is to *participate* in the cislunar marketplace. I set a price for propellant based on purely commercial considerations. But having NASA as an additional customer purchasing propellant for, say, a Mars mission would significantly improve the business case and attract more competitors driving more innovation and lowering costs even further. That is the virtuous circle of the free market.

Finally, NASA could invest through a public-private partnership in, for example, a water mining operation. This approach has proven successful with commercial crew and cargo and works well when the risks are too great for the private sector to take on by itself. Of course, a significant return on investment should accrue to both parties.

NASA has chartered a scientific analysis group to assess lunar exploration priorities. Called the Lunar Exploration Analysis Group (LEAG), this group has retained a Commercial Advisory Board (CAB) of which I am a member. The LEAG CAB conducted a workshop in June and developed several findings which are consistent with my testimony. The one-page summary of the workshop is included as Attachment 1.

Conclusion

In conclusion, humankind is on the cusp of a third major economic revolution that promises to bring unprecedented prosperity and well-being for all. The first step is the creation of the cislunar economy. The private sector is poised to begin. Government participation will only accelerate its realization. I close with a quote from John Marburger, the science advisor to President George W. Bush, from a 2006 address.

> *The Moon has unique significance for all space applications for a reason that to my amazement is hardly ever discussed in popular accounts of space policy. The Moon is the closest source of material that lies far up Earth's gravity well. Anything that can be made from Lunar material at costs comparable to Earth manufacture has an enormous overall cost advantage compared with objects lifted from Earth's surface. The greatest value of the Moon lies neither in science nor in exploration, but in its material.*

Thank you again for inviting me to testify. I look forward to your questions.

Attachments:

1. Back to the Moon Workshop Report

Back to the Moon Workshop Report

21-22 June 2017, Lunar & Planetary Institute, Houston.

Executive Summary

- There are many private sector companies that have aspirations to do things on and around the Moon. We heard from several of them at the meeting. No one has flight proven capability……yet, but the first commercial expedition has regulatory approval for late this year.
- Many of these capabilities will enable real economic development of cislunar space and real wealth creation.
- We heard universal agreement that the following were the greatest challenges to further progress in commercial lunar missions:
  - not having a permanent regulatory framework for commercial lunar missions,
  - NASA transitioning to a customer.

Finding 1: A permanent regulatory framework for commercial lunar missions is part of a current Congressional discussion, embedded in the American Space Commerce Free Enterprise Act of 2017. The ASCFE framework builds on the 'Mission Approval' that Moon Express received from the USG in 2016. The meeting participants fully support these efforts as part of the ASCFE.

Finding 2: NASA can enable rapid development of the commercial lunar industry by offering to be a customer. The sooner NASA does this, the faster commercial capabilities will be developed. The range of capabilities offered would reflect the breadth of investigations that NASA could offer.

- There is a spectrum of services that NASA SMD and HEOMD could buy. For example, transportation services to lunar orbit, transportation to the lunar surface, rover services on the surface through buying samples or data.
- Commercial companies are already taking on scope and risk and will be able to attract more investments if they can show NASA as a customer. NASA can leverage that willingness, save time and dollars by crafting programs that take advantage of the new capabilities offered by commercial lunar companies.

Finding 3: In addition to paying for payload flights, NASA should strongly consider buying transportation services, samples and/or data. In order for this to succeed, the nature of the samples/data required must be adequately specified.

- The benefit of this approach is all the technical and financial risk is on the company. NASA's risk is that the company fails and the ride, data or samples are not available or obtained.
- NASA can mitigate some of this risk by partnering with the company by investing dollars or resources or expertise i.e., establish a public-private partnership.

Finding 4: NASA should consider public-private partnerships for particularly difficult or risky activities to share the risk, increase mission cadence and the probability of success, and enhance the business case for the commercial partner.

- **CONCLUSION**: There is a lot of enthusiasm for commercial lunar missions and capabilities of the private sector could enable a new era of lunar science and exploration.