Statement of
Walt Faulconer
President, FCG, LLC

Before the

Committee on Science, Space and Technology,
Subcommittee on Space and Aeronautics
U.S. House of Representatives

Hearing on:
Keeping Our Sights on Mars: A Review of NASA's Deep Space Exploration Programs and Lunar Proposal

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Chairwoman Johnson, Ranking Member Lucas and members of the subcommittee, I am honored to be here today to discuss and support NASA's deep space exploration programs first returning the United States to the surface of the moon by 2024 and on to Mars in the 2030s. This year while we are celebrating the 50th anniversary of the Apollo 11 moon landing, China, India and Israel are sending their craft to the moon. Where is the United States? We are currently facing a formidable challenge from China to surpass our leadership in certain critical areas such as Deep Space Exploration Programs and Lunar exploration. I for one actually welcome this challenge because it helps us to focus and galvanize to maintain our leadership in space. Leveraging over 60 years of experience that brought us the Space Shuttle, the International Space Station and now new craft like SLS/Orion, CST100, New Shepherd, DreamChaser, Cygnus, and Dragon we have an armada of capabilities to build upon to return to the moon and head on to Mars.

I applaud the goal of returning to the surface of the Moon by 2024 because it provides needed urgency and focus. It is also achievable. It took us 7 years from President Kennedy's speech in September 1962 starting with very little to get to the Moon with Apollo 11 in July 1969. In fact, when President Kennedy gave us the challenge to go to the moon, only 3 Americans had flown in space, Shepard, Grissom and Glenn. That was it. In 1964, five years before the Apollo 11 mission, launch of the powerful Saturn V was still more than two years away. And this time it will be different when we go back to the moon because besides investing in these craft over the past 10 years, we will be going with our international partners and a robust commercial industry.

The second core requirement is to go back to the Moon in a sustainable way. We are going back to stay. That means we have to address what we are going to do on the Moon after we get back in 2024. As I addressed in the paper I provided you, there are key questions we will be able to answer on the Moon in our endeavor to explore including:

- Science questions – we have discovered many new questions and science pursuits since the Apollo program and that includes things called lunar swirls, "skylights" and applied science providing ground truth to the resources and minerals we have seen from orbit.
- Exploration questions – Do humans have a future in space, can we "live off the land", and what adjustments to our plan do we have to make based on what we learn along the way?
- Business questions – Is there a sustainable commercial business on or around the moon?
- National Interest questions – How do we ensure American leadership in space?

The third core requirement is keeping our sights on Mars. We need an approach that is extensible to getting us to Mars. The National Academy Pathways study that Dr. Luine represents had a key recommendation to maintain long-term focus on Mars as the horizon goal for Human space exploration. It is correct, but let's face it, we're not ready to go to Mars today because the risk is too high. One of the studies going on at JPL for example is looking at quantifying the risk and determining how much of the risk can be retired by going to the surface of the Moon, or identifying what risks are not being retired by anything we're planning. That will be important to help create an extensible exploration architecture, starting with the end goal in mind. When we go back to the Moon we need to learn how to live off of the land, live for longer durations and deal with the hazards that astronauts will face on Mars. All of this will be essential to understand before we send humans on that very long journey to Mars.

We can achieve these goals but our largest challenge is not the technology, engineering or ingenuity rather it is overcoming the institutional momentum that slows the process down, keeps the status quo, and protects rice bowls or "programs of record". We need to organize and streamline for success. When Dr. George Mueller came to NASA from Bell Labs to lead us getting to the Moon in 1963 he recognized that NASA even in its infancy needed to be re-organized and refocused from top to bottom. He bravely and fearlessly took on the establishment and streamlined program efficiencies borrowing from the success of the Air Force minuteman program while strengthening independent system engineering with bringing on Bellcom to provide the needed enterprise level systems engineering and integration. All of this can be accomplished with courageous leadership - leadership of this committee and people at this table.   I look forward to very soon seeing American's walking again on the surface of the moon and soon after walking on Mars.

As President Kennedy Stated, "The goal will serve to organize and measure the best of our energies and skills. A challenge we are willing to accept and one we are unwilling to postpone" Thank you very much for opportunity to appear before this committee and I look forward to your questions.

“Boots on the Moon”
The Next Step to Enabling Human Expansion Across the Solar System
A purpose-focused integrated space exploration campaign to return to the Moon

1.0 INTRODUCTION

President Trump signed Space Policy Directive-1 on December 11, 2017. It stated that the United States is to:

> *Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.*

The direction is clear to set a logical and unambiguous path forward with realistic near-term goals. ***The next step is to execute, to accomplish this direction with urgency and purpose.***

To expand human presence across the solar system we need to first explore and exploit the potential of the Moon. Much more is known today about the potential benefits of the Moon than was known in the days of Apollo. We have learned from the Apollo experience and lunar samples with continuously advancing technology and observation. The Apollo samples provide evidence of oxygen content in the regolith on a global scale. We now have discoveries from lunar satellites and probes that have globally characterized surface features, mapped resources, and determined the Moon’s planetary characteristics. The Lunar Reconnaissance Orbiter (LRO) and the Lunar Crater Observation Sensing Satellite (LCROSS) have proven the existence of water (ice) in permanently dark craters at the poles. This has led to new and compelling ideas on what could be accomplished in sending robots and explorers to the lunar surface.

This detailed knowledge has led scientists to identify multiple locations on the Moon with high potential for further discoveries. For example, we have recently discovered the existence of over 300 “skylights” or possible lave tube entry areas leading to potentially massive underground caverns. It has provided the maps and information needed to seek ground truth on the lunar surface. Exploration for in-situ prospecting can determine in what form the useful resources exist and the appropriate techniques for extraction and production.

