The Moon is an enabling asset that can boost the U.S. economy, affirm U.S. leadership in space exploration, and send humans out into the Solar System.

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Introduction.

President Donald Trump campaigned on a platform of "making America great again". This noble goal must include reestablishing our role as **the world leader** in human and robotic space exploration. The change in administration comes at a time of significant commercial and entrepreneurial interest and activity with a new era of space commerce unfolding focusing on the Moon. History has shown us that investment in our nations space program produces new industries and economic growth. It is time to repeat that lesson based on the knowledge we have learned over the last 50 years. The new administration has an imperative to revive our national human spaceflight program and in doing so, open up this new economic sector for our nation. While human exploration of Mars is many years away, the Moon offers great opportunity to reclaim our rightful place as world leaders in space exploration. We can return America to the surface of the Moon in a relatively short timeframe undertaking robotic surface roving operations for resource prospecting. This can be followed by sending humans to the lunar surface (2017 marks 45 years since we were on the Moon with Apollo 17), affordably re-establishing critical spacefaring capabilities needed for future more ambitious voyages. In the process, we will train a new generation of engineers and scientists, minimizing knowledge loss through attrition and work-force aging, and lay the foundations for strong economic growth in a vibrant space commerce sector. A definitive commitment to human space exploration beyond low-Earth orbit will enhance US national security and facilitate a strong economy driven by continuing technological and scientific innovation, which will ensure that the United States remains a leader in the challenging global economy of the 21st century.

Over the last eight years NASA has taken a back seat among this nation's priorities in terms of budget, vision, and leadership. In 2010, President Obama committed to expanding NASA's budget by $6 billion over the next five years. As of 2015, that budget actually decreased by $714 million and resulted in minimal progress in the human space flight program. The official policy for human space exploration is currently visiting a near-Earth asteroid to prepare for human missions to Mars. This mission will cost billions of taxpayer dollars as we continue to pay Russia to transport U.S. astronauts to the International Space Station. While there is a lot of media hype about sending humans to Mars in the near future, that reality requires several decades of effort to develop the technology to allow humans to safely travel to Mars, land, and return. Mars is not a feasible near-term goal for U.S. human spaceflight.

The Moon.

Why is the Moon important? Basically, the Moon contains resources that enable *sustainable* human Mars and Solar System space exploration as well as boosting our economy. One major

resource is water that we now know exists within the Moon as well as on the surface. Water provides life support consumables as well as rocket fuel - a game changer because we will not need to bring everything from Earth as we did during the Apollo program. Apollo was unparalleled in its accomplishments but it did not achieve sustainability. Lunar resources are critical for developing a sustainable human space exploration program and stimulating a *cis-lunar space* economy (*cis-lunar space* = space around the Earth-Moon system). Therefore, the next stage in our human spaceflight program will also stimulate technology development. New industries will develop based upon the extraction, refinement, and use of lunar resources that we know are there. This approach will allow for the creation of high technology jobs, which will stimulate the U.S. economy.

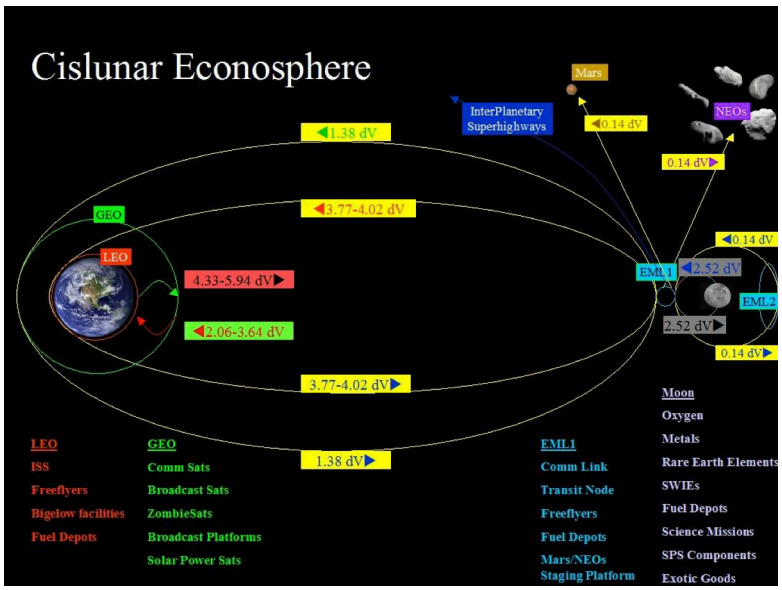

Figure 1: Potential economy of cis-lunar space that shows the potential new industrial sector. Taken from http://www.thespacereview.com/article/2033/1)