Fifty years after the Apollo Moon landings, it is time for the United States to return to the Moon with the purpose of exploration, science, national interests, economic development and leading the way to Mars. Building on the national investments and capabilities that NASA has been developing including the International Space Station (ISS), the Space Launch System and the Orion Crew Exploration Vehicle we are ready and better positioned for the next chapter of exploration leveraging 1) private investment and commercial development that is currently providing essential transportation and satellite services, and 2) an international community brought together through the ISS that now has significant capabilities to offer. Not unlike the Mercury-Gemini-Apollo campaign, our new missions can increase in complexity in support of these goals, building on and adapting to the discoveries along the way. ***It is time for ‘Boots on the Moon’ again!***

2.0 OBJECTIVES AND GOALS

The Exploration Campaign has five strategic goals:[1]

1. Transition U.S. human spaceflight activities in low-Earth orbit to commercial operations that support NASA and the needs of an emerging private sector market.
2. Lead the emplacement of capabilities that support lunar surface operations and facilitate missions beyond cislunar space.
3. Foster scientific discovery and characterization of lunar resources through a series of robotic missions.
4. Return U.S. astronauts to the surface of the Moon for a sustained campaign of exploration and use.
5. Demonstrate the capabilities required for human missions to Mars and other destinations.

What is missing is a clear integrated outcome-driven campaign plan that connects these together into a portfolio as to how, when, why, what, who, and where. The United States must lead and integrate the top-level vision with the various elements that NASA, industry and international partners are developing. We need to answer basic questions of what we are going to do on the surface of the Moon, do humans have a future in space, can we "live off the land", and how does lunar exploration prepare us for Mars exploration, as shown in Table 1. This integrated definition is needed to enable NASA leadership to coordinate across the stakeholder community to re-focus government, industry and international participants into an executable campaign with purpose and urgency.

Table 1 The campaign portfolio approach supports each stakeholder in answering key questions, and achieving their goals with compatible strategies.

	SCIENCE	EXPLORATION	BUSINESS	NATIONAL INTERESTS
DRIVING QUESTIONS	Is there life elsewhere? How did we get here? Where are we going?	Do humans have a future in space? Can we live off the land? What are we going to do on the Moon?	Is there sustainable commercial business in lunar space beyond the Government?	How do we ensure American leadership and values in space?
GOALS	Answer fundamental origin questions	Explore for national interest	Develop long term markets and competitive advantage	Strengthen our relationships with our friends and protect from our enemies
STRATEGY	Follow the water	-Explore in a sustainable way -Boots on the Moon -Prepare for Mars -Create economic & international benefit along the way	-Public-private partnerships -Private investment	-U.S. leadership -Secure the high ground

[1] NASA Space Exploration Campaign Report, September, 2018, pg. 5.

3.0 LUNAR DEVELOPMENT

The development of the Moon follows an "early enabler" or catalyst model followed by methodical, evolutionary, adaptive and integrated processes. Recent studies show that there are high concentrations of oxygen in the lunar regolith. Supplies of oxygen are essential for human life support (air and water), rocket propellant, and other needs. Oxygen availability as a resource provides a basis for development of commercial markets and services. Therefore, one likely early enabler is the oxygen economy. However, the lunar exploration campaign is flexible to evolve based on what we discover and learn along the way

The O_2 Economy as a Possible Foundation

There have been many ideas suggested as to how the Moon can be used. A recent study by Roscosmos and the European Space Agency shows promise of utilizing lunar soil for 3D or alternative manufacturing of lunar habitats and space hardware.[2] Mining of volatiles or water has long been cited as a possible resource.

Oxygen is the most abundant element in the lunar soils, constituting 40 percent of those soils by weight.[3] Oxygen makes up approximately 85% of the weight of a typical spacecraft at launch, as oxidizer for the rocket fuel. Oxygen mined from the Moon can play a pivotal role for developing a new space economy needed for exploration, lunar development and even refueling of Earth orbiting systems. Besides giving the United States leverage in our space transportation leadership, lunar oxygen can become one of the lunar economy's first and most important economic export.

Moon dust or regolith is a mixture of many different minerals, and nearly all of them contain oxygen in considerable abundance. One of the most common lunar minerals is *ilmenite*, a mixture of iron, titanium, and oxygen. (Ilmenite also often contains other metals such as magnesium). The processes to extract oxygen are very straightforward. Processes so far studied for extraction of oxygen from lunar soils are fluorine wet chemistry, the reduction by hydrogen of ilmenite (iron-titanium oxide), and electrolysis. The reduction processes, particularly those which use hydrogen as the reducing agent, are the most technologically mature. Oxygen which is chemically bound to iron in lunar minerals and glasses can be extracted by heating the material to temperatures above 900°C and exposing it to hydrogen gas.[4] The University of Cambridge has demonstrated extracting O_2 from lunar rocks through an electrochemical process. MIT is working on a high-temperature technique called molten salt electrolysis that can extract O_2 from the Moon's regolith. Production of LLOX (lunar liquid oxygen) from ilmenite (FeTiO3) in fluidized-bed reactors can be the pathfinder for an expanding economy including use of regolith to shield an expandable habitat complex, paving to control dust production, and power management tuned to the mid-latitudes' 2-week lunar night.[5]

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[2] Dmitry Rogozin, Chief, Russian space agency Roscosmos, Nov 3, 2018. *Europe's Vision of a Future Moon Base*, Made out of Moon Dust, Universe Today, Nov 23, 2018.

[3] Pioneering the Space Frontier, The Report of the National Commission on Space, Aug 14, 2009.

[4] Oxygen Extraction from Lunar Samples, *by Carlton C. Allen, Lockheed Martin Engineering and Sciences Co., NASA JSC, 2006*

[5] *Principles of a Practical Moon Base*, Brent Sherwood, IAC-18.A3.1.6.X46496, Oct 2018, Pg. 1.

Another consideration is that the regolith needed is everywhere on the Moon. Lewis and Clarke blazed a trail that appeared to be the path of least resistance to get across the Rocky Mountains. Likewise, it makes sense to follow the lunar path that appears to have high benefit and low risk. More difficult and challenging locations like cold traps at the poles likely containing frozen water are very challenging to reach and extract with near absolute zero environments. Eventually our abilities can expand to include volatiles like water which is important for future development, but the oxygen economy is the right first step given its access, low risk process and significant economic leverage. This first step can demonstrate our ability to "live off the land" versus always bringing everything needed from Earth, as illustrated in Figure 1.

Additionally, the process of extracting oxygen from Ilmenite creates a spinoff of Titanium. Today on Earth, most titanium metal is produced from rutile laboriously mined from sands in Florida and Australia. However, if in an evolutionary, efficient process for Titanium is developed for extracting rutile from ilmenite, we might serendipitously have an economic effect on the world's titanium production as well as resources for in-situ fabrication of surface assets.

Lunar oxygen provides great benefits in production of breathing air and oxidizer for rocket fuel. It is very likely that water ice can also be recovered from craters, providing drinking water and effective radiation protection for crews. Hydrogen for rocket fuel is the most efficient of all chemical propulsion. Hydrogen and oxygen can be used together in fuel cells to produce power. The pursuit, development and exploitation of oxygen and hydrogen guides exploration activities and operations. The highest priority is to establish the knowledge of where and how best to extract oxygen from indigenous regolith. The process of establishing the oxygen economy results in missions and infrastructure, in a deliberate and focused fashion that enables other established objectives. Exploration and science discoveries can be achieved.

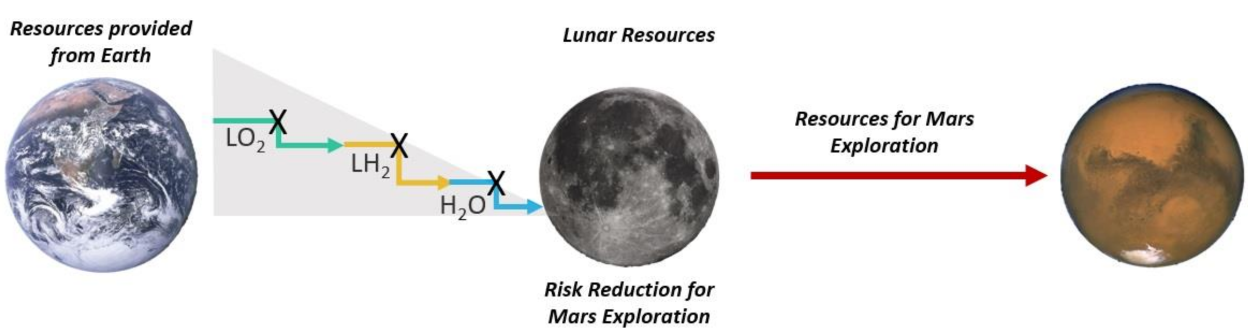

Figure 1 The government enables industrial development of lunar resources, breaking the dependence on Earth and feed-forward to Mars exploration. Creating an O_2 economy is a logical first step of utilizing lunar resources thus reducing the amount of resources brought from Earth.

This campaign has many important possible outcomes including identification of other resources that may have production value. It enables testing and maturation of technologies and operations that accelerate the knowledge needed for human Mars missions. It further enables collaboration and friendships with our international partners in space, and opens possibilities for commercial activity through the buying and selling of commodities and services. The endeavor motivates educational initiatives with new knowledge of the Earth's neighborhood, our solar system and universe. The successful development of an oxygen economy provides the impetus to grow a lunar base or even bases, depending on an understanding of the return that can be realized. U. S. leadership of these achievements establishes the United States as the leader in setting the "rules of the road" in the lunar vicinity, establishes the precedents for continued exploration and utilization, enhances our national pride and the desire for further exploration of space, not to mention our security.

Because of our current understanding that oxygen is global, and yet concentrated in permanently dark craters, the first landing site of explorers could be at the Moon's North or South Pole near a promising permanently dark crater, where prospecting and experiments can determine extraction techniques for oxygen in both forms. The choice of exact location also considers high priority science objectives. An advantage of a polar location is also the availability of longer-term solar power and thermal stability than is available away from the poles. Detailed objectives and decisions shall be determined with broad community input, including civilian and non-civilian government agencies, the science community, international space agencies, industry, academia, space policy experts, Administration and Congressional stakeholders, etc.

Build out Lunar Development

Lunar development based on prior systematic step-by-step initiatives can occur. Further, new initiatives can be expected based upon exploration and science discoveries. Business partners are likely the primary initiators within the build-out lunar development phase. This phase should include government investment and incentives in support of infrastructure such as transportation, power, communications and navigation aids.