Our next venture into the Solar System must include transportation architectures with reusability as the central tenet, and with refueling depots positioned in cis-lunar space. These depots will be supplied by lunar resources, and will facilitate deep space travel including to the horizon destination of Mars (Fig. 1). They could also be used to refuel Earth-orbiting satellites, reducing the necessity of repeat launches and halting or at least reducing the build-up of hazardous space junk surrounding our planet. Having resources available that can be refined into useful products provides an excellent on-ramp for the burgeoning space commerce sector. For example, a spacecraft refueling depot orbiting the Moon, supplied with fuel refined from lunar resources that is privately operated and selling its products to various national space agencies, has real potential to ***bring the Moon into our economic sphere of influence***.

The Moon is also important strategically because there is significant international focus on our nearest neighbor. When the United States changed focus from the Moon to the Asteroid Redirect Mission, other nations we had partnered with to go to the Moon continued their interest in lunar exploration. China in particular has made important advances in their lunar exploration program, becoming the third nation to successfully soft-land on the Moon in 2013 and the second to successfully rove on the lunar surface. Later this year, China is attempting something that the United States has never achieved to date – robotically returning a sample from the lunar surface.

Only the Soviet Union has done this before - three times in the 1970s, resulting in 0.3 kg (total) of lunar regolith being return for analysis in Earth-based laboratories. Next year, China will be the first nation to send a robotic rover to the farside of the Moon. This build-up of capability by China demonstrates that the Moon is strategically important to them. This should be a wake-up call to the United States because the Moon is the key to consistent and sustained access to cis-lunar space.

The plan envisaged for the United States is that the Moon enables several important goals for space exploration and our country that need to be articulated clearly:

1) The Moon enables Solar System exploration, both for humans and robots. This is not a lunar-centric plan, but much bigger! It is our gateway to the Solar System and if we set up radio telescopes on the radio-quiet farside, we will be able to see back to the earliest times of the Universe;
2) The Moon enables economic expansion due to the presence of resources, as noted above;
3) The Moon enables the United States to reaffirm its leadership in human spaceflight and lead the world into the Solar System rather than watching other nations claim a beach-head, as has happened over the last eight years because the United States has relinquished its leadership position;
4) The Moon allows us to learn to live and work off planet at a place that is relatively nearby in order that human missions to Mars are successful. It is a local testbed.

The plan outlined here requires a change in the way we think of the NASA budget. It should be considered an investment in our future, and way to revitalize the American industrial base. This investment begins with robotic exploration to understand if the resources that we know are present on the Moon are mineable, and present in sufficient quantities to sustain exploration long into the future. The initial build-up of infrastructure on the lunar surface can be enabled by NASA in conjunction with commercial partnerships. Once established, such assets can be leveraged as commercial on-ramps, including industrial resource exploitation and space tourism. The investments will be used to achieve the four goals noted above and this approach must be built into any space exploration architecture from the start. Lunar resources enable this and the time is right to begin this new strategy.

The United States is in a position to lead an international effort to facilitate this critical endeavor. NASA has a Resource Prospector mission in development, which represents a good start for resource exploration, but much more capable missions are required to enable lunar resources to be characterized and test technologies for their exploitation. We must accelerate our program, however, as Russia (in close partnership with the European Space Agency) also has a robotic lunar exploration program under development involving surface prospecting at the poles and culminating in cryogenic sample return.

Summary.

In this era where United States leadership is continually challenged, we have an opportunity to lead the world out into the Solar System, rather than spend another administration standing on the sidelines watching the rest of the world leaving us behind. Yes, Mars is our horizon destination, but our current ill-defined pathway on how to get there will result in an unsustainable "flags-and-footprints," touch-and-go mission at best. As highlighted in this white paper and summarized below, the Moon will enable sustainable space exploration while creating jobs:

- Leveraging the experience of NASA and the enthusiasm and innovation of U.S. private industry to return the US to the Moon (and beyond) will develop new American manufacturing industries, promote American leadership in space exploration, create high-technology jobs for Americans, and meaningfully enhance U.S. national security.
- Making a return to the Moon the focus of U.S. space policy will reverse 8-years of little-to-no progress and restore America's leadership position in space exploration.
- China is making determined moves in cis-lunar space and on the lunar surface that must be countered.
- Returning to the Moon will revitalize a severely weakened American aerospace industrial base, stimulate the new space economy, and encourage the next generation to enter the science and engineering fields.
- A return to the Moon, properly executed, should require little increase to the NASA budget, but will require meaningful public-private partnerships and smart focusing of current resources.