Portfolio Lunar Development

The lunar development entities, all with different agendas, need to be coordinated as a portfolio throughout the various phases of development. (e.g. initial, build-out, adaptive). As we learn from exploration, economic development, science, international and national interest the portfolio is rebalanced along the way. Coordination of different agendas requires compromise but not cancellation of entities goals and objectives. This portfolio coordination ensures cost-effective resource handling, efficient interfaces, minimize overhead costs, and enhance mission achievement. It also enables on-ramps and off-ramps as we learn and answer key questions along the way.

Adaptive Lunar Development

All lunar development participants, perhaps from the start, are faced with the quintessential challenge - 'We don't know what we don't know'. This fact of lunar exploration requires adding risk mitigation backups as a part of resource and cost development planning as well as flexibility in the planning to address new discoveries. As difficult as defining and planning for the impact of the unknown is, it is a greater impact not to include some best estimate by all participant planners.

4.0 Lunar Development Endeavors

Development endeavors evolve differently between exploration, science, commercial business, and national security. Each endeavor has different thrusts in demonstrating essential capabilities as illustrated in Table 2.

Exploration

The U. S. government's unique role in space is to lead in answering questions through exploration, where there is an uncertain but potential return for national, public and commercial interests. With the policy set in Directive 1, NASA is positioned to provide the leadership and initial investment to set this policy in motion to benefit all interested parties fairly. The exploration aspect of the endeavor supports national interests, business, science, and international relations in space by providing leadership, the operations and means to accomplish their objectives. Exploration drives technology and provides testing opportunities, operational capabilities, and uncovers knowledge from discoveries. As a unique exploration objective, experimentation and achievements at the Moon enables further understanding of what it takes for the next steps in exploring Mars.

While NASA's leadership and initial investment is key to helping create the lunar economy, it is important to reflect upon how far human spaceflight has advanced over the last 60 years and the role of NASA for the next phase. We are on the cusp of private industry sending humans into low Earth orbit, and advances in commercially available launch services open a range of new possibilities for government and industry to both pursue their own outcomes on the new frontier. NASA can play a first-among-equals role in this respect, clearly pursuing its exploration and discovery agenda toward a future human mission to Mars, as well as establish a regulatory and infrastructure environment in the lunar vicinity that private industry can leverage for its own purposes, be they purely commercial or as services to the government (further described in the next section).

Astronauts supporting scientists on Earth collect lunar samples to compare details of the actual oxygen and other resource concentrations and composition with remote measurements from lunar orbit. The form of these resources is also investigated to understand how they are combined mechanically or in compounds within the rocks and regolith. This informs designs of machines to recover and extract the desired elements. Astronauts perform experiments with techniques to extract oxygen, water ice and other desirable minerals to inform science and industry as they plan the mining operations that look most promising.

Table 2 Lunar endeavors for Exploration, Science, Commercial Business and National Security

	EXPLORATION
“Boots on the Moon” What are we going to accomplish?	-Explore new parts of the Moon and provide essential “ground truth” through prospecting promising locations -Demonstrate surface mobility and resource utilization: In-Situ Resource Utilization (ISRU) -Identify and mitigate risks for Mars exploration -Pave the way for commercial development (leave behind initial capabilities & infrastructure), e.g. reusable lander
	SCIENCE[6]
	-Establish the period of giant planet migration and its effects in our solar system (The Moon contains the solar systems and bombardment record) -Provide an absolute chronology for Solar System events -Use the accessible vantage from the lunar far side to view deep space and the Universe -Understand and utilize the special water cycle of the Moon and other airless bodies (The Moon has all 3 forms of water: endogenic, sequestered external and in-situ) -Characterize the Moon’s interior to reveal how this differentiated neighbor of Earth formed and evolved (Lunar Geophysical Network) -Evaluate the extended record of space weather and fundamental processes of plasma interactions with surfaces. -Lunar swirl investigation. -Lava tube/skylight investigation
	COMMERCIAL / INDUSTRIAL ECONOMIC DEVELOPMENT
	-Leverage cost-effective Government incentives with private investments - ISRU/production of LO2, H2O, H3, LH2, titanium, etc. -LH2 delivery from Earth and other resupply services -Small / Medium Commercial Landers for Science and Technology -Large commercial vehicles (e.g. landers, and surface transportation) for humans, resources, development and services - Exploration infrastructure, e.g. communications and navigation Construction and services dedicated to Mining initialization and expansion. - Lunar-oriented satellite placement, operations, and associated services. - Arena for Multinational cooperation opportunities in commercial endeavors.
	NATIONAL SECURITY
	-Leadership and establishing the “rules of the road” -International participation and partnership -Cis-Lunar Access and Situational Awareness -Build the industrial base & infrastructure with friends and allies enhancing foreign policy

The U. S. led international teams of explorers witness much more extreme and dramatic vistas than even those of the Apollo era. During Apollo, benign landing sites were chosen in those first steps, because so much was unknown. Their experiences of these modern explorers are shared with the people on Earth as all are inspired with the new lunar home. The experience and discoveries motivate education and the aspirations of our youth.

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[6] Transformative Lunar Science, Dr. Carle Pieters, Dr. Robin Canup, Dr. David King, Dr. James Head, Astronaut David Scott, January 2018.
NOTE: This is a summary. There are many other science objectives documented by the Lunar Exploration Analysis Group (LEAG)

Astronauts learn the techniques of working with hardware on the lunar surface. They will gain experience in new space suit designs in the reduced gravity. Their health will be monitored to study the physical effects of living in gravity, thermal, lighting, dust, radiation and other environments that are much different than what people encounter on Earth. Designs will be tested and evolved to mitigate the deleterious environmental effects. Astronauts will test operational techniques including scientific tasks such as digging, sampling, and observation that will not only improve lunar operations, but will feed forward to future Mars missions. Designs for landers, rover transportation, life support, habitation, power, and other hardware used in these operations will also be chosen to test details that will feed forward to Mars designs.

The exploration role of lunar astronauts will pave the way for those who choose to follow and take advantage of the knowledge gained, while NASA pursues new objectives at the Moon and/or plans for the next destination- Mars. After the lunar experience, we will have a much better-informed understanding of those challenges.

Business Economic Development

Business enterprise participation is motivated by profit and developing long term competitive advantages. Government entities are motivated by national objectives and goals. History, has shown the two arenas do not always conflict and mutually support each other (e.g. U.S. 19th century frontier expansion, and 20th century national highway system). This historical intersection is the *key theme* concerning Lunar Evolutionary Development (LED). The following economies are a listing of potential Business and Industrial opportunities at the start of LED. LED economies are characterized as having NASA initiatives developing an 'Anchor Tenant' (providing basic exploration, infrastructure, and services). Subsequent expansion within the LED opportunities is solely within the Business and Industrial domain driving towards maximum commercial opportunity investment and revenue success.

The Transportation Economy - Transportation demands providing surface mobility is needed with the first arrival of 'Boots on the Moon' activities. Initial (1-2 years) exploration requires multi-functional lunar surface transport (MLST) vehicles to meet exploration and science requirements providing access to lunar regions of interest for mapping, geological testing, establishing ground truth along with providing logistical services for initial site establishment. Both the transportation of personnel and materials is required accommodating multi-passengers, increasing cargo mass with a longer surface range of designations. Long-term surface transportation is determined by the rate of growth of exploration, science and economic development on the lunar surface. The transportation economy business and industrial economy provides multi-layered opportunities to meet requirements including increasing transportation fleet capabilities, maintenance, energy services, storage, supplies, spare parts, mission customization, shuttle service, along with towing and recovery. NASA may require the initial fleet (2-3 vehicles) be government procured to support exploration and science needs. However, surface transportation services are a likely commercial endeavor for business and industrial expansion.

The Mining Economy - Compared to the Apollo era, LED mining leads the enterprise from the start; a) Building upon prior exploration from the science community, alongside industry, defines their mission objectives and goals to extract life-supporting elements for lunar residing and operations (e.g.

Explorers/miners at the Moon's Poles where oxygen concentrations are in permanently dark craters, longer term solar power, and thermal stability); b) Business/industrial mining efforts will expand at a greater pace upon earth-adaptive operations brought to the Moon in search/development of heavy metals, further basic resources, rare earth elements; energy requirements, etc. (e.g. lunar regolith [3-20 meters], bedrock/crust of the Moon [> 60 kilometers]); c) Long-term mining is notional but can be expected to support an ever increasing/evolving lunar infrastructure as resources extracted are utilized for lunar manufacturing operations, earth-export products, orbital services, Mars exploration initiation.

<u>The Services Economy</u> - People require a diversity of support services as they begin to occupy the Moon on a more permanent basis, whether for research, exploration, resource extraction, solar system observation, or as a departure point for trans-lunar and deep space missions. Material, tools and equipment are needed to be stored, serviced and repaired. Infrastructure is developed including garages for lunar transporters, satellite servicing, robotic maintenance, and long-term research laboratories. Servicing and repair of space suits is one of the first required services given the lunar dust environment. Medical acquisition both on site and remote response service is required as the number and frequency of lunar activity increases. These key demands exceed the basic services of the 'Anchor Tenant' capability and open significant commercial opportunity.

Further, human needs are to be accommodated, initially with bare necessities but over time and with an increasing cadre, the standards of service need to mimic those available on earth. Training, hotel services, food, laundry, telecommunications, and entertainment are examples of these expanding services. Moon-based agriculture provides fresh food to the increasing lunar population reducing dependence on Earth resupply. Moon residents need contact with Earth-bound family and friends through high definition communications.

The service economy provides unique opportunities for earth-based private sector companies to expand their expertise into the space domain.

<u>Private Investment Coupled with Government Incentives:</u> History is replete with examples of government-established functions that have been transitioned to the private sector, fully or partially including Intelsat, Inmarsat, the Tennessee Valley Authority, the Federal National Mortgage Association (FNMA), to name but a few. The transition for many of these organizations took a long period of time, and often a number of rearward steps. Bringing commercial companies in at the beginning is key to enhance success versus the usual "build it and they will come" approach often used. These companies have the experienced insight to envision more cost-effective approaches that are more likely profitable.

One of the government's objectives in the establishment of a lunar base of operation is to attract private sector investment in and operation of Moon-based industrial and commercial enterprises from the outset, including non-traditional aerospace. The government needs to create mechanisms to address commercial market financial and technical risks. Most public companies are risk averse. For example, today there are numbers of companies growing crops in vertical "urban farms." Some crops are grown hydroponically while other crops are seeded and grown in trays that rotate for sunlight exposure, drip and spray watered, excess water cleaned and recycled. A first "Moon farm" would combine government experience and assurances with lunar operations with urban farm technology in a small-scale "package" farm transferred to the Moon. The government would have to pay for this demonstration farm and provide an initial guaranteed market for the crops. As other entities inhabit the Moon, private investment would scale the farm. At this point the Moon farm would reflect the institutional, market, financial, and technical risks of operating on the lunar surface. It is likely that the government would continue to provide Earth-lunar transport for companies by paying for transport on commercial rockets. Over a longer time, horizon, even these costs would migrate to the companies as they gain operational experience.