The Moon is truly the enabling key to boosting our economy and achieving a sustainable program of human exploration to Mars and beyond.

Background Information

The Lunar Exploration Analysis Group (LEAG: http://www.lpi.usra.edu/leag/) has developed a Lunar Exploration Roadmap (http://www.lpi.usra.edu/leag/roadmap/) over many years that develops the Moon as an enabling asset for human space exploration and economic expansion. The Roadmap identifies three themes:

- ***Science Theme*** has a long heritage of study, including National Academies studies, and represents community consensus.
- ***Feed Forward Theme*** has been coordinated with the Mars Exploration Program Analysis Group and the Small Bodies Assessment Group. It uses the Moon to enable human space exploration of other destinations.
- ***Sustainability Theme*** uses the lunar resources to establish commercial space enterprises that can sustain human presence on our nearest neighbor. This is critical for a sustainable human space exploration program that would go deeper into the Solar System and eventually to Mars.

The roadmap is intended to layout an integrated and sustainable plan for lunar exploration that enables humans to visit destinations farther afield. The Roadmap will allow NASA to transition from the Moon to other bodies in the Solar System without abandoning the lunar infrastructure that support explorations and built up using taxpayer dollars. This is achieved by enabling commercial development, through early identification of "commercial on ramps", which will create wealth and jobs as a return on the initial taxpayer investment. In addition, the Roadmap will, with careful planning, affirm U.S. leadership in space exploration through international cooperation as we lead the world into the Solar System.

In 2011, LEAG published an implementation strategy for the Roadmap that was sent to NASA (http://www.lpi.usra.edu/leag/reports/RoboticAnalysisLetter.pdf). This three-phase approach is focused on lunar resources as these will enable the Roadmap and much more. The different phases are summarized here.

Phase 1: Lunar Resource Prospecting. Mobile robotic explorers are the required next missions to explore polar regions (volatiles) and non-polar regions (e.g., mature Ti-rich soil for solar wind implanted H, pyroclastic deposits for indigenous volatiles, etc.). These prospectors will incrementally address science, exploration, technology, commercial and public outreach objectives by:

- Defining the composition, form, and extent of the resource;
- Characterizing the environment in which the resources are found;
- Defining the accessibility/extractability of the resources;
- Quantifying the geotechnical properties of the lunar regolith in the areas where resources are found;
- Being able to traverse several kilometers and sample and determine lateral and vertical distribution on meter scales;

- Identifying resource-rich sites for targeting future missions.

Phase 2: Lunar Resource Mining. Based on the Phase 1 results, an end-to-end resource miner feasibility demonstration would be deployed to the top three areas with the most abundant and extractable resources. During this phase the following need to be demonstrated:

- Feedstock acquisition and handling;
- Resource extraction, refinement, transport, and storage;
- Usability of resources (e.g., fuel cell, small engine test; propellant depot test);
- Regolith handling and size sorting technologies (only for mineral-based resources);
- Operable life to give information on the longevity of systems and materials in the lunar environment;
- Dust mitigation strategies.

Phase 3: Lunar Resource Production. Based upon the results of Phase 2, a larger-scale (i.e., more appropriate scale) continuous processing capability would be deployed to the most appropriate site. Greater quantities of resources will be produced and be used to undertake more extensive demonstrations such as life support, mobility technologies, and fuel for a robotic sample return. Eventually production will be scaled up to support a lunar base and supply cis-lunar refueling depots.

Example architectures for development of cis-lunar space can be found at:

- Several papers by P. Spudis and co-authors can be found at http://www.cislunarnext.org/Site/Home.html
- United Launch Alliance: http://www.ulalaunch.com/uploads/docs/Published_Papers/Commercial_Space/2016_Cislunar.pdf
- Sowers G.F. (2016) A cislunar transportation system fueled by lunar resources. Space Policy 37, 103-109. http://www.sciencedirect.com/science/article/pii/S0265964616300352

Clive R. Neal (http://www.nd.edu/~cneal) has been involved in the study of the Moon since 1986 using Apollo samples, lunar meteorites, as well as remotely sensed data from missions including and since Apollo. He has also served on mission and research review panels, including being the Chair of the Lunar Sample Allocation subcommittee 2005-2009, and was a member of the Senior Review panel for NASA's Planetary Science Division in 2012 and chaired that panel in 2014. He is the current chair of NASA's Lunar Exploration Analysis Group, a group that he also chaired from 2006-2010. Neal is passionate about NASA and in returning humans to the Moon and beyond in a sustainable, economically beneficial way. In 2015, he received the NASA "Wargo Award" for contributions to the integration of exploration and planetary science throughout his career.