To start developing the markets and the requisite business plans, government entities need to help address the key technical and market risk areas to build the capability. In addition, government entities also need to serve as "anchor tenants" to purchase services to "seed" the marketplace. As an "anchor tenant" the government would evaluate competing commercial initiatives to ensure sound investment of taxpayer funds. Government funding models have to extend beyond the typical contractor relationships and into industry and marketplace development partners. Approaches from the development leading to commercial air travel would be useful analogs to pursue for lunar business models.

Science

Beyond building a Lunar Economy, there is plenty to learn about the Moon. Science plays a critical role for NASA and USG involvement on the Moon and the broader exploration objectives.[7] A half-dozen scientific missions have revealed a Moon Apollo never knew. Today we know the Moon holds a large inventory of polar volatiles, in various forms: adsorbed solar wind, accumulated crystalline water ice and even surface frost in some PSRs (permanently shadowed regions), and perhaps deep ice from ancient cometary impacts. The science community has also developed a prioritized list of about two dozen key investigation sites around the lunar globe.

Among other objectives, absolute chronologies can calibrate ages across the solar system. The Moon preserves many of the geologic processes that occurred early in our Solar System and during the period when life formed. It preserves a record of the impact history over geologic time. Such records have been obliterated on planetary bodies that are active and have atmospheres. The Moon also preserves a record of the Sun's activity in its regolith and the early evolution of terrestrial planets. Volatile deposits at the lunar poles may contain a record of the volatiles transported to the inner Solar System. The radio-quiet lunar far side enables

[7] The Global Exploration Roadmap, ISECG, Jan 2018

astrophysical investigations into the earliest stages of our universe through the deployment of radio telescopes. Human presence on the Moon would permit detailed geologic mapping, the collection of critical samples for analysis in Earth-based laboratories, and the emplacement of delicate instrumentation, including seismometers and other geophysical instrumentation.
Specific examples of high value lunar science are described back in Table 2[8] and the NASA Lunar Exploration Analysis Group (LEAG) has recently published the key science concepts for future investigations shown in Table 3. As with all science, we don't know what we don't know and as we answer the key questions that currently exist along the way, a magnitude of new questions arises. Therefore, we now have better prospects for using the Moon to bootstrap off-world achievements. Scientifically, the stage is set for a robust lunar program.

Table 3 The LEAG Themes Driving Lunar Science Investigations

Concept 1: The bombardment history of the inner Solar System is uniquely revealed on the Moon.
Concept 2: The structure and composition of the lunar interior provide fundamental information on the evolution of a differentiated planetary body.
Concept 3: Key planetary processes are manifested in the diversity of lunar crustal rocks.
Concept 4: The lunar poles are special environments that may bear witness to the volatile flux over the latter part of Solar System history.
Concept 5: Lunar volcanism provides a window into the thermal and compositional evolution of the Moon.
Concept 6: The Moon is an accessible laboratory for studying the impact process on planetary scales.
Concept 7: The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies.
Concept 8: Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state.
New Concepts that must be considered as we move into a new phase of lunar exploration.

- *The Lunar Volatile Cycle*
- *The Origin of the Moon*
- *Lunar Tectonism and Seismicity*

National Security Interests

It is in the U. S. interest to lead the world in exploration of the Moon. After many years of collaboration with international space agencies, NASA is looked to as the leader in space exploration. It has been and continues to be clear that all the other international agencies have a preference for the Moon as the next destination to explore. As espoused by Alfred Thayer Mahan in "The influence of Sea Power on History, 1660 to 1783," nations who control the sea, control their destiny. It is a perfect analogy to our era in space. To continue our leadership as a fair international partner helps to ensure that

[8] Transformative Lunar Science, Dr. Carle Pieters, Dr. Robin Canup, Dr. David King, Dr. James Head, Astronaut David Scott, January 2018.

the playing field is controlled with integrity. It is imperative that we maintain that role. The exploration of the Moon drives U. S. technology and the U. S. space industrial base. It also is important for the U. S. to lead in lunar commerce that is generated. The Moon provides a stable and solid satellite for observation and communications for the Earth-Moon system including cis-lunar space. It is important to secure this capability.

5.0 Legal Considerations

The potential development and usage of lunar resources has been a topic of legal resolutions since the late 1960s. The United Nations (U.N.) has been in the forefront of passing several Treaties (agreed by all Nations) regarding lunar Sovereignty and Property Rights (e.g. early 1960s General Assembly declarations; 1967 Outer Space Treaty; 1979 Moon Agreement). Principally, the 1979 Moon Agreement, the current presiding document, has far-reaching lunar development requirements and restrictions. The United States is not a signatory to the 1979 Moon Agreement and not bound by its provisions. However, the U.S. Congressional Commercial Space Launch Competitiveness Act of 2015 is the single current U.S.-centric legal/policy document influencing both Governmental and Industrial entities and initiatives.

"But above all else, we choose to lead in space because we know that the rules and values of space, like every great frontier, will be written by those who get there first – and we owe it to mankind to bring American values to the boundless expanse of the heavens." (Vice President Mike Pence, first meeting of the National Space Council)

The development of space will depend on the development of laws, regulations, and institutions that support and enable the expansion of human activity into this new domain.[9]

6.0 Summary

Our Administration has wisely recognized that our nearest neighbor, the Moon, holds an abundance of opportunities for commerce, international collaboration, science and further exploration. Clearly, the United States as the most accomplished leader in space must continue in that auspicious role. The Moon holds great potential for our future and must not be overlooked on our way to Mars. Successfully developing an ability to leverage lunar resources may have a fundamental impact on how and when a human Mars landing might be achieved. Mastering the Moon and its environment prepares humanity for interplanetary flight. We are overdue in returning explorers to the lunar surface.

In the mean time we have learned a great deal from experiences in space with advanced vehicles, amazing missions, international space relations, and both past and current lunar investigations. This knowledge inspires the direction for our return. Current commercial endeavors, experience on the International Space Station, and building of the Space Launch System and Orion have provided the basis for our successful return. Striving to build an economy at the Moon focuses

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[9] *Space Development, Law and Values*, Dr. Scott Pace, IISL Galloway Space Law Symposium, December 12, 2017.

our campaign for a self-sustaining path for the future and enables our numerous lunar and space endeavors. We must seize lunar opportunity, enabling the foundation for solar system exploration opportunities, and provide a stable path forward that can be supported by our broad space community as it answers their objectives. With the right direction we can accomplish the "boots on the Moon" vision propelling exploration, science and economic development motivating positive aspirations for a new generation and provide positive outcomes that benefit all the people of Planet Earth.

"Boots on the Moon" The Next Step to Enabling Human Expansion Across the Solar System
RECOMMENDATIONS

Visibility, consensus building, participation, and buy-in for sustainable success

1. **FINDING:** NASA Science Mission Directorate (SMD) and the science community does an excellent job of establishing goals, objectives and programs that garner wide community support. The established process of National Academy Decadal Survey, conducted by the National Science Foundation, funded NASA studies on the feasibility of key missions and broad consensus building and advocacy through the various Analysis Groups (Lunar Exploration Analysis Group-LEAG, Mars Exploration Program Analysis Group-MEPAG, Outer Planets Analysis Group-OPAG, Small Bodies Analysis Group-SBAG and Venus Exploration Analysis Group (VEXAG). The only parallel on the human exploration initiative is the International Space Exploration Coordination Group (ISECG). The human exploration program is driven more by NASA internal aspirations along with a few states and contractors that directly benefit.

RECOMMENDATION: We recommend that for the success of sustained human exploration there needs to be a similar domestic US structure that provides transparency, broad input and consensus building in the various human exploration, science, commercial development, national security and international communities. Similar to the science decadal process, this structure should exist outside of NASA where the agency is an active participant and principle respondent. Consider the formation of a National Space Council Implementation Working Group that could serve as a Human Exploration Program Analysis Group (HEPAG) coordinating with these communities along with the LEAG, MEPAG, and ISECG. We also recommend that each of these analysis groups need to be evaluated for maximum possible representation for buy-in, input, and advocacy.

2. FINDING: New exploration initiatives have a better probability of success if community involvement is sought and incorporated providing stakeholder buy-in. For example, after the

Vision for Space Exploration was revealed several events helped to communicate and enable stakeholder involvement. These include the AIAA Space Exploration Conferences, the first being held in Jan 2005 and the Lunar Development Workshops held in 2006 bringing together all stakeholders in an actual "working" workshop to develop further details in the exploration objectives and roadmap. Following the cancellation of Constellation, several initiatives were announced by NASA including Humans to Asteroids and the Asteroid Redirect Mission which did not utilize broad stakeholder involvement and participation and thus garnered significant criticism. Having a few people make decisions to "send humans to an asteroid" or "build a Gateway" without broad stakeholder participation significantly reduces the sustainability of such long term programs.

RECOMMENDATION: We recommend that similar Exploration Conferences and Workshops be planned in early 2019 and executed in conjunction with NASA, the stakeholders and aerospace professional organizations including AIAA and AAS. The cost of these efforts is minimal considering the advocacy, participation, education and public outreach, "excitement", and buy-in that they can garner.

3. FINDING: The NASA-produced National Space Campaign Report, published September 2018 attempts to address many of the issues identified in this white paper but falls short in many areas including the lack of stakeholder participation and lack of answers to fundamental questions such as "what are we going to do on the moon" and "why is a gateway required? The current document comes across as a plan to build ISS-2 at the moon versus a real campaign plan focused on lunar exploration and development.

RECOMMENDATION: We recommend that we continue the work started with this White Paper under the direction of the National Space Council and NASA to perform a "virtual think tank" approach to build a better, more inclusive campaign plan that can be used as the departure document for a Stakeholder Workshop and Conference in 2019. This effort would eventually be part of the HEPAG to sponsor and facilitate.

Organize for long-term success

4. FINDING: NASA's organization especially HEOMD is currently better organized for operations, coming out of operating the Space Shuttle, the ISS, launch services and infrastructure (i.e. TDRSS). New development for space is hard. The current organization has had significant issues in effectively managing new development as indicated in recent GAO and IG independent performance audits. This is mainly due to the necessary difference in mindset between operations which is capability and service driven, and development which is outcome driven. Efficient operation is different from effective new development and the lines are currently blurred.

RECOMMENDATION: Separate HEOMD into two separate Directorates. The Development Organization needs to be outcome or mission focused with roles, responsibilities and accountability along with experienced leadership and expertise for the development life cycle. The second organization should be focused on providing efficient and cost effective operations and services. Overall organization from HQ to Centers needs to be evaluated and aligned for success of programs and missions as opposed to institutional desires. There also needs to be clear criteria and processes for transition from development to production and operations. The development organization should have clear "outcomes" driven by operability and life cycle cost. The operations organization should maintain representation in the development effort to ensure new development is aligned with cost-effective operations.

Systems Engineering and Integration

5. FINDING: There is a lack of independent Plans, Analysis and Evaluation (PA&E) function to provide the data, system trade-offs and evaluations to 1) ensure effective decision making by the Administrator's office, and 2) provide independent quality control of important program, management and budget decisions, and 3) provide an integration function across the mission directorates and other NASA functional areas.

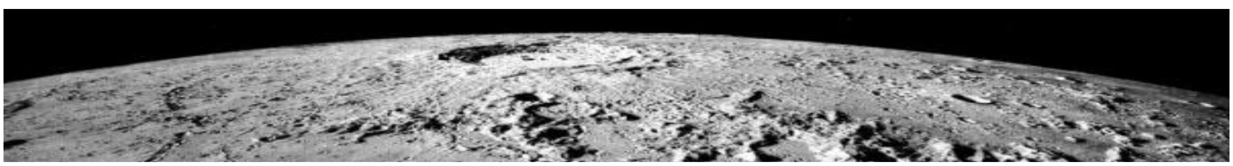
RECOMMENDATION: Re-establish an independent PA&E organization that reports to the Administrator. This organization needs the skills and resources including access to independent subject matter experts and FFRDC resources.

6. FINDING: NASA has a lack of robust systems engineering and integration for the large-scale development due primarily to the infrequency of such developments, which prevents sustainment of a strong pipeline of systems engineering talent. Such talent is required for formation and execution of an integrated campaign including SLS, Orion, a Gateway, lunar landers, surface development, Mars preparation, etc. This is evident by continued system disconnects between SLS, Orion and Ground Systems working to sub-optimal requirements with a relatively poor understanding of key driving requirements and outcomes (e.g. what is to be accomplished on and around the moon?). Recent GAO and IG reports highlight the weakness.

RECOMMENDATION: NASA needs to reinvigorate and supplement its SE&I capabilities for effectively managing the Exploration campaign, especially at the "system of systems" level. Given the overall erosion of internal SE&I capabilities utilizing an independent, with hardware exclusion SE&I contractor, FFRDC or team should be investigated where NASA leverages government trusted agent capabilities with high acumen in systems engineering. There also needs to be clear leadership at the Program Director level at NASA Headquarters integrated with clear lines of responsibility and authority across the SE&I resources actually performing the work at the Centers. The NASA Programs and Centers must be held accountable for the overall leadership, with clearly defined programmatic and technical decision authority directly traceable and responsive to a clear set of outcome-focused requirements. This approach also needs clear measures of effectiveness along with the longer-term plan to re-build a strong SE&I capability back within the agency.

7. FINDING: NASA, over the past decade, has responded to lack of budget support for exploration by making difficult but pragmatic decisions relative to exploration systems development. This has resulted in a "capability driven" management model that treats schedule as a "free variable" and lacks definition that is driven by clear needs, goals and objectives related to specific destination outcomes. Therefore, we observe the difficulty NASA is having cultivating stakeholder support for the Gateway concept.

RECOMMENDATION: Use the IWG/HEPAG to establish clear "Level 0" needs, goals and objectives – informed by both public and private sector outcomes - to which NASA's development organization can then respond with a clear set of systems engineering requirements and a fully responsive architecture. Lacking this, with obscure and litigious rationale for "capability driven" elements, NASA will continue to suffer from lack of stakeholder confidence and buy-in. The separation suggested by the IWG/HEPAG truly drives a national strategy and not just a NASA-centric one.



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Mr. Faulconer is President of FCG which he founded to provide a full range of services to help customers be more successful in their strategic planning in uncertain times, win new business to grow their bottom line, and strengthen basic systems engineering and management practices for mission success. FCG provides a deep bench of advisors and subject matter experts that are supporting commercial, national security, and civil space clients.

Walt is currently a member of the NOAA Science Advisory Board and the Executive Secretary for the Department of Defense Strategic Capabilities Office Advisory Group. He manages NASA's Flight Project Development Program to develop the next generation project managers and leaders. Previously he served as a past Executive Vice President of the American Astronautical Society and on the Constellation Program Standing Review Board for NASA.

From 2005-2010 Walt was the Business Area Executive for Civilian Space at the Johns Hopkins University's Applied Physics Laboratory. His responsibilities included managing all aspects of the Civilian Space Business Area. Programs included the development, launching and operations of the NASA New Horizons mission to Pluto, the MESSENGER mission to Mercury and the twin STEREO spacecraft to study the sun. Mr. Faulconer's leadership helped to develop a backlog of new and exciting NASA science missions including the twin Radiations Belt Storm Probe satellites that were launched in 2012, the Parker Solar Probe mission launched in 2018 and the Europa Clipper mission to be launched in 2023. He instituted important quality, management, and safety practices in support of APL achieving its AS9100 certification.

Previously Walt served in various capacities for 26 years at Lockheed Martin. He was the Director for Space Exploration Business Development for Space Systems Company responsible for the business development for Space Exploration including: Shuttle Return to Flight, International Space Station, and Project Constellation–Crew Exploration Vehicle - Orion. Walt's roles at Lockheed Martin included Director for Business Development for the Space Transportation line of business, including Atlas and Titan launch vehicles, and Advanced Space Transportation. He also served as director of Strategic Planning and Development for Space Systems Company, responsible for leading the strategic planning and development team. Before that, he served as the program manager for the 2nd Generation Reusable Launch Vehicle program as part of the Space Launch Initiative and supported the Space Shuttle program in payload integration, operations and astronaut training. Walt has also been a mission systems engineer on numerous national security programs.

Walt holds a Bachelor of Science degree in Space Sciences from the Florida Institute of Technology and a Masters degree in Systems Management from the University of Southern California.

